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**GEOLOGY OF THE STOUGHTON-ROQUEMAURE GROUP,
BEATTY AND MUNRO TOWNSHIPS, NORTHEASTERN ONTARIO**

by

ROBERT MacGREGOR JOHNSTONE

A thesis submitted to the Department of Geology
in conformity with the requirements for the
degree of Master of Science.

Carleton University

Ottawa, Ontario, Canada

April, 1987

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"GEOLOGY OF THE STOUGHTON-ROQUEMAURE GROUP, BEATTY AND MUNRO
TOWNSHIPS, NORTHEASTERN ONTARIO"

submitted by

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the degree of Master of Science

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Abstract

The examination of the stratigraphy and volcanic rocks of Stoughton-Roquemaure Group in Beatty and Munro Townships, northeastern Ontario, indicates that; (i) there is a much broader range of rock types exposed here than that known in the group elsewhere and, (ii) most of this deep-water volcanic assemblage was deposited within an active, east-west oriented rift zone. The 8-9 km thick, Stoughton-Roquemaure Group succession consists of, in order of abundance, medial to high-Fe tholeiites, high-Mg tholeiites, basaltic komatiites, peridotitic komatiites, calc-alkaline volcanic rocks and fine-grained interflow sediments. Calc-alkaline lavas, intercalated with tholeiites, and Fe-rich basaltic komatiites are unique features of this particular Stoughton-Roquemaure Group succession. The komatiites, for which northern Munro Township has become well known, exhibit as a group a much broader range of spinifex textures and compositions than that indicated by previous research. The existence of Fe-rich basaltic komatiites and calc-alkaline volcanic rocks.

The Stoughton-Roquemaure Group lavas were deposited on the lower flanks or adjacent to a calc-alkaline volcanic pile (Hunter Mine Group). The deposition of tholeiitic and calc-alkaline lava was initially restricted to the edge of a deep marine basin into which a sedimentary rock assemblage (Porcupine Group) was being deposited. The rate and distribution of lava deposition then increased with the onset of rifting (related to the early development of the west-trending Destor-Porcupine Fault Zone) and simultaneous komatiitic and tholeiitic volcanism became focused along an east-west rift zone.

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Credit must be given to all the field assistants who supported the mapping project during the summers of 1982 through to 1986 for collectively showing much patience with a party leader who insisted in seeking out even the smallest outcrop in the insect-infested swampland which constitutes much of the Beatty and Munro Township area.

Table of Contents

	Page
ACCEPTANCE SHEET	ii.
ABSTRACT	iii.
ACKNOWLEDGEMENTS	iv.
TABLE OF CONTENTS	v.
LIST OF FIGURES	ix.
LIST OF TABLES	xii.
LIST OF MAPS	xiv.
LIST OF PLATES	xv.
 CHAPTER 1: INTRODUCTION	 1.
1.1 Aims of the study	6.
1.2 Location and access	7.
 CHAPTER 2: REGIONAL GEOLOGY	
2.1 Introduction	8.
2.2 Regional stratigraphy	8.
2.2.1 The revised stratigraphy of the southern Abitibi Belt	9.
2.2.2 Groups represented in the study area	11.
2.2.3 Hunter Mine Group	11.
2.2.4 The Porcupine Group	12.
2.2.5 The Stoughton-Roquemaure Group	15.
2.2.5.1 The Stoughton-Roquemaure Group type section	19.
2.3 Regional structure	21.
2.4 Regional metamorphism	25.
 CHAPTER 3: GENERAL GEOLOGY OF BEATTY AND MUNRO TOWNSHIP	 31.
 CHAPTER 4: STRATIGRAPHY	
4.1 Introduction	37.
4.2 North-facing stratigraphic sections of Beatty Township	41.
4.2.1 Column I, western Beatty Township	41.
4.2.2 Column II, eastern Beatty Township	44.
4.3 North-facing stratigraphic sections of Munro Township	46.
4.3.1 Column III, west Munro Township	46.
4.3.2 Column IV, south-central Munro Township	47.
4.3.3 Column V, north-central Guibord Township to North Kettle Lake, east-central Munro Township	49.
4.4 South-facing stratigraphy of northern Munro Township	53.
4.4.1 Columns VI, VII, and VIII	53.
4.5 Aeromagnetic interpretations	59.

4.6 Regional stratigraphic correlation	64.
4.7 Stratigraphy and depositional models	67.
4.7.1 Bimodal volcanism and age relationships	67.
4.7.2 Eruption rate indicated by stratigraphic relationships	69.
4.7.3 Syndepositional model for the contact relationships between the Stoughton-Roquemaure and Procupine Groups	72.
4.7.4 Evidence of rifting	73.
4.7.5 Basin subsidence	74.
4.8 Conclusions	77.

CHAPTER 5: THOLEIITES

5.1 Introduction	80.
5.2 Physical appearance, petrology, texture and structure of the tholeiitic rocks	80.
5.2.1 General characteristics of tholeiitic rocks	80.
5.2.2 Tholeiitic pillowed lavas	81.
5.2.3 Massive tholeiitic flows	83.
5.2.4 Volcanoclastic deposits	84.
5.3 Characteristics of layered flows	86.
5.3.1 Structures, textures and petrography of Theo's Flow	86.
5.3.2 Structures, textures and petrography of other tholeiitic layered flows	88.
5.4 Structures, textures and petrographical characteristics of variolites	89.
5.4.1 Characteristics of variolites	89.
5.4.2 Models for the formation of varioles	90.
5.4.3 Characteristics of variolites within the study area	92.
5.5 Geochemistry of tholeiites	94.
5.6 Tectonic setting and environment of deposition of the tholeiitic volcanic rocks	97.
5.6.1 Flow direction	97.
5.6.2 Lava effusion rate	98.
5.6.2 Centers of eruption	99.
5.6.4 Water depth	100.
5.7 Conclusions	101.

CHAPTER 6: KOMATIITIC LAVAS

6.1 Introduction	114.
6.2 Petrographic and petrological classification of komatiites ..	115.
6.2.1 Terminology	117.
6.2.2 Diagnostic textures and minerals of komatiites	118.
6.3 Petrology of basaltic komatiites	121.
6.3.1.1 Properties of basaltic komatiites in general	121.
6.3.1.2 Properties of olivine-rich komatiitic basalts	125.
6.3.1.3 Properties of pyroxene-rich komatiitic basalts	126.
6.3.2 Petrology and stratigraphy of individual basaltic komatiite flows	127.
6.3.2.1 Introduction	127.
6.3.2.2 Fred's Flow	127.
6.3.2.3.1 Dee's Flow	130.
6.3.2.3.2 Origin of Dee's Flow	132.
6.4 Petrology of peridotitic komatiite flows	135.
6.4.1 General properties	137.

6.4.2 Flow type 'A'	139.
6.4.3 Flow type 'B'	141.
6.4.4 Flow type 'A-B'	142.
6.4.5 Flow type 'C'	146.
6.4.6 Crystallization model for peridotitic komatiite flows	146.
6.5 Geochemistry of komatiites	149.
6.6 Evidence of synvolcanic tectonism in komatiites	154.
6.7 Flow direction	161.
6.7.1 Pillowed flows	161.
6.7.2 Fred's Flow -vent location and flow direction	161.
6.8 Centers of eruption -komatiitic lavas	164.
6.9 Ponded flows and rifting	165.
6.10 The nature of komatiitic volcanism: conclusions	166.

CHAPTER 7: CALC-ALKALINE VOLCANIC ROCKS WITHIN THE STOUGHTON-ROQUEMAURE GROUP

7.1 Introduction	191.
7.2 Characteristics of calc-alkaline volcanic rocks	191.
7.3 Geochemistry of Calc-alkaline volcanic rocks	193.
7.4 Models for the eruption of calc-alkaline magmas	195.
7.4.1 The megacauldron theory	195.
7.4.2 Localized, high-level partial melting	197.
7.5 Concluding statement	199.

CHAPTER 8: MAJOR SILLS

8.1 Introduction	202.
8.2 Munro Sill	202.
8.3 Munro Lake Sill	206.
8.3.2 Evidence of synmagmatic tectonism	213.
8.4 Painkiller Lake Complex	213.
8.4.2 Evidence of synmagmatic tectonism	216.
8.5 Summary	217.

CHAPTER 9: A DEPOSITIONAL MODEL 220.

CHAPTER 10: SUMMARY 226.

10.1 Introduction	226.
10.2 Summary of stratigraphy	227.
10.3 Summary of conclusions	230.
10.4 Suggestions for further research	233.

REFERENCES 236.

APPENDIX 1: A description of the Jensen Cation Plot 246.

APPENDIX 2: Structural geology 251.

APPENDIX 3: Geochemical data 280.

List of Maps

Beatty Township geology map	rear pocket.
Munro Township geology map	rear pocket.
Geochemical sample location map	rear pocket.

List of Figures

Figure	Page.
1. Geological sketch map of the Abitibi Belt	2.
2. Geological map coverage of the Black River-Matheson area	4.
3. Map showing the distribution of rock types belonging to the Porcupine and Hunter Mine Groups	13.
4. Map showing distribution of the Stoughton-Roquemaure Group ...	16.
5. Sketch map of the generalized geology of the northwestern Black River-Matheson area	17.
6. Sketch map of the generalized geology of Coulson, Warden and Milligan Townships	18.
7. Geological map of the Timmins-Kirkland Lake area	22.
8. Sketch map of the generalized geology of Beatty and Munro Townships	rear pocket.
9. Locations of stratigraphic columns in relation to the major structures of Beatty and Munro Townships	38.
10. South limb stratigraphic columns	rear pocket.
11. North limb stratigraphic columns	rear pocket.
12. Regional areomagnetic map	60.
13. Areomagnetic map of Beatty, Munro and McCool Townships	61.
14. Rock types, chemical and mineralogical variation in Theo's Flow	87.
15. Projections of chemical analyses of tholeiitic volcanic rocks on a Jensen Cation Diagram	95.
16. Diagrammatic section through Fred's Flow	128.
17. Rock types, chemical and mineralogical variation in Fred's Flow	129.
18. Lithological map of Dee's Flow	133.
19. Mineralogical profile of Dee's Flow	134.
20. Diagrammatic section of an ultramafic 'A' flow unit	139.
21. Sketch of an 'A-B' type peridotitic komatiite flow	144.

22.	Diagrammatic sections of type 'A', 'B' and 'C' peridotitic komatiite flows	148.
23.	Projections of chemical analyses of komatiitic volcanic rocks on a Jensen Cation Diagram	150.
24.	Projections of the chemical analyses of volcanic rocks of the Stoughton-Roquemaure Group type section on a Jensen Cation Diagram	153.
25.	Jensen Cation plots of analyses of the Stoughton-Roquemaure Group along the Destor-Porcupine Fault Zone (Lightning River area)	153.
26.	CaO/Al ₂ O ₃ vs. MgO plots of komatiite samples	156.
27.	Sketch diagram of a syndepositional fracture in a peridotitic komatiite flow	158.
28.	Projections of the chemical analyses of the calc-alkaline volcanic rocks on a Jensen Cation Diagram	194.
29.	Diagram displaying the transformation of simatic crust into sialic crust in a primary megacauldron	196.
30.	Model variation diagram of the the Centre Hill section of the Munro Lake Sill	208.
31.	Stratigraphic correlation diagram between the Warden-Munro and Centre Hill sections of the Munro Lake Sill	209.
32.	Depositional model for the Stoughton-Roquemaure Group in Beatty and Munro Townships	221. 223. 225.
33.	The Jensen Cation Plot	247.
34.	A model for structural thickening during folding	256.
35.	Structural/depositional model interpreting stratigraphic relationships across the Destor-Porcupine Fault Zone	258.
36.	Model for the structural evolution of the north-central Munro Township area	265.

6.7.2 Fred's Flow -vent location and flow direction	125.
6.8 Centers of eruption -komatiitic lavas	128.
6.9 Ponded flows and rifting	129.
6.10 The nature of komatiitic volcanism: conclusions	131.
 7 CALC-ALKALINE VOLCANIC ROCKS WITHIN THE STOUGHTON-ROQUEMAURE GROUP	
7.1 Introduction	139.
7.2 Characteristics of calc-alkaline volcanic rocks	139.
7.3 Geochemistry of Calc-alkaline volcanic rocks	141.
7.4 Models for the eruption of calc-alkaline magmas	145.
7.4.1 The megacauldron theory	145.
7.4.2 Localized, high-level partial melting	146.
7.5 Concluding statement	147.
 8 MAJOR SILLS	
8.1 Introduction	149.
8.2 Munro Sill	149.
8.3 Munro Lake Sill	153.
8.3.2 Evidence of synmagmatic tectonism	158.
8.4 Painkiller Lake Complex	158.
8.4.2 Evidence of synmagmatic tectonism	161.
8.5 Summary	162.
 9 A DEPOSITIONAL MODEL	164.
 10 SUMMARY	170.
10.1 Introduction	170.
10.2 Summary of stratigraphy	171.
10.3 Summary of conclusions	174.
10.4 Suggestions for further research	176.
 REFERENCES	177.
 APPENDIX 1: A description of the Jensen Cation Plot	180.
APPENDIX 2: Structural geology	186.
APPENDIX 3: Geochemical data	212.

List of Tables

Table.	Page.
1. The stratigraphic succession of the Kirkland Lake area	10.
2. Petrological descriptions of Mg-rich and Fe-rich tholeiitic basalts	82.
3. Characteristics of komatiitic lavas	122.
4. Classification of northern Munro Township komatiites	123.
5. MgO and Al_2O_3/TiO_2 values for komatiites from the first and second komatiite lava successions	155.
6. Stages in the development of 'megacauldrons'	198.
7. Petrological summary for the Munro Lake Sill (Centre Hill Complex)	212.
8. Calculation of cation percentages	249.
9. Summary of the major structures within Beatty and Munro Townships in relation to regional tectonic events	273.

16.	Close-packed picritic breccia at Centre Hill	109.
17.	Small, dispersed varioles in a massive Fe-rich tholeiite flow, southeast Beatty Township	111.
18.	Varioles coalescing into the core of a tholeiitic basalt pillow, Painkiller Lake, north-central Beatty Township	111.
19.	Massive Fe-rich tholeiite from the variolitic marker horizon. Varioles coalescing to form a small pod of rhyolite	111.
20.	Photomicrograph of a devitrified variole in a chloritized, ferruginous matrix	113.
21.	Photomicrograph of variolite from same variolite sample as Plate 20.	113.
22.	End-on view of 'string-beef' clinopyroxene spinifex from an olivine-rich basaltic komatiite flow located north of the Munro Mine in southwest Munro Township	170.
23.	Longitudinal view of 'string-beef' clinopyroxene spinifex from same flow (Plate 22)	170.
24.	Photomicrograph of 'string-beef' clinopyroxene in cross-section	172.
25.	Large columnar joints in the base of a ponded, peridotitic komatiite flow, Potter Mine area, central Munro Township	172.
26.	Type 'A' peridotitic komatiite flow from Pyke Hill, northern Munro Township	174.
27.	Coarse olivine spinifex from an 'A-B' type peridotitic komatiite flow in northeast Guibord Township	174.
28.	Photomicrograph of a 'slaggy' textured basaltic komatiite	176.
29.	Photomicrograph of a 'slaggy' textured basaltic komatiite	176.
30.	Photomicrograph of olivine spinifex	176.
31.	Photomicrograph of olivine spinifex	176.
32.	Rectangular jointing in the cumulate zone in an 'A-B' type peridotitic komatiite flow, northeast Guibord Township	178.
33.	Photomicrograph of serpentinized olivine crystals	

List of Plates

Plate.		Page.
1.	North-central Munro Township looking west towards Warden Hill	28.
2.	Felsic block and ash deposit from the felsic marker horizon at the top of the Stoughton-Roquemare Group succession, Pike River, north-central Hislop Township	28.
3.	Typical Porcupine Group sedimentary rock: finely-bedded siltstone/mudstone, southwest Munro Township	30.
4.	Photomicrograph of fine-grained feldspathic wacke from the Porcupine Group	30.
5.	Pillowed tholeiitic basalt, lava tube budding a pillow in a down-dip direction	36.
6.	Mg-rich tholeiitic basalt, partially exposed lava toe, north-central Munro Township	36.
7.	Interflow sedimentary unit <u>enclosed</u> by the Munro Lake Sill: Laminated silicic and tuffaceous siltstone, north-central Munro Township	71.
8.	Pillowed Fe-rich tholeiitic basalt: two lava tubes, one displaying 'pillow shelves' and the other a 're-entrant' structure indicating a budding pillow. Maude Lake Gold Mines Ltd. open pit, northwest Beatty Township	71.
9.	Photomicrograph of a fairly 'fresh' fine-grained, massive Fe-rich tholeiite	105.
10.	Photomicrograph of a porphyritic Mg-rich tholeiitic basalt	105.
11.	Photomicrograph of hyaloclastite from a tholeiitic basalt flow top	105.
12.	Photomicrograph of a glass shard with pumpellyite and chlorite-filled vesicle and a mass of fine spherulites	105.
13.	Photomicrograph of the upper edge of a pillow (tholeiitic basalt)	107.
14.	Photomicrograph of a pillowed tholeiitic basalt. Quenched 'swallow-tail' plagioclase and sericitized plagioclase phenocrysts in a spherulitic chlorite-rich groundmass	107.
15.	Flow breccia; tabular lava fragments in a hyaloclastite matrix	109.

49. Discontinuous clinopyroxenite layers in peridotite,
Munro Lake Sill, south-central Warden Township 219.
50. Rhythmic gabbro, leucogabbro and clinopyroxenite
layering, Munro Lake Sill, Centre Hill 219.
51. North-trending normal cross-fault exposed in the
northern wall of the 'A' pit, Munro Mine, southwest
Munro Township 279.
52. Small S_2 folds with southwest-striking axial
planes within the Porcupine Group sedimentary rocks
of southwest Munro Township 279.
53. The Contact Fault in southwest Munro Township 279.

Chapter 1: Introduction

The geological mapping which forms the basis of this thesis has been concentrated in Beatty and Munro Townships encompassing a 200 sq. km area within the Black River-Matheson region of Northeastern Ontario, an area centrally located in the western Abitibi Belt of the Superior Province (Figure 1).

The area has both economic and geological significance. Former gold (Lucky Ben, Blue Quartz, Argyll, Aljo, Stewart-Abate and Croesus Mines), copper-lead-zinc (Potter and Potterdoal Mines), and asbestos (Munro Mine) mines were located there and there is continuing gold exploration activity and the development of a new gold mine (Maude Lake Property) in Beatty Township. There has been considerable academic interest in recent years in the spinifex-bearing komatiite lavas and the layered flows and sills exposed within Munro Township. Komatiitic flows from Munro Township are cited as type examples of Archean komatiites of the Canadian Superior Craton.

The large number of research studies conducted in Munro Township can be divided into two main groups: (1) economic, research centered on gold [i.e. MacRae and Crockett, 1977, Pyke et al., 1976), nickel (Arndt, 1976), copper-zinc (Coad, 1976), and asbestos (Freeman, 1954); and (2) petrological research studies, concentrated on the komatiites and layered intrusions found within the township (i.e. MacRae, 1963, Pyke et al., 1973, Fleet and MacRae, 1975, Arndt, 1975, Arndt et al., 1977, Arndt and Nesbitt, 1982, 1984, Campbell and Arndt, 1982). The work done on the Munro komatiites has been the most significant of this research, making a couple of the rock exposures in the township classic sites for the investigation of ultramafic lava flows. The literature produced from

these studies deals with: (i) the petrological and geochemical characteristics, (ii) the classification, and (iii) the petrogenesis of komatiite lava flows, and has set a standard for the investigation of similar lavas in other areas.

The townships have not been mapped since the years 1947 and 1951 (Satterly and Armstrong, 1949, Satterly, 1952a) when the Ontario Department of Mines first published two 1 inch to 1000 feet scale maps of the area. Surrounding areas, including Carr, Hislop, Guibord, Michauld, McCool, Milligan, Warden and Coulson Townships, have been mapped recently (Johnstone and Trowell, 1985, Johnstone, 1986) and the maps are currently being prepared for publication. The ten township area is bordered by 1 inch to 1/4 mile (1:15840) scale map sheets to the south, southeast and east (Jensen, 1985ab, 1982ab -Figure 2).

Although Munro Township geology has become synonymous with komatiites, recent mapping has indicated that both Munro and Beatty Townships are underlain by a broad range of intrusive and extrusive rocks, representing the products of komatiitic, tholeiitic and even calc-alkalic magmatism. The rocks of Beatty and Munro Townships are deformed by tight isoclinal folds between splays of the Porcupine-Destor Fault Zone located on the north limb of the easterly-plunging Blake River Synclinerium. Although almost all of the major gold deposits of northeastern Ontario have been found along this east-west trending break, and along the parallel trending Kirkland Lake-Larder Lake Break to the south, very little is known about the nature of folding and faulting along it. This is particularly true along the fault's central portion where there is a lack of exposure and comprehensive geological mapping. Gold mineralization, being largely structurally controlled in the area, makes the pursuit of structural interpretations more important than just

- ① O.G.S. Map P.2433, Jensen, 1982.
- ② O.G.S. Map P.2434, Jensen, 1982.
- ③ O.G.S. Map P.2861, Jensen, 1985.
- ④ O.G.S. Map P.2860, Jensen, 1985.

FIGURE-2. Geological map coverage of the Black River-Matheson area.

for stratigraphic reconstruction.

The Blake River Synclinorium south of the Destor-Porcupine Fault Zone is thought by Jensen and Langford (1983) to have formed through a process of prolonged basin subsidence combined with cycles of volcanism and associated periods of sedimentation and plutonism. Each cycle is characterized by a succession from base to top of komatiitic, tholeiitic and calc-alkaline lavas. The volcanic rocks of Beatty and Munro townships are believed by Jensen and Langford (1983) to belong to the Stoughton-Roquemaure Group, which represents the basal mafic and ultramafic member of the younger of two volcanic cycles recognized on the north limb of the synclinorium.

The oldest rocks exposed on the north limb belong to the calc-alkaline Hunter Mine Group marking the end of the first cycle of volcanism. Calc-alkalic volcanic rocks, possibly related to late Hunter Mine Group volcanism, occur within the Stoughton-Roquemaure Group succession in the study area. The argillites and greywackes of the Porcupine Group, also found within the study area, are thought to represent basinal sediments deposited between, and derived from, calc-alkaline volcanic piles (Pike, 1981, Jensen and Langford, 1983).

The subaqueous Stoughton-Roquemaure Group lavas in the study area both underlie and overlie the Porcupine Group metasediments, and consist of two successions dominated by komatiites and Mg-rich tholeiites alternating with two, thicker successions dominated by Fe-rich tholeiites.

It has been proposed by Jensen and Langford (1983) that the Stoughton-Roquemaure volcanics erupted from widely spaced centers distributed throughout the basin, and the tholeiitic sequences of the overlying Kinojevis Group erupted from the mid-basin centers of two basins: one small basin located immediately north of the Porcupine-

Destor Break in the Lightning River area, and another, much larger basin situated between the Destor-Porcupine and Kirkland Lake-Larder Lake Fault Zones.

Evidence suggesting that the Stoughton-Roquemaure eruptive centers which extruded the Beatty and Munro township flows were localized along the hinge and subsequent fault zone now represented by the Destor-Porcupine Fault Zone is presented as part of this thesis.

1.1 Aims of the study

The first aim was to produce detailed 1:15840 scale maps for the two townships designed to highlight lithological divisions down to the scale of individual flows. Producing a detailed geological map for the two townships and applying a modern and more detailed rock classification will help tie the area's stratigraphy in with the regional stratigraphy recently established to the east in the Lightning River area (O.G.S. Map P.2433, Jensen, 1982a). To this end therefore, the second aim was to correlate the stratigraphy and briefly describe the different lithologies found within the study area.

By describing certain stratigraphic relationships and physical features within lava flows and sedimentary strata, a model for the deposition of the Stoughton-Roquemaure Group lavas within the western Black River-Matheson area is proposed. In the course of this discussion, every attempt has been made to comment and build upon earlier research into the nature and setting of komatiitic lavas. The model is intended to complement a larger scale model for the evolution of the Abitibi Greenstone Belt in the Kirkland Lake area constructed by Jensen and Langford (1983).

1.2 Location and access

Beatty and Munro Townships are located immediately southwest of Lake Abitibi and about 80 km east of Timmins, in the Black River-Matheson district of northeastern Ontario (see Figure 2). Highway 101 running east to Rouyn-Noranda and west to Timmins through the town of Matheson, cuts through the southern edge of the two townships.

Access to the interior of the two townships is provided by two well maintained gravel roads at either side of the study area and by two short secondary roads leading to the Munro and Croesus mine (abandoned) sites in southwest Munro township. Several east-west trending trails branch off the roads and provide access to most of the major outcrop areas in the townships (see the Beatty and Munro Township maps -rear pocket).

Chapter 2: Regional Geology

2.1 Introduction

Beatty and Munro Townships are centrally located in the Abitibi greenstone belt in the Superior Province of the Canadian Precambrian Shield. The Abitibi Belt is crudely S-shaped, approximately 800 km long and 240 km wide and extends in a ENE direction from Wawa in central Ontario to Chibougamou in Quebec (Figure 1). The belt is bounded to the north by the Opatika Subprovince, to the west by the Kapuskasing Structural Zone and to the south by the Southern Province and the Pontiac Subprovince. It is largely underlain by steeply dipping volcanic and sedimentary assemblages intruded by plutons of tonalitic to trondhjemitic composition. The volcanic rocks include minor ultramafic lavas, abundant basalt to dacite lavas, and locally abundant rhyolite flow and pyroclastic rock.

2.2 Regional Stratigraphy

The stratigraphy of the southern Abitibi Belt in the Timmins-Kirkland Lake-Noranda region as defined and interpreted by Goodwin (1979) consisted of twelve stratigraphic groups of which nine were volcanic. Many of these groups have since been either renamed or redefined (Jensen and Langford, 1983, Dimroth et al., 1982), and have been recently incorporated in a lithostratigraphic map of the Abitibi Subprovince prepared jointly by the Ontario Geological Survey and the Direction Générale de l'Exploration Géologique et Minérale du Québec (O.G.S. Map 2484, MERQ-OGS, 1983). This more recent classification scheme incorporates stratigraphic correlations over a much broader area and includes the calc-alkalic volcanic rock found within the study area which was not included in the Goodwin classification.

2.2.1 The revised stratigraphy of the southern Abitibi Belt

Detailed stratigraphic successions have been established in the Kirkland Lake area (Jensen and Langford, 1983) and on the flanks of the Lake Abitibi and the La Motte anticlines in Quebec (Dimroth et al., 1982, Gelinas et al., 1977a). Based on these successions, several workers (Jensen and Langford, 1983, Pyke, 1982, Dimroth et al., 1982) have concluded that the stratigraphy of the central Abitibi Subprovince represents two complete volcanic cycles, each consisting of a komatiitic base overlain in turn by tholeiitic and calc-alkalic rocks and, for the second cycle, capped by alkalic volcanics. In addition, the komatiitic base of the first cycle is underlain by calc-alkalic volcanic rocks (Pacaud Tuffs) in the Kirkland Lake area, representing the top of an older volcanic cycle. The two complete volcanic cycles are stratigraphically represented by the Upper and Lower Supergroups. Each of the rock groups belonging to the Upper and Lower Supergroup sequences are presented in Table 1 (also see Figure 7).

The rocks of the Upper Supergroup occupy most of the Blake River Synclinorium, with the Lower Supergroup rocks situated on the outer margins of the synclinorium fringing two large trondhjemitic intrusive complexes, the Round Lake (southern edge) and Lake Abitibi (northern edge) Batholiths. The Lake Abitibi Batholith truncates the Lower Supergroup on the north limb of the synclinorium and the Round Lake Batholith obscures any rocks which would have predated the Pacaud Tuffs of the earliest volcanic cycle.

The oldest rocks exposed on the northern limb of the synclinorium belong to the calc-alkaline Hunter Mine Group, the uppermost group of the Lower Supergroup. The absence of lower units may be due to erosion or a lack of exposure. Jensen and Langford (1983) have suggested that

TABLE 1: STRATIGRAPHIC SUCCESSION OF THE KIRKLAND LAKE AREA.

SOUTH LIMB OF SYNCLINORIUM *

Upper Supergroup

Timiskaming Group

Volcanic rocks: Mafic, intermediate, felsic trachyte, and K-rich dacite and rhyolite flows and tuffs.
Sedimentary rocks: Fluvial conglomerate, sandstone, and argillite
Intrusions: Stocks and dikes of syenodiorite, syenite, quartz monzonite, and lamprophyre

Blake River Group

Volcanic rocks: Calc-alkalic basalt, andesite dacite and rhyolite flows and tuffs
Sedimentary rocks: Volcaniclastic slump deposits
Intrusion: Stocks and dikes of gabbro, quartz gabbro, hornblende gabbro, diorite, quartz diorite, and subvolcanic rhyolite domes.

Kinojevis Group

Volcanic rocks: Mg-rich and Fe-rich tholeiitic basalts, and tholeiitic andesite, dacite and rhyolite flows and tuffs.
Sedimentary rocks: Thin interflow argillite and chert.
Intrusions: Sills of Mg-rich and Fe-rich gabbro

Larder Lake Group

Volcanic rocks: Flows of peridotitic and basaltic komatiite, and Mg-rich tholeiitic basalt, and minor Fe-rich tholeiitic basalt, and minor Fe-rich tholeiitic basalts and interflow rhyolite tuff-breccias.
Sedimentary rocks: Turbiditic conglomerate, greywacke and argillite, and iron formation chert, limestone, and dolostone.
Intrusions: Sills and stocks of peridotite, pyroxenite, and gabbro

Lower Supergroup

(Unnamed Unit)

(Conglomerate with trachyte and syenodiorite pebbles)

Skead Group

Volcanic rocks: Mainly calc-alkalic rhyolite tuff-breccia with some calc-alkalic basalt, andesite and dacite flows and tuff-breccias.
Sedimentary rocks: Chert and cherty argillite.
Intrusions: Stocks of feldspar porphyry and quartz diorite

Catherine Group

Volcanic rocks: Mg-rich and Fe-rich tholeiitic basalts.
Sedimentary rocks: Interflow chert.
Intrusions: (None mapped)

Wabewawa Group

Volcanic rocks: Peridotitic and basaltic komatiite, Mg-rich tholeiite basalt and minor Fe-rich tholeiitic basalt, and a few interflow rhyolite tuffs.
Sedimentary rocks: (None mapped)
Intrusions: Layer sills (possibly flows) of dunite, pyroxenite, and gabbro.

Pacaud Tuffs

Volcanic rocks: Calc-alkalic andesite, dacite, and rhyolite tuffs.
Sedimentary rocks: Chert, argillite, iron formation.
Intrusions: Trondhjemite of Round Lake Batholith.

NORTH LIMB OF SYNCLINORIUM*

Upper Supergroup

Destor - Porcupine Complex

Volcanic rocks: Alkali basalt, benimorite, hawaiite, mugearite, and alkali-rich dacite and rhyolite.
Sedimentary rocks: Turbiditic conglomerates, greywacke, argillite, and ironstone.
Intrusions: Stocks and dikes of syenodiorite, granodiorite, and quartz monzonite

Blake River Group

(See south limb)

Kinojevis Group

(See south limb)

Sloughton - Roquemaure Group

Volcanic rocks: Flows of peridotitic and basaltic komatiite and Mg-rich tholeiitic basalt and minor Fe-rich tholeiitic basalt and minor interflow calc-alkalic rhyolite tuff and cherty tuff
Sedimentary rocks: Minor chert and iron formation.
Intrusions: Sills and stocks of peridotite, pyroxenite, and gabbro

Lower Supergroup

Hunter Mine Group

Volcanic rocks: Mainly calc-alkalic dacite and andesite tuff-breccia with some calc-alkalic basalt, andesite and dacite flows.
Sedimentary rocks: Cherts, iron formation and turbiditic greywacke, and argillite (may be equivalent to Porcupine Group)
Intrusions: Dikes of quartz-feldspar porphyry and trondhjemite of Lake Adiribi Batholith.

* Blake River Synclinorium

(after Jensen and Langford, 1983)

the Hunter Mine Group in the Lake Abitibi area, the Upper Formation of the Deloro Group (Pyke, 1982) in the Timmins area, and the Skead Group in the Kirkland Lake area represent spatially separate calc-alkaline volcanic piles all disconformably overlain by a common group of komatiite-rich lavas forming the base of the Upper Supergroup. Geochronological data (Nunes and Pyke, 1980, Nunes and Jensen, 1980) has indicated that the different calc-alkaline groups are stratigraphically equivalent, but not necessarily time equivalent.

The komatiitic and tholeiitic base of the Upper Supergroup can be traced around the nose of the Blake River Synclinorium, being represented by the Stoughton-Roquemaure Group on the north limb, the Larder Lake Group on the south limb, and the Lower Formation of the Tisdale Group at the nose of the synclinorium in the Timmins area (Jensen and Langford, 1983). (see Figure 7)

The Stoughton-Roquemaure Group and the calc-alkalic Blake River Group of the Upper Supergroup are stratigraphically separated by the predominantly tholeiitic Kinojevis Group (Jensen, 1978) and the equivalent Middle Formation of the Tisdale Group (Pyke, 1982) in the Timmins area.

2.2.2 Groups represented in the study area

Volcanic rocks belonging to both the Stoughton-Roquemaure and Hunter Mine Groups and sedimentary rocks of the Porcupine Group are found within the study area. A general picture of the distribution of these rocks along the northern edge of the synclinorium is presented in this section.

2.2.3 Hunter Mine Group

The name 'Hunter Mine Series' was first applied by Dimroth et al. (1973) to a succession of "mainly felsic flow breccias with minor

agglomerate, rhyolite tuff and greywacke" at the Hunter Mine in Palmarolle Township, Quebec, 19 km east of the Ontario border. From this location the Hunter Mine Group extends northwest into Roquemaure Township (Eakins, 1972)(see Figure 3).

Approaching Ontario, the group disappears under younger komatiitic and tholeiitic volcanics of the Stoughton-Roquemaure Group and then reappears in two areas: (i) extending out from the western end of Lake Abitibi, where the group is found as pods fringing the Lake Abitibi Batholith, and (ii) to the south and southwest of the lake, where the Group is bounded by two eastward-verging splays of the Destor-Porcupine Fault Zone. This latter belt has a maximum width of approximately 8 km and extends west for at least 29 km from Frencheville Township to McCool Township and perhaps into Warden Township to the northwest. It largely consists of massive and pillowed calc-alkalic basalt and andesite flows and calc-alkalic andesite, dacite and rhyolite tuffs and tuff breccias. The Hunter Mine Group rocks disconformably underlie the Stoughton-Roquemaure Group along much of the belt but, at its western end, stratigraphic relationships are not as clear with small occurrences of calc-alkalic rock appearing within the Stoughton-Roquemaure Group succession in northeast McCool Township and southern Warden, Beatty and Munro Townships (Johnstone and Trowell, 1984, Johnstone, 1986): The center of the belt, in southern Rand Township, is characterized by a circular, 4 km diameter rhyolite complex which is thought by Jensen and Langford (1983) to represent a former explosive vent area.

2.2.4 The Porcupine Group

Metasedimentary rocks are exposed on the north side of a southern splay of the Destor-Porcupine Fault Zone in Michaud, Garrison and Harker

FIGURE 3. Map showing the distribution of rock types belonging to the Porcupine and Hunter Mine Groups.
(modified after Jensen and Langford, 1983)

Townships. These rocks are mainly turbiditic greywackes, interlayered with argillaceous iron formation, and are described by Satterly (1952b) as being composed of angular quartz and feldspar (oligoclase) grains and rock fragments of quartzite and acid lava set in a groundmass of quartz, feldspar, chlorite, biotite and white mica. Based on this composition, Jensen and Langford (1983) have suggested that these sediments were derived from a volcanic terrain with abundant dacite and rhyolite and that the deposits are a deep-water marine facies of the Hunter Mine Group (see Plates 3 and 4).

In contrast, Satterly (1954) had previously suggested that the Michauld, Garrison and Harker sedimentary rocks are extensions of a sedimentary group which underlie the mafic and ultramafic volcanics of Guibord, Munro and Beatty Townships. In the study area, these metasediments, referred to as the Porcupine Group (Lorsong, 1975, Pyke, 1982), belong to a broad belt of metasediments which extends east from Timmins to a point in northern Guibord Township. The greywacke and argillite exposed in the study area belong to the Beatty Formation, the stratigraphically highest member of the four formation Porcupine Group (Lorsong, 1975).

In the Timmins area, the Porcupine Group straddles to Lower Supergroup-Upper Supergroup boundary and is time-equivalent with the Upper Formation of the Deloro Group and the lower half of the overlying Tisdale Group (Pyke, 1982). Based on geochronological studies (Nunes and Jensen, 1980, Nunes and Pike, 1980), the Beatty Formation may be time-equivalent with the lower half of the Tisdale Group, a stratigraphic position within the base of the Upper Supergroup that is confirmed in Beatty, Hislop and Guibord Townships where the Porcupine Group (Beatty Formation) pinches out within a north-facing Stoughton-Roquemaure Group

succession (Johnstone and Trowell, 1985 -see Figure 5), The Stoughton-Roquemaure Group-Porcupine Group contact appears to be conformable in most areas but an angular unconformity, which does exist in Beatty Township, appears to be both structural and a depositional in nature.

There is also a narrow east-west trending belt of sedimentary rock immediately north of the study area in Wilkie, Coulson and Warden Townships (see Figures 3 and 6) which contains rock similar to that found in the main Porcupine Group belt in Beatty and Munro Townships (Johnstone, 1986). Stratigraphic correlation is difficult to make due to the lack of exposure and structural complexity in the northern townships, but it is possible that these sediments are stratigraphically equivalent to the Porcupine Group, if not even a portion of the same assemblage repeated by folding.

2.2.5 The Stoughton-Roquemaure Group

The Stoughton-Roquemaure Group occupies much of the area between the Lake Abitibi Batholith and the Destor-Porcupine Fault Zone (Figure 4). From its type-section in Stoughton and Roquemaure Townships, where Jensen (1978) has defined a top and bottom, the group extends west across the length of Lake Abitibi into Milligan, Warden and Coulson Townships. The basal sections of the Stoughton-Roquemaure Group are located in the southern parts of Lamplugh and Frencheville Townships, along the north boundary of Garrison Township, and along the northern edge of the Destor-Porcupine Fault Zone. Westward, the Stoughton-Roquemaure Group rocks are divided into two belts separated by a wedge of the Porcupine Group rock. The larger northern belt is 10-12 km wide and trends at 95-120 degrees through much of McCool, Munro and Beatty Townships and the southern halves of Coulson and Warden Townships. The northern edge of the group is bordered by a second belt of Porcupine

Figure 4. Map showing the distribution of the Stoughton - Roquemaure Group in the map area and adjacent areas. (modified after Jensen and Langford, 1983)

FIGURE 5. Sketch map of the generalized geology of the northwestern Black River-Matheson area.

FIGURE 6. Sketch map of the generalized geology of Coulson, Warden and Milligan Townships.

Group metasedimentary rocks which trends west through Warden, Coulson and Wilkie Townships (Johnstone, 1986 -see Figure 6).

The western end of the belt is not well exposed. However, the komatiitic lavas and a large differentiated sill exposed in Dundonald Township, over 30 km west of Coulson Township, and a similar assemblage west of Frederick House Lake (Lower Tisdale Group) are interpreted by Arndt (1975) to be extensions of this belt.

The Stoughton-Roquemaure Group rocks of the southern belt are also poorly exposed. The most recent regional compilation (O.G.S. Map 2484) suggests that the belt is bordered by the southern branch of the Destor-Porcupine Fault Zone to the north and by a discontinuous felsic tuff and tuff breccia marker horizon (Plate 2), defining the top of the succession, and the transition to the the Kinojevis Group to the south. The marker horizon underlies the tholeiitic lavas of the Kinojevis Group and extends for about 60 km from Garrison Township to Bond Township. The marker horizon is only exposed in a few small outcrops along its length, and it is difficult to judge the nature or even the position of the Stoughton-Roquemaure Group-Kinojevis Group transition in most places (Johnstone and Trowell, 1985). Westward, the Stoughton-Roquemaure Group becomes known as the Lower Tisdale Group (Pyke, 1982) as the belt enters into the Nighthawk Lake area.

2.2.5.1 The Stoughton-Roquemaure Group type-section

The type-section of the Stoughton-Roquemaure Group, in Stoughton Township, Ontario and Roquemaure Township, Quebec, is more than 15 km thick (Jensen and Langford, 1983). The lower 1500 m of the group is described by Eakins (1972) as consisting of elongated, coarse-grained bodies of gabbro, peridotite and dunite, interlayered with lesser amounts of massive and pillowed lava, and overlain by mainly pillowed

and fine-grained massive lavas. This succession is also described as being interlayered with a few finely-bedded felsic tuff horizons.

Some of the peridotites and gabbros appear to cut the base of the Stoughton-Roquemaure Group and the top of the Hunter Mine Group at low angles, indicating intrusive relationships, but certain gabbro bodies are also believed to be thick, tabular massive flows (Jensen and Langford, 1983). The largest peridotite body described by Eakins (1972) is 160 m wide and over 2 km long while the largest gabbro sill, the 'Roquemaure Gabbro', is also 100 to 200 m wide and several kilometres long. Some of the gabbro intrusions contain xenoliths of chert and, in the case of the Roquemaure Gabbro, rhyolite and basaltic lava. Eakins (1972) believed that the chert fragments were derived from the underlying Hunter Mine Group rocks, implying that these bodies were probably intrusions. Jensen and Langford (1983) though have noted that basal Stoughton-Roquemaure Group lava flows found elsewhere can contain xenoliths of interflow cherty tuff, chert and iron formation, and that interflow units of calc-alkalic cherty dacite and rhyolite tuff are present in the flow succession.

The composition of the lavas of the lower succession in Roquemaure Township has not been examined in detail. However, Jensen and Langford (1983) have concluded from the available data, that if it is assumed that most of the gabbros are thick flows, the succession is composed of Fe-rich tholeiitic basalts and minor Mg-rich tholeiitic basalts overlain by komatiitic lavas. This succession may not represent the earliest Stoughton-Roquemaure Group lavas, as earlier lavas may have erupted elsewhere at lower erosional levels on the calc-alkaline volcanic pile (Jensen and Langford, 1983).

The upper 6 km of the group in Stoughton Township is described by Jensen (1978) as consisting of fourteen volcanic units, each of which is composed of only one rock type forming one or more flows of massive and pillowed lavas. The units form a cyclical pattern of peridotitic komatiite at the base overlain consecutively by basaltic komatiite, Mg-rich tholeiitic basalt and Fe-rich tholeiitic basalt. The group is topped by a 350 m thick Fe-rich tholeiitic basalt flow. Varying from 300 to 1700 m in thickness, these cycles may have oscillations from one rock type to another or may be incomplete, lacking a peridotitic komatiite base or an Fe-rich tholeiite top.

In general, Mg-rich tholeiitic basalt increases in abundance and thickness upward in the higher cycles relative to the ultramafic and basaltic komatiites. Some of the cycles are separated by thin (<10 cm thick) units of chert and iron formation. (Jensen and Langford, 1983)

2.3 Regional structure

The main structural features of the Kirkland lake area are the Blake River Synclinorium and the two major fault zones; the Porcupine-Destor Fault Zone and the Kirkland Lake-Larder Lake Fault Zone on the north and south limbs of the synclinorium respectively (see Figure 7). Jolly (1978), in a regional examination of metamorphic facies patterns, has concluded that these structural features formed during the deposition of the volcanic succession rather than later, and were little affected by the Kenoran Orogeny (2.4-2.6 Ga.). Regional structural and stratigraphic studies in the adjacent Ontario (Jensen and Langford, 1983) and Quebec (Dimroth et al., 1982, 1983) portions of the Abitibi Belt have indicated that the major fault zones were active during the later stages of volcanism and sedimentation, characterized by normal growth faults, but that there was some reactivation of the fault zones during the Kenoran

Figure 7. Geological map of the Timmins - Kirkland Lake area. (modified after Jensen and Langford, 1983)

Orogeny.

Jensen and Langford (1983) have presented the following model for the development of the fault zones;

Jensen's tectonic model for the evolution of the central Abitibi Belt

(i) The fault zones began as a series of faults which developed along the edges of the basin, now represented by the synclinorium, next to the volcanic piles identified by the felsic volcanic rocks of the Hunter Mine and Skead Groups. These felsic volcanoes erupted at the points of flexure about the basin and the resulting complexes possessed a higher degree of tectonic stability than that of the surrounding strata.

(ii) The accumulation of the Porcupine Group sediments followed by the thick succession of ultramafic and mafic lavas belonging to the Stoughton-Roquemaure, Larder Lake and Kinojevis Groups within the basin and in the low areas on the marginal shelves of older volcanic piles promoted differential subsidence. Strata tilted up around the edge of the subsiding basin, faults developed and older faults were reactivated.

(iii) As the volcanism represented by the Kinojevis and Blake River Groups became focused in the center of the subsiding basin, the downward displacement next to the older and more buoyant volcanic terrains became localized along the marginal fault zones. The fault zones at this time probably consisted of a series of fault blocks rather than a single fault. The centralized subsidence within the basin would have produced tensional forces along the already active fault zones, and this would have led to the evolution of graben structures. It was into these that the Timiskaming Group and Destor-Porcupine Complex lavas, tuffs and clastic sediments were deposited.

The nature of the Porcupine-Destor Fault Zone in the Black River-Matheson District is uncertain. The three main splays of the fault zone are unexposed, and their magnitude and sense of displacement are unknown. It is assumed that most of the movement along the splays was in a vertical sense (Jensen and Langford, 1983).

Where the Porcupine-Destor Fault Zone can be observed in the Timmins area, Pike (1982) has described its main shear zone as being 150 m wide with a sinistral-sense strike-slip component and a component of vertical movement whereby the south block moved up relative to the north block. Dimroth et al. (1983) has reported an opposite sense of vertical displacement for the fault zone from its Quebec extension. Here, the

north side rose relative to the south side during the final stage of volcanism.

The Kenoran Orogeny was a period of north-south compression in the Abitibi Belt. The effects of this deformational period in the Rouyn-Noranda area have been summarized by Dimroth et al. (1983). The north-south compression initially produced a set of flexure folds, F_1 , that curve around the consolidated cores of central volcanic complexes and are generally oriented in an easterly direction. Synclinoria nucleated at the deeply subsident depocenters of the Blake River Group. Continued north-south flattening and subvertical stretching produced east-trending F_2 folds, the tightening of F_1 folds and the development of axial-plane schistosity S_2 and two locally superposed schistosity S_3 and S_4 . At this time the Duparquet-Destor breaks became a thrust fault and northeast- and southwest-dextral strike-slip faults formed. All of this faulting possessed a sense of shear consistent with the north-south compression. The Duparquet-Destor displays minor (<3 km) dextral-sense strike-slip. The Kenoran Orogeny was also characterized by the diapiric rise of late- to post-kinematic granitic plutons (Dimroth et al., 1983). Apart from the shear zones within the two major fault zones and at the margins of the batholiths, most of the rocks of the Kirkland Lake area show little or no penetrative deformation. This is thought by Jensen and Langford (1983) to be a feature of syn-depositional deformation with most of the differential movement being taken up by narrow strike-slip faults which developed throughout the evolving synclinorium during the depositional period. Dimroth et al. (1983) have noted that penetrative deformation tends to be absent from those portions of the Abitibi plate that have been stiffened by major synvolcanic plutons.

The area is transected by numerous vertical and near-vertical post-

depositional faults. These have been described as normal tensional faults which have caused only minor offsets of strata (Jensen and Langford, 1983). Diabase dikes have intruded two sets of these faults, thus helping to define faults that would not otherwise have been obvious. A large number of Matachewan dikes (age 2.63 Ga.-Gates and Hurley, 1973) have intruded a north-trending set of faults and several large Abitibi dikes (age 1.14 Ga.-Fahrig and West, 1986) have penetrated along a younger northeast-trending set of faults.

An examination of the orientation of Matachewan dikes adjacent to the Kapuskasing Structural Zone has indicated that there was a westward tilting of the crust in the eastern Abitibi Belt in the time period before the Grenville Orogeny, and following the Kenoran Orogeny (Ernst and Hall, 1984).

2.4 Regional metamorphism

The Kirkland Lake area is located at the widest point of the Abitibi Belt and this core preserves the lowest grades of metamorphism, viz: prehnite-pumpellyite facies developed at pressures of about 1 kb (Jolly, 1974). Zeolite facies metamorphic grade appears to be absent in the central Abitibi Belt (Jolly, 1978, Dimroth et al., 1978) and lower to middle greenschist grade metamorphism occurs in the Hunter Mine Group rocks (Jensen and Langford, 1983). Within the volcanic pile, lower greenschist facies contact aureoles are also found surrounding sub-volcanic intrusions (Jolly, 1978).

Since the estimated 1 kb confining pressure indicates a depth of burial far less (<4 km) than any of the estimates of total stratigraphic thickness given by various workers (Jensen and Langford, 1983, Ridler, 1970, Baragar, 1968) for the area, Jolly (1978) concluded

that these were apparent thicknesses which reflected "thickening by structural features or topographical irregularities produced during and after volcanism". One of these 'structural features' is the Porcupine-Destor Fault Zone. Since prehnite-pumpellyite facies metamorphism occurred on both sides of the Porcupine-Destor Fault Zone, the thick upper part of the volcanic succession (Blake River Group) on the south side could never have been deposited north of the fault during this later period of volcanic activity. The fault zone, Jolly (1978) therefore concludes, represented a hinge line south of which considerable subsidence occurred during the eruption of the upper part of the volcanic pile.

The low grade metavolcanic rocks were later locally affected by two contact metamorphic events; (i) the rise of late-stage syenite and alkali syenite stocks, and (ii) the Kenoran Orogeny when the Lake Abitibi and Round Lake Batholiths were emplaced. Metamorphic aureoles of albite-epidote-hornblende, hornblende, and pyroxene hornfels occur in the volcanic rocks surrounding the region's alkalic intrusions, and alkali metasomatism is common, particularly where rocks are sheared along the Destor-Porcupine Fault Zone. Towards the Lake Abitibi Batholith, the metamorphism increases from subgreenschist to lower, middle and upper greenschist facies and at the contact, amphibolite facies (Jensen and Langford, 1983).

Plate 1. North-central Munro Township looking west towards Warden Hill.

Plate 2. Felsic block and ash deposit from the felsic marker horizon at the top of the Stoughton-Roquemaure Group succession, Pike River, north-central Hislop Township.

Plate 3. Typical Porcupine Group sedimentary rock: finely-bedded siltstone/mudstone, southwest Munro Township.

Plate 4. Photomicrograph of fine-grained feldspathic wacke from the Porcupine Group. Immature quartz (Q) and plagioclase (P) grains enclosed by a matrix of chlorite, sericite, quartz, plagioclase, calcite, and hematite. Note: the hematite gives the rock a reddish weathered colour.

Chapter 3: General Geology of Beatty and Munro Townships

The predominant Stoughton-Roquemaure Group rocks exposed in Beatty and Munro Townships are of tholeiitic affinity. Komatiitic mafic and ultramafic volcanic rocks and sedimentary rocks make up about half of the rock underlying the two townships with most of the komatiitic volcanics located in Munro Township and most of the sediments found in Beatty Township. Komatiitic lavas are confined to narrow bands located in northeast and north-central Beatty Township and northern, central and south-central Munro Township. Two thin lenses of calc-alkaline volcanic rocks occur within this mafic and ultramafic Stoughton-Roquemaure Group succession in central Beatty and southwest Munro Townships. A belt of Porcupine Group sediments occupies most of the southern half of Beatty Township and a portion of southwest Munro. The belt widens from about 2.5 km to over 4.0 km as it passes westward through Beatty Township into Carr Township (see Figure 8 -rear pocket).

The volcanic assemblages are largely composed of thin (1 m to 20 m thick) pillowed and massive flows interlayered with several thick (90 m to 120 m thick), layered flows that are differentiated from peridotite at the base to gabbro at the top. Many lava flows possess flow-top breccia layers and it is common to find deposits of flow breccia, pillow breccia and hyaloclastite ranging in thickness from 1 m to over 100 m. Interflow sediments, usually consisting of fine-grained wacke, argillite, tuffaceous siltstone and chert, are rare.

The komatiites of northern Munro Township have been dated at 2765 ± 42 Ma. by Zindler et al. (1978) using Nd and Sr geochronology. However, a slightly younger and more precise U-Pb zircon age of 2714 ± 2 Ma. (S. Marmont, geologist, Ontario Geological Survey, personal communication,

1986) has been derived from a calc-alkalic rhyolite flow in central Beatty Township which is situated at a lower stratigraphic position within the Stoughton-Roquemaure Group succession than the komatiites dated by Zindler et al. (1978).

The volcanic rocks have been intruded by small peridotite sills and dikes, peridotite-pyroxenite sills and large, layered peridotite-pyroxenite-gabbro sills. The sills are high-level intrusions which can be seen in some cases to laterally erupt as flows. In the case of the largest layered sill in the area, the Munro Lake Sill, part of the intrusion grades westward into a thick, differentiated flow of tholeiitic affinity known as Theo's Flow (Arndt, 1975).

There are also a number of complex gabbro, diorite and quartz diorite intrusions which intrude the volcanic rocks and their associated sills. Some of the gabbros have partially intruded along strike faults, but most of these intrusions clearly show their discordant nature.

The strata are also cut by a large number of lamprophyre and feldspar-porphyry dikes. Most of the feldspar porphyry dikes have an east-west trend and some can be directly traced to a quartz diorite stock in the center of Munro Township and to two small syenitic stocks in southeast Beatty Township. Diabase dikes belonging to three dike swarms intrude all earlier rocks. These include the large northeast- to east-northeast-trending Abitibi (1.14 Ga.-Fahrig and West, 1986) olivine diabase dike, the northeast-trending, Pressiac (2.14 Ga. -Fahrig and West, 1986) quartz diabase dike and numerous, small, north-trending Matachewan (2.63 Ga. -Gates and Hurley, 1973) olivine diabase dikes.

All rocks except the discordant gabbro, diorite and felsic intrusions and the diabase dikes are folded about 90-120 degree trending fold axes. The strata are folded about a major syncline, the McCool Hill Syncline,

and a series of minor fold axes within the fold. The McCool Hill Syncline is a tight, upright to slightly north-inclined fold while the minor, second order folds are upright, doubly-plunging and isoclinal. Based on regional structural trends, the McCool Hill Syncline may also be doubly-plunging but the fold is not well enough exposed beyond the study area. With the axial surface trace of the syncline passing through the northern half of the study area and most of the minor folds concentrated in the north-central portion of the study area, most of the strata in Beatty Township and southern Munro Township faces north (Figure 8).

Although vertical displacements are difficult to determine, the major faults in the area appear to be subvertically-dipping, bedding-parallel faults which are likely related to motions along the Porcupine-Destor Fault Zone. There are at least four major faults; the Contact Fault (Satterly, 1952a), along the northern edge of the Porcupine Group sediments from the volcanic rocks, the Munro Fault Zone coring a komatiitic lava succession in southwest Munro Township and thought to be an extension of the Middle Branch of the Porcupine-Destor Fault (Jensen and Langford, 1983), the Centre Hill Fault (Satterly, 1952a), cutting strata immediately below the Munro Lake Sill in the center of Munro Township and the Warden Hill Fault, obscured by a gabbro intrusion in northern Munro Township, which repeats a large part of the stratigraphy on the north limb of the McCool Hill Syncline (see Figure 8).

The west- to west-northwest-trending folds are overprinted by a set of closely-spaced, southwest-plunging, open folds. This second set of minor folds also involve the major faults in the area and possibly deform the diabase dikes.

The dominant metamorphic grade in the study area is sub-greenschist (Prehnite-pumpellyite facies). There is a general absence of extensive recrystallization and many of the rocks still have their original mineralogy. Komatiites tend to be more readily altered than the tholeiitic volcanic rocks (Arndt, 1975), and the olivine in ultramafic flows and intrusions is usually partially or completely replaced by serpentine. The degree of alteration appears to be a little higher in southern Munro Township and Arndt (1975) has suggested that the metamorphic grade increases to lower greenschist facies in this area. This may be partially due to the higher concentration of readily altered ultramafic rocks and the proximity of major faults which have acted as conduits for fluids. Located within this area is the Munro Fault Zone, a broad zone of shearing and alteration contained within an komatiitic flow succession, and the Contact Fault which is characterized by a series of large pods of intense carbonatization.

Contact metamorphism is recognised adjacent to the area's later intrusions in narrow metamorphic aureoles. In the case of diabase dikes in mafic volcanic rocks, it is characterized by zones where olivine has been replaced by secondary hydrous minerals and pyroxene by tremolite and chlorite (Arndt, 1975).

Plate 5. Pillowed tholeiitic basalt, lava tube (below assistant) budding a pillow in a down-dip direction. The bedding is slightly overturned to the south at this location in northeast Beatty Township.

Plate 6. Mg-rich tholeiitic basalt, partially exposed lava toe, north-central Munro Township.

Chapter 4: Stratigraphy

4.1 Introduction

The volcanic assemblages in both Beatty and Munro Townships are dominated by tholeiitic basalts and, to a much lesser degree, andesites and dacites. Tholeiites make up approximately 75 % of the volcanic strata in Beatty Township and 65 % of the volcanic strata in Munro Township. Komatiitic lavas make up about 12 % of the strata in Beatty Township and 20-22 % of the strata in Munro Township. The remaining volcanic strata in both townships consists of calc-alkalic lavas and pyroclastics (2-3 %) and mafic and ultramafic sills (10 %). All the volcanic rock belongs to the Stoughton-Roquemaure Group except the calc-alkalic lavas and pyroclastics in central Beatty and southwest Munro Townships which, although contained within the Stoughton-Roquemaure Group succession, may be related to late Hunter Mine Group volcanism.

In reconstructing the stratigraphy, outcrop distribution, folds and major faults must be taken into consideration. Exposure is poor or non-existent in southwest, central and northeast Beatty Township, throughout the central part of Munro Township, and along the entire length of the eastern margin of Munro Township where the Munro esker is found. The overall structure is that of a tight, west to west-northwest-trending syncline (McCool Hill Syncline) with a vertical to slightly south dipping axial plane, plunging approximately 65° in a northwesterly direction. The southern limb of the syncline is truncated by the Destor-Porcupine Fault Zone and the fold is cored by a minor, upright isoclinal anticline with a sub-parallel trend. It can be seen in Figures 8 and 9 that the presence of this doubly plunging anticline causes a break in the axial surface trace of the McCool Hill Syncline. The fold pattern

FIGURE 9. Locations of stratigraphic columns in relation to the major structures of Beatty and Munro Townships.

shown in the northern half of the study area is produced by the western end of the anticline plunging into the north limb of the syncline and the eastern end plunging into the syncline's southern limb. A pair of second-order upright, isoclinal folds (A and B -Figure 9) also trends westward within the southern limb of the McCool Hill Syncline.

The most significant faults disrupting the stratigraphy are two closely spaced faults in northern Munro Township. One, the west- to north-northwest-trending Warden Hill Fault, repeats a section of the stratigraphy while the north-northwest-trending Axis Fault reduces the apparent thickness of that same section. The Munro Fault Zone, partially bordered by the west-trending pair of isoclinal folds, and running parallel to bedding in southwest Munro Township, is considered to be a major structural feature, but it is assumed to have not greatly disrupted the stratigraphy. Shearing may have somewhat condensed the komatiitic lava succession within which the fault zone is contained, but fault motions parallel to bedding would not have thickened or reduced the stratigraphic sections involved.

As is the case in the rest of the region (Jensen and Langford, 1983), most of the rock within the study area shows little or no evidence of penetrative deformation. Strain is generally taken up by less competent rocks, thin flow top breccia and interflow sedimentary units. It is assumed therefore, that strain associated with the tight folding and bedding-parallel faulting in the study area had only a limited affect on the thickness of the stratigraphic section.

The isoclinal folds within the McCool Hill Syncline however, did thicken the stratigraphy. As elsewhere in the area, most of rock within these folds lacks evidence of strain and it is therefore valid to assume that the section is nearly doubled in this area by these horizontal

upright folds. However, stratigraphic correlation is not attempted between the limbs of the minor folds, only between the north and south limbs of the McCool Hill Syncline.

Section 4.7.5 introduces a model involving flexural slip and the transposition of strata during the development of the McCool Hill Syncline. This model indicates a process which could produce structural thickening of the stratigraphy, but it is only presented as a hypothesis and it is not considered in stratigraphic reconstruction. A more detailed description of structural geology, including structural models, is presented in Appendix 2.

As such, the stratigraphy will be described using eight stratigraphic sections (see Figures 9, 10, and 11 -rear pocket) specifically located in areas which optimize the available bedrock data, involve major lithological features and avoid major stratigraphic discontinuities caused by folds or faults. Two of the columns, I and II, are located in Beatty Township within the south limb assemblage which covers most of the township. The Munro Township stratigraphy is described using six columns; three (III,IV,V) in the south limb assemblage of the southern half of the township, and three short columns (VI,VII,VIII,) involving the north limb stratigraphy in the northern third of the township.

In this chapter, tholeiitic volcanic rocks are divided into high-Mg tholeiites (HMT) and marginal or medial to high-Fe tholeiites (MHFT) in recognition of a compositional gap which exists on a Jensen Cation Diagram between those volcanic rocks which plot as a cluster in the high-Mg tholeiite field and those which plot in a cluster which occupies the high-Fe, low-Fe and low-Mg fields (see Section 5.5 -Chapter 5). The tholeiitic basalts which are intermediate in composition between Fe-rich

and Mg-rich tholeiite can not be defined as a separate tholeiitic lava group in the field.

The stratigraphy is discussed in terms of regional correlation considerations (section 4.6), and depositional models (section 4.7).

4.2 North-facing stratigraphic sections of Beatty Township (Fig. 10).

4.2.1 Column I, western Beatty Township

Column I in western Beatty Township represents a stratigraphic section extending from the Destor-Porcupine Fault Zone to the axial surface trace of the McCool Hill Syncline. It includes within it the stratigraphically lowest strata of the Stoughton-Roquemaure Group in the study area, a thick assemblage of Porcupine Group sedimentary rocks and, at the top of the column, tholeiitic and komatiitic volcanic rocks of the Stoughton-Roquemaure Group and some calc-alkalic volcanic rock which, as previously mentioned, may be related to late Hunter Mine Group volcanism.

The Destor-Porcupine Fault Zone at the base of the column marks a reversal in stratigraphic facing direction and is characterized by schist bands, tectonic breccia, quartz veining and alteration zones (silicification, epidotization).

The approximately 100 m thick succession underlying the Porcupine Group, as it is recorded in a diamond drill hole log, consists of mafic lavas (massive and pillowed flows including variolites) of the Stoughton-Roquemaure Group and felsic lavas at the top of the succession of unknown geochemical affinity. The succession also contains a relatively high proportion of intercalated tuff(?) and argillaceous sediment. The lower contact of the Porcupine Group may be gradational in nature.

The lower half of this column represents an area in southwest Beatty Township where the geology is interpreted from limited diamond drill

hole data and aeromagnetic maps. As such, precise estimates of the thicknesses of major lithological units are uncertain. The apparent thickness of the Porcupine Group is about 3700 m here, but it is likely that the true thickness of the assemblage is slightly thinner. There are indications from drill hole data to the southeast in northern Guibord Township that a narrow portion of the stratigraphy, close to the lower contact of the group, has been affected by folding. Based on data derived from outcrop groups located further east, the dip of the bedding in the area of the section is probably as steep as that of most of the study area: greater than 75 degrees and usually greater than 80 degrees. Much of the southern stratigraphy is overturned.

The upper contact of the Porcupine Group in the south central part of the township appears to be an angular unconformity marked by a normal fault, the Contact Fault (Satterly and Armstrong, 1949), which cross-cuts the strata up-section. To the southeast, the fault becomes a strike fault and, in the area of column I, it either dies out or departs from the volcanic/sedimentary contact.

The first 100 m of the overlying Stoughton-Roquemaure Group succession also contains some intermediate to felsic volcanic rocks (massive andesite, rhyolite or dacite flow breccia, tuff) amongst the mafic flows. These occurrences are probably quite rare along the western extent of the Porcupine Group contact zone, and may in fact represent the western extension of a band of calc-alkalic volcanic rocks (Hunter Mine Group) and intercalated tholeiitic lavas in an area immediately south of Salve Lake in the center of the township.

The first 1100 m of the volcanic succession consists of both high-Mg and marginal to high-Fe tholeiitic lavas with a predominance of the

latter, particularly towards the base. This interval is topped by an ultramafic unit of uncertain nature and extent. In a large open pit at the Maude Lake Gold Mines property in the northwest corner of the township, a portion of a peridotite sill is exposed intruding mafic pillow lavas along an interflow horizon of cherty fine-grained sediments and massive pyrite. Diamond drill hole data indicate that the sill is about 60 m thick, and geophysical data indicate that it extends for at least 2 km to the northwest. Core examined from an isolated drill hole located immediately east of the open pit indicates the existence of an ultramafic flow unit, at least 75 m thick, consisting of coarse olivine spinifex-bearing flows. Induced polarization and magnetometer survey data provided by Maude Lake Gold Mines Ltd. indicate that the ultramafic unit probably extends southeast, and then east towards Salve Lake. What is not known is whether the unit consists of the sill, the ultramafic flow succession, or both.

The next 1700 m of the section is composed of massive and pillowed flows and flow breccia units belonging to both the high-Mg tholeiite (HMT) and medial to high-Fe tholeiite (MHFT) groups. The interval is characterized by a HMT base (400 m) overlain by a MHFT succession (600 m) including a 120-130 m thick gabbroic-textured flow and thick pillow breccia units. The remainder of this interval contains a mixture of the two tholeiite groups, and includes a single variolitic flow.

The top 900 m of the section is dominated by high-Mg tholeiites and a small number of thin, intercalated basaltic komatiite flows. Thicker flows belonging to this succession are found further east. These basaltic komatiite flows are generally fine-grained and characterized by 'slaggy textures' (see Chapter 6), and, in some cases, by varioles. In addition, core from a diamond drill hole located next to the synclinal

fold axis at the top of the section, displays thin zones of olivine spinifex. This may either indicate the presence of peridotitic komatiite lavas, or simply the existence of olivine spinifex zones within the basaltic komatiite lavas here. The drill log for this hole indicates flow banded dacite lavas, but examination of some of this core shows that at least some of this rock is silicified variolitic basalt.

4.2.2 Column II, eastern Beatty Township

This column starts at the Contact Fault at a location in southeast Beatty Township. Here, the contact zone is characterized by pods of green, fuchsite-rich carbonate, and has been intruded along strike by a small elongate peridotite body and a small feldspar porphyry body. The volcanic succession northward begins with a 300-400 m thick interval of variolite-dominated Fe-rich basalts. Most of these lavas are thick, massive flows (up to, 100 m thick). One of these thick flows, at the top of the succession, contains unique pods of coalesced varioles. This variolitic lava succession is part of strong marker horizon which extends for at least 10 km along the contact with the Porcupine Group to the east. Immediately west of the section it is truncated by the Contact Fault. As seen in Figure 10, the variolitic marker horizon is used to correlate the other south limb stratigraphic columns.

The variolitic marker unit is overlain by approximately 700 m of massive and pillowed high-Mg tholeiites overlain in turn by between 200 m and 300 m of medial to high-Fe tholeiites. This second succession contains a variolitic pillowed flow and several felsic dikes, 1-10 m thick, which appear to be feeder dikes for the calc-alkaline lavas overlying this interval.

These calc-alkaline lavas belong to a band, 200-500 m thick, largely

composed of massive rhyolite and dacite flows, autoclastic breccia, minor tuff breccia and intercalated tholeiitic basalts, andesites and dacites. The thickest section of this band is located immediately south of Salve Lake. It was noted that the proportion of fragmental rocks in the assemblage increases laterally east and west of this section. The easternmost tip of the band is found at the east Beatty Township boundary where it has been partially intruded by an ultramafic sill, variously referred to as the Munro-Beatty Sill (Satterly, 1952a), the Barton Creek Sill (McRae, 1969) or the Munro Sill (this study).

The overlying 900 m of stratigraphy is poorly exposed, owing probably to the down-weathering of shear zones associated with the western extension of the Munro Fault Zone, and possibly to the differential erosion of any serpentinitized komatiitic lavas which may be in the fault zone. Only one outcrop of massive, medium-grained basaltic komatiite was located in this area and, based on the results of recent exploration drilling (R. Bennett, Maude Lake Gold Mines Ltd., personal communication, 1986), it is unlikely that many other flows of this composition occur in this section which is otherwise dominated by high-Mg tholeiitic basalts. The closest komatiitic succession (the Munro Fault Zone succession) is exposed along strike to the east at the township boundary and perhaps it is in this section that there is a westward depositional termination of the komatiitic lava succession. The ultramafic lava unit at the Maude Lake Gold Mines property is at approximately the same stratigraphic level as this komatiitic succession. Another feature of this interval is a 70-80 m thick sill consisting of gabbro and a thin peridotite cumulate layer.

This high-Mg lava succession is overlain by a 700-800 m thick interval composed of Fe-rich tholeiitic lavas (including variolitic pillow

lavas) and flow breccia units. The succession is shallowly cross-cut by an anticlinal/synclinal fold pair. Their axes are set 400 m apart at this location and it is believed that these tight, isoclinal folds do not involve a significant stratigraphic thickness.

The upper 800-900 m of the section primarily consists of Mg-rich lavas and, at the base of the succession, an approximately 175 m thick, differentiated peridotite-gabbro sill is found underlain by a thin (approx. 40 m thick) flow unit of spinifex-bearing peridotitic komatiite lava. This interval is also poorly exposed and gives indications that there may be basaltic komatiite flows within it. Only one outcrop of pillowed and massive flows of this composition was located in the area represented by this stratigraphic section.

4.3 North-facing stratigraphic sections of Munro Township (Fig. 10)

4.3.1 Column III, west Munro Township area

As in column II, the first 300-350 m is occupied by the variolitic marker unit, overlain by a interval, 600-650 m thick, largely consisting of high-Mg tholeiitic basalts. The 900-1000 m MHFT interval above these divisions contains a few variolitic pillowed flows in addition to a regular assemblage of massive and pillowed flows. Enclosed within the tholeiitic lavas is a 400-450 m thick band of calcalkaline rhyolite and dacite flows and flow breccia, which extends for almost 4 km southeast from the west Munro Township border. The Munro Sill, dominantly composed of serpentized peridotite and dunite, intrudes the mafic strata immediately above this felsic unit. This intrusion is about 175 m thick in this section but laterally its thickness varies by as much as 200 m along strike. A 75 m thick layered flow (gabbro-pyroxenite-peridotite) is found at the top of the MHFT interval. It is overlain by a thin HMT interval (350-375 m) composed mainly of pillowed high-Mg tholeiite flows

marking the top of the tholeiite succession in southwest Munro Township.

The tholeiitic succession is overlain by a 200-300 m thick komatiitic lava succession. The precise thickness of the succession is uncertain because the Munro Fault Zone cores the komatiitic lava band and a minor anticlinal fold axis cross-cuts the succession in the area of the section. To the southeast the succession thickens appreciably. The succession begins with a peridotitic komatiite flow, and then is succeeded by a series of both peridotitic and basaltic komatiite flows along with a small number of intercalated tholeiitic flows. Many of these komatiitic flows are thick massive flows with well developed spinifex zones. One example is a thick (80 m max.), layered basaltic komatiite flow, Dee's Flow (Arndt, 1975), located at the base of the komatiitic succession next to the west Munro Township boundary. This flow has a very short strike length (< 400 m), and is composed of a thick gabbro portion with a thin discontinuous pyroxene spinifex upper margin and peridotite/pyroxenite base.

The remainder of the section above the komatiitic succession consists dominantly of high-Mg tholeiitic basalts with a small number of high-Fe tholeiitic flows (usually massive flows) dispersed within the succession. A synclinal fold axis (A) passes through the basal zone of the succession making an exact estimate of stratigraphic thickness uncertain, but it is reasonably estimated that the succession is between 1600 m and 1700 m thick below the major anticlinal fold axis which also marks the top of columns I and II.

4.3.2 Column IV, south-central Munro Township

In column IV the variolitic marker unit is 200-300 m thick and underlain by a 5-10 m thick deposit of silicified tuffaceous sediment on the

north side of the Contact Fault. The Contact Fault is characterized by a discontinuous zone of intense carbonatization. As in column II, a thick, massive flow at the top of the succession contains pods of coalesced varioles.

Unlike columns II and III there is not a distinctive succession of high-Mg tholeiite lavas overlying the marker unit. Instead, most of the tholeiitic succession here (approx. 1100 m) consists of MHFT lavas. Most of these lavas appear to have compositions intermediate between that of high-Mg and high-Fe tholeiites. High-Mg tholeiites become more common up-section and east and west along strike. The same stratigraphic interval along strike to the east is dominated by HMT lavas. Towards the top of the succession, the eastern end of the calcalkaline flow unit of column III occurs. At this end the 100-200 m thick unit ~~consists~~ of rhyolite, dacite, and andesite lava flows, tuff breccia and flow breccia.

Both tholeiitic lava groups are equally represented in the next 500 m of the section. A little further east along strike, a small number of intercalated basaltic komatiite lavas occur with the high-Mg tholeiite lavas at the top of the succession. This interval contains three intrusions; a small, discordant peridotite body, a 60 m thick peridotite-gabbro sill, about 400 m in strike length, and a 120 m thick, gabbro-peridotite body of uncertain nature. This third intrusion, stratigraphically located above the other two, appears to be the eastern extension of the Munro Sill. The contact between the gabbro and the peridotite is not exposed, so it is possible that the gabbro is a separate intrusion. This end of the Munro Sill however, is differentiated and small lenses of gabbro with gradational contacts do occur, partially exposed in the Munro Mine area, within the peridotite and

pyroxenite. The complexities of the Munro Sill are more fully discussed in the chapter dealing with layered sill.

The Munro Fault Zone succession of komatiitic lavas is about 1200 m thick in this section, but the upper half of this succession should really be considered part of a separate stratigraphic division, enclosed east and west along strike by a high-Mg tholeiite succession. The lower half is composed, as it is in column III, of ultramafic and mafic komatiite lavas with peridotitic komatiite lavas starting the succession. Unfortunately, the rock exposure is poor along the Munro Fault Zone. The upper half of the succession contains only a few, thin peridotitic komatiite flows in a section dominated by basaltic komatiites and intercalated high-Mg tholeiite flows. Within the upper half, variolitic flows are common and spinifex texture is rare. The only anomalous flow is a 70-80 m thick, layered peridotite-gabbro flow, stratigraphically located in the middle of the komatiitic succession. This basaltic komatiite flow displays pyroxene spinifex, and has a strike length of about 800 m.

The anticlinal/synclinal fold pair found in column II and III passes through the area of this section immediately above the komatiitic succession. Here the fold axes are only 100 m apart as the folds die out eastward. Few strata are removed from the remaining 1600-1700 m of the section as a result. This interval dominantly consists of high-Mg tholeiites with marginal to high-Fe tholeiites becoming more common up-section.

4.3.3 Column V, north-central Guibord Township to North Kettle Lake, east-central Munro Township

The Porcupine Group contact is not exposed in the area represented by the base of this section. It has been suggested from old mining data

(Prest, 1953) that the contact becomes conformable here. Field mapping has confirmed that the Contact Fault has departed from the contact in the process of dying out. The variolitic marker unit is still present and is estimated to be about 200 m thick in this location. The tholeiitic succession, including the marker unit is approximately 1500 m thick and generally consists of a MHFT dominated base and an upper portion enriched in high-Mg tholeiites. At the top of the succession a 10 m thick peridotite-pyroxenite sill intrudes the strata immediately below the contact with the Munro Fault Zone komatiitic succession.

A thick, ponded olivine-rich flow begins the 1100-1200 m thick komatiitic succession and peridotitic komatiites continue to be found throughout the succession. There are indications that basaltic komatiite flows are more common in the center of the succession, but judging the proportion of the two groups is difficult due to a lack of outcrop in the center of the fault zone and the possibility that faulting has structurally introduced or deleted strata from the section. One outcrop indicates the presence of at least one high-Mg tholeiitic flow within the flow succession. The presence of the fault zone in the center of the succession also complicates estimates of its thickness since it is unknown how much of the strata have been transported by faulting.

In the Deadman Hill area in south-central Munro Township (between columns IV and V) (see Munro Township map -rear pocket), a second zone of intercalated basaltic komatiites, a few ultramafic flows and high-Mg tholeiites occur immediately above the main band of komatiitic lavas in the Munro Fault Zone. This zone occupies a 500-600 m thick interval at the base of the second tholeiitic succession and has a strike length, at its broadest point near its top, of about 2 km. A 70-80 m thick,

basaltic komatiite layered flow with a strike length of about 800 m occurs along the base of the Deadman Hill succession.

The overlying tholeiitic succession is over 3500 m thick and consists almost entirely of high-Mg tholeiite flows. Thick massive flows are common in the second tholeiitic succession, particularly along the base. One of these tholeiitic basal flows has a strike length of about 1 km. Marginal to high-Fe flows only become common higher up in the succession. The exact thickness of the upper 1600 m of this succession is uncertain because somewhere within this outcrop-poor area, a pair of fold axes die out. The section here could actually be much thinner by a few hundred meters.

A major sinistral strike-slip fault, the Centre Hill Fault (Satterly, 1952a), cuts across the top of the tholeiitic succession a short distance below a 600 m thick, differentiated sill. This peridotite-pyroxenite-gabbro sill, the Munro Lake Sill (McRae, 1969), intrudes the strata at the base of the second komatiitic lava succession in the core of the McCool Hill Syncline. The Munro Lake Sill can be traced from Centre Hill in the center of Munro Township, southeast to a fold closure at McCool Hill in south-central McCool Township and back along the north limb of the fold for about an equal distance. At Centre Hill the sill, also known as the Centre Hill Complex (Satterly, 1952a), terminates in a vertical, asymmetric fold and it is in this area that a thicker section of the overlying strata can be observed. The sill is first overlain by a very thin unit of high-Mg tholeiite (picrite) massive flows and breccia below the base of the komatiitic succession.

The komatiitic succession in the area of the section is dominated by peridotitic komatiitic flows, including thick ponded flows and flows with well developed olivine spinifex zones. Massive and pillowed basal-

tic komatiite flows occur higher up in the 450 m thick section.

Information about the second komatiitic succession must be gathered from two areas; the Pyke Hill area northeast of Centre Hill, and an area including outcrops and an abandoned mine site, the Potter Mine, extending north from the western edge of Centre Hill to the southern edge of the northern outcrop group. The eastern area exposes a succession dominated by ultramafic flows, including a thick ponded flow. Many of these flows have well developed spinifex zones. Basaltic komatiites, including pillowed flows, become more common up-section.

The outcrop on the western side of Centre Hill exposes an 80-100 m thick, ponded ultramafic flow underlain by massive, pyroxene-spinifex-bearing flows of basaltic komatiite and overlain by a mixture of both massive peridotitic komatiite and high-Mg tholeiite flows and flow breccia. Being beyond the folded western end of the Munro Lake Sill, these lavas are situated within the lower half of the komatiitic succession but the precise stratigraphic level is not known. Above these flows in the center of the succession, underground data from the Potter Mine indicate a steeply-dipping assemblage of komatiitic lavas alternating with three thin bands of tholeiitic lava, flow breccia, hyaloclastite and minor deposits of chert and dacitic tuff (tuffaceous sediment ?) (Coad, 1976). Based on the subsurface data presented by Coad (1976) and what is exposed at the surface, there is an up-section increase in the proportion of basaltic komatiites and Mg-rich tholeiites to peridotitic komatiites.

In addition to this assemblage of komatiitic lavas, a small number of outcrops located 1-2 km south of Centre Hill expose a south-facing assemblage of peridotitic and basaltic komatiite flows. This indicates

that a minor fold located south of the hill has repeated a portion of the Centre Hill komatiitic lava succession.

The total combined thickness of the north-facing succession of Stoughton-Roquemaure Group and Porcupine Group strata from the Destor-Porcupine Fault Zone in southwest Beatty Township to the core of the McCool Hill Syncline in east-central Munro Township is 8-9 km.

4.4 South-facing stratigraphy of northern Munro Township (Fig. 11)

4.4.1 Columns VI, VII and VIII

The stratigraphy on the north limb of the McCool Hill Syncline is described using three short sections; column VI in northwest Munro Township, and columns VII and VIII in the north-central part of the township. Together, the Munro Township sections represent the uppermost strata of a tholeiitic succession, intruded by a thick, differentiated sill, and an overlying komatiitic succession. The upper halves of columns VII and VIII represent a succession of strata which is repeated by the Warden Hill Fault, which is believed to be a north-dipping, oblique-slip fault now obscured by an elongate gabbro body (see Appendix 2). The large, peridotite-pyroxenite-gabbro sill, referred to by McRae (1969) as the Munro-Warden Complex, is interpreted to be the extension of the Munro Lake Sill on the north limb of the McCool Hill Syncline. The continuation of the sill from Centre Hill to its second exposure at the nose of the syncline at McCool Township and back along the north limb to the north-central Munro Township exposures, is supported by the similarity of the rock types in the three outcrop areas and by aeromagnetic data (see section 4.5). The cumulate layers of the sill have a strong magnetic expression on the aeromagnetic maps which can be traced from Centre Hill on the south limb to McCool Hill and back to the southeast corner of the north-central Munro Township outcrop group on

the north limb (see Munro Township map). The continuation of the layered sill on the north is also confirmed by the intersection of pyroxenite and peridotite by two diamond drill holes located north and northeast of Munro Lake, several small outcrops of gabbro in the Geisler Lake area, and a large number of small outcrops exposing gabbro, melanogabbro and pyroxenite in the Camp Lake area.

The eastern extension of the Munro-Warden Complex north of the Warden Hill Fault is obscured by cross-faults, a discordant gabbro body, a peridotite body, and a lack of outcrop; therefore, the stratigraphic connection between the Munro-Warden Complex on the north fault block and the group of gabbro, melanogabbro and pyroxenite outcrops east of Theo's Flow on the second fault block is difficult to establish. It is reasonable to suggest that the Munro-Warden Complex, as it passes out of the northern outcrop group, swings southward within the minor fold found in an area occupied by a peridotite/dunite stock and a discordant gabbro body. The peridotite/dunite stock is only delineated by drill hole data, so it is possible that one or more of the drill holes shown on the Munro Township map has been misinterpreted, and actually intersects the cumulate layer of the complex. This would confirm the existence of the sill southeast of its last exposed position, trending towards the Warden Hill Fault. The fault-repeated extension of the Munro-Warden Complex would therefore be the Munro Lake Sill represented by the gabbro, melanogabbro and pyroxenite exposed at the southeast edge of the outcrop group. The recognition of the role of this fold in swinging the strata south to the Warden Hill Fault is critical to this interpretation. The trend of the sill within the fold was unrecognized by Arndt (1976) in his structural reconstruction of northern Munro Township because the pertinent outcrops and drill hole collars were located beyond the eastern boundary of his

thesis map area in north-central Munro Township.

Layering within the Munro Lake sill cannot be as clearly defined in the Camp Lake area as it can be in other exposures of the sill. This may be partially due to undetected cross-faults between the scattered outcrops of this area, and possibly due to a separate gabbro body which is intruding the sill. Diamond drill hole data indicate that a semi-discordant gabbro body does intrude along the lower contact of the Munro Lake Sill in McCool Township. Only one small lense of peridotite was exposed within a band of pyroxenite towards the top of the sill. The main cumulate portion of the sill is likely truncated by the gabbro intruding the Warden Hill Fault, but the fact that peridotite, pyroxenite and gabbro does overlie a gabbro layer here indicates the presence of an additional cyclic unit not present at the top of the sill elsewhere. Since this extra unit grades westward along strike into Theo's Flow, it must be at a slightly higher stratigraphic level than the upper contact of the sill on the northern fault block. Based on what is exposed in the Camp Lake area and the thickness of the cumulate portion of the sill in column VIII, the Munro Lake Sill south of the Warden Hill Fault could be about 900 m thick, approximately 100 m thicker than the Munro-Warden Complex in column VII, about 300 m thicker than the McCool Hill Complex and about 500 m thicker than the Centre Hill Complex. This indicates that the thickest point of the Munro Lake Sill, prior to folding, was close to a point where Theo's Flow extruded from the sill, a point towards the western end of the body.

The Munro Sill on the north limb has intruded a lava succession largely consisting of marginal to high-Fe tholeiites in the central part of the area (columns VII and VIII) and Mg-rich tholeiites at the north-

eastern and northwestern (column VI) edges of the large outcrop group centered in north-central Munro Township. Stratigraphically, this succession should be equivalent to the second tholeiitic lava succession in column V, but the general lack of exposure in the upper half of that succession on the south limb makes direct correlation of tholeiitic lava groups unfeasible. Based on what is exposed of the two equivalent sections, the north limb succession has a much greater proportion of interflow sediments and there are a few flows and flow breccia deposits of intermediate and basaltic komatiite composition which are not found in the south limb succession. The basaltic komatiite flows occur intercalated with Mg-rich tholeiite flows in the two areas where Mg-rich tholeiite flows dominate. Also found within these areas are several 1-5 m thick pyroxenite sills and a 100 m thick layered, pyroxenite-gabbro-leucogabbro sill.

In column VIII the tholeiitic succession, starting at the most northern extent of the outcrop group in this area, is 1100 m thick. Within this section the sill is at its thickest point, about 800 m. It rapidly thins eastward and westward to about 450 m. The Munro Lake Sill is thicker in this section due to a thickening of its cumulate portion and the addition of a 150-160 m thick leucogabbro layer which intrudes a thick interflow sedimentary unit immediately above the main body of the sill. A discontinuous, 15-20 m thick layer of chert, tuffaceous and siliceous siltstone and fine-grained wacke partially separates the gabbro and leucogabbro portions of the sill, and similar sediments can be found in a 10-20 m thick deposit directly overlying the leucogabbro and as xenoliths within it. The abrupt thinning of the sill to the east (between columns VI and VII) may also be related to a northeast-trending fault zone truncating the western end of the leucogabbro layer. The

leucogabbro grades into gabbro at the eastern edge of the outcrop group.

The tholeiitic succession is topped by a thick, layered Fe-rich tholeiite flow referred to as 'Theo's Flow' (Arndt, 1975, 1977). The flow is approximately 120 m thick and has a strike length of about 700 m occurring in column VII. Westward (column VI), its stratigraphic interval is occupied by deposits of mafic flow breccia, hyaloclastite and blocks of tuffaceous siltstone and to the east, the horizon contains massive (variolitic) and pillowed lavas and flow breccia units of related composition.

A second layered flow, a basaltic komatiite given the name 'Fred's Flow' (Arndt, 1975, 1977), marks the base of the komatiitic lava succession. It is about 160 m thick near its eastern end in north-central Munro Township (column VIII) and thins slightly westward (columns VI and VII). It extends for at least 5 km before passing beyond the western end of the outcrop group in southwest Warden Township. Fred's Flow extends a little further east than Theo's Flow, therefore at its eastern end it overlies massive and pillowed tholeiitic flows. As Fred's flow thins out to the east, it becomes underlain by a wedge of basaltic komatiite flows. Where it overlies Theo's Flow (columns VII and VIII), the two flows are separated by a thin deposit of tuffaceous and siliceous siltstone and fine-grained wacke. This unit continues into the western area as a discontinuous marker horizon, broken up where thin peridotitic komatiite flows and flow breccia layers underlie Fred's Flow.

In column VIII, Fred's Flow is overlain by an approximately 400 m thick succession consisting of two peridotitic komatiite flow units alternating with two basaltic komatiite flow units. These units thin westward (column VII) and, in the area represented by column VI, the

succession is dominated by basaltic komatiite flows and a pillowed, variolitic, Mg-rich tholeiite flow appears in the section. The Warden Hill Fault, obscured by the intrusion of a large discordant gabbro body along its length, repeats most of the north limb stratigraphy just described. The 350 m thick succession exposed in the central area (tops of columns VII and VIII) consists of Theo's Flow, with its base truncated by the gabbro, the 10-20 m thick deposit of interflow sediment and flow breccia, and the lower half of Fred's Flow. The succession is then truncated by the northwest-trending Axis Fault which removes from the succession, at least 100 m of komatiitic strata. Basaltic komatiite lavas are found in a few small outcrops south of the fault, immediately north of the axial surface trace of the McCool Hill Syncline.

Theo's Flow has a strike length of about 2.3 km within this fault block, thinning out in tholeiitic lavas westward and passing imperceptively eastward into the gabbro belonging to the uppermost portion of the Munro Lake Sill. If it is assumed that the peridotite cumulate portion of the flow in the second fault block was as thick as it is in the north fault block, then it is estimated that the fault repeated version of Theo's Flow must be almost twice as thick.

The top of Fred's Flow is truncated by the Axis Fault but, based on the thickness of its cumulate layer (100-150 m), this layered flow may also be thicker. The strike length of the flow is uncertain due to a lack of exposure, but it is at least 3 km. Towards the western end of the flow, a thin gabbro-pyroxenite band with an olivine spinifex zone occurs bordered above and below by outcroppings of peridotite. This may indicate that a thin, layered flow underlies the rapidly thinning Fred's Flow near its western terminus. A peridotite sill intrudes the sedimentary rock/breccia layer underlying Fred's Flow at the southeastern

edge of the outcrop group.

The stratigraphy in the north-central part of the study area (up-section from column VI) is broken up by three sets of cross-faults, three minor east-west trending folds, and is intruded by an east-west oriented, discordant gabbro body which, in this area, obscures both the Warden Hill and Axis Faults which disrupt the stratigraphy in the main outcrop area. Precise stratigraphic correlation with the north-central Munro Township lava successions is therefore uncertain, but what can be stated, is that the succession of komatiitic lavas, found between the southern edge of the thickened western extension of the gabbro body at Warden Hill and a thin succession of variolitic high-Mg flows next to the axial surface trace of the McCool Hill Syncline represents the western end of the second komatiitic lava succession. Komatiitic lava flows are not exposed beyond this area westward along strike, and there is no indication on aeromagnetic maps of an extension of komatiites into southeast Coulson Township.

The komatiitic succession is estimated to be about 1000 m thick and almost all of the constituent lavas are basaltic komatiites, mainly pillowed and often, variolitic flows. 'Slaggy textures' (see Chapter 6) are the only diagnostic pyroxene textures present in the massive flows. The overlying tholeiitic sequence becomes enriched in Fe-rich tholeiitic lavas westward along strike in northeast Beatty Township.

4.5 Aeromagnetic interpretations

Two computer-generated, colour enhanced aeromagnetic maps are reproduced in Figures 12 and 13. These reproductions were derived from a series of second derivative aeromagnetic maps recently produced for the Ontario Geological Survey through the Black River-Matheson Project.

Legend for aeromagnetic maps

A -Abitibi diabase dike
CH -Centre Hill
D -Diorite
DI -Diabase
DPFZ -Destor-Porcupine Fault Zone
FF -Fred's Flow
G -Gabbro
HM -Hunter Mine Group
KG -Kinojevis Group
LS -Small layered sills
MFZ -Munro Fault Zone
MH -McCool Hill
MLS -Munro Lake Sill
MS -Munro Sill
MW -Munro-Warden Complex (Munro Lake Sill)
P -Peridotite intrusion
PD -Preissac diabase dike
PL -Painkiller Lake Complex
QD -Quartz diorite
VMH -Variolitic marker horizon

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Thesis contains coloured
photographs & explanatory tables
which when microfilmed lose their
significance. The hardcopy of the
thesis is available upon request
from Carleton University Library.

FIGURE 12 Regional aeromagnetic map.

These maps and two 1:20 000 scale, total intensity aeromagnetic maps (Beatty Twp. -O.G.S. Map 80585, Munro Twp. -O.G.S. Map 80586) were consulted to constrain geological contacts within areas of low rock exposure.

In generating the colour aeromagnetic maps, data have been filtered to more clearly define magnetic anomalies. Zones of high magnetic response are red with blue borders. Rocks which appear as magnetic anomalies are peridotites, dunites, pyroxenites, gabbros, diorites and Fe-rich tholeiites.

The notable features on the regional-scale map (Figure 12) are the hairpin shape indicating the folding of the Munro Lake Sill within the McCool Hill Syncline in McCool Township, the area of low magnetic response in central Beatty and northwest Guibord Township indicating the position of the Porcupine Group metasedimentary rocks, the traces of the Abitibi and Preissac diabase dikes trending northeast through the region, the elongate peridotite, gabbro, and syenite bodies along the Destor-Porcupine Fault Zone in southwest Beatty, northeast Hislop and central Guibord Townships (compare with Figure 5), and the banding produced by the cyclical alternation of Fe-rich and Mg-rich tholeiites within the Kinojevis Group (KG).

The aeromagnetic map of Beatty, Munro and McCool Townships (Figure 13) clearly shows the major intrusions of the study area. The cumulate portion of the Munro Lake Sill (MLS) shows as a fairly continuous band from Centre Hill (CH) to McCool Hill (MH) and back around the McCool Hill Syncline to north-central Munro Township where it thins out due to interfingering gabbro within the sill and truncation of the sill by the discordant gabbro (G) intruding the Warden Hill Fault. Two similar breaks in the trace of the sill's cumulate layer caused by discordant or

semi-discordant gabbro bodies also occur southeast of Centre Hill and at a point along the north limb of the McCool Hill Syncline northwest of McCool Hill. The cumulate zones of the Munro-Warden (MW) and Painkiller Lake (PL) Complexes and various, thin layered sills (LS) northeast Beatty and southeast McCool Township can also be distinguished. The Munro Sill (MS) is indicated by a irregular teardrop-shaped anomaly consistent with thickening and thinning of the intrusive complex (see Chapter 8) and cross-faulting in the area. A peridotite sill (PS) which is largely unexposed in the base of the north limb komatiitic succession, appears as solid red band in east-central Munro Township trending back to one of the two red bands demarking the cumulate base of Fred's Flow (FF). The thin, peridotite sill in northwest Beatty Township shows only a slight magnetic response. Various gabbro (G), diorite (D), quartz (QD), and peridotite (P), intrusions also appear on the map.

The Fe-rich tholeiites constituting the variolitic marker horizon (VMH) bordering the contact fault, can be defined in southwest Munro Township trending into Beatty Township. The termination of this anomaly in southeast Beatty Township is interpreted as indicating the truncation of the marker horizon at an angular unconformity. The volcanic/sedimentary rock contact in the center of Beatty Township is not magnetically defined due to the greater depth of the clay overburden in this area and possibly due to the lack of magnetic contrast between the sedimentary rocks and a volcanic succession which may be dominated by Mg-rich tholeiites and calc-alkaline rhyolites and dacites.

4.6 Regional stratigraphic correlation

It is obvious from the stratigraphic columns that the absence of extensive stratigraphic marker horizons makes stratigraphic correlation

over a distance greater than a few kilometres impossible. The first and second komatiitic lava successions, seen in columns III, IV and V, are not continuous and apart from the Fe-rich tholeiite basalts overlying the Porcupine Group, consistency in tholeiitic lava type along strike is lacking. It is therefore not surprising that the stratigraphy does not compare with that of other areas (Stoughton/Roquemaure Townships, Ghost Range, and Garrison Township) in the region described by Jensen and Langford (1983).

There are a number of significant differences between the Stoughton-Roquemaure Group stratigraphy of the study area, and that indicated by the Stoughton-Roquemaure Group type-section. Intercalated calc-alkaline volcanic rocks and tholeiitic intermediate to felsic volcanic rocks, the Porcupine Group strata, komatiitic layered flows and komatiitic lava flows with well developed spinifex are all absent from the Stoughton and Roquemaure Township stratigraphy. The upper 6 km of the Stoughton-Roquemaure type-section displays a cyclical pattern of peridotitic komatiite at the base overlain consecutively by basaltic komatiite, Mg-rich tholeiitic basalt and Fe-rich tholeiitic basalt. These cycles vary from 300 m to 1700 m in thickness and can have oscillations from one rock type to another, or be incomplete, lacking a peridotitic komatiite base or an Fe-rich tholeiite top. No such cyclicity can be defined in the study area. The general increase in the proportion of basaltic komatiites to peridotitic komatiites up-section in the area's komatiitic successions may represent magmatic evolution on a broader scale; however, if there is some form of partial volcanic cyclicity, it is being obscured by the pattern produced by simultaneous komatiitic and tholeiitic volcanic eruptions. In particular, Fe-rich tholeiites can be found associated with any volcanic rock type, so it is more probable

that they represent a unique magma, unrelated by shallow-level fractionation.

The Stoughton-Roque-maure type-section lavas are not thought to have been the earliest lavas of the Stoughton-Roque-maure Group, having been higher up on the flanks of the Hunter Mine volcanic pile than the SRG lavas from other areas in the Lake Abitibi region (Jensen and Langford, 1983). The stratigraphies of the study area and of the regional type-section (Chapter 2) are probably not time-equivalent; the lavas of Beatty and Munro Townships must have been extruded earlier at lower elevations on the paleo-surface of the calc-alkalic volcanic pile. The lavas of the study area may, in fact, be older than any of the other SRG lavas exposed in the region. The Porcupine group strata within the assemblage, indicates deep basin deposition and the calc-alkaline lavas may indicate that this assemblage was deposited closer to the main period of Hunter Mine Group volcanism than the other assemblages which lack these rocks. In addition, the Hunter Mine Group rocks underlying the SRG succession in McCool Township are more typical of material found on the lower flanks of a calc-alkaline volcano (tuff breccia, flow breccia, tuffaceous sediment, pillowed flows) and stratigraphic relationships suggest that these calc-alkaline rocks may actually represent the westernmost extent of that volcanic pile. The angular unconformity between the two volcanic groups is very steep and there is no indication of the Hunter Mine Group rock of the volcanic pile being repeated on the other limb of the McCool Hill Syncline despite the exposure of at least 4 km of strata below the stratigraphic position of the volcanic pile on the north limb.

4.7 Stratigraphy and depositional models

In this section certain details of the stratigraphy are used to construct models concerning bimodal volcanism, rates of lava extrusion, basin subsidence, syn-depositional tectonism, rifting, and centers of lava extrusion.

4.7.1 Bimodal volcanism and age relationships

A U-Pb zircon age of 2714 ± 2 Ma. (S. Marmont, geologist, Ontario Geological Survey, personal communication, 1986) for a rhyolite flow within the Stoughton-Roquemaure Group succession in Beatty Township (column II, Figure 10) calls into question another U-Pb zircon date of 2710 ± 2 Ma. (Nunes and Jensen, 1980) derived from the Hunter Mine Group rocks in Rand Township, 35 km to the east. The calc-alkaline volcanic rocks of Rand Township should be older because they are thought to constitute the core of the same Hunter Mine Group volcanic pile which underlies the Stoughton-Roquemaure Group succession in northern McCool Township (Jensen and Langford, 1983) (see Figure 5). The depositional model of Jensen and Langford (1983) states that a period of erosion preceded the deposition of the Stoughton-Roquemaure Group and post-dated the deposition of the Hunter Mine Group. Even if it is assumed that the Stoughton-Roquemaure Group lavas began to be extruded immediately after the construction of the Hunter Mine volcanic pile, there should be a significant time period between the deposition of the dated rhyolite flow in Beatty Township and the deposition of the lavas constituting the Hunter Mine volcanic pile. At least 2 km of Stoughton-Roquemaure and Porcupine Group strata must underlie the rhyolite in central Beatty Township (columns I and II, Figure 10).

The relative dates contradict the depositional model of Jensen and Langford (1983) so an alternative model is suggested involving bimodal

volcanism, with the extrusion of the calc-alkaline flows occurring well after the start of Stoughton-Roquemaure Group volcanism. Although there is no evidence of this elsewhere in the region, the existence of calc-alkaline lava flows in the Stoughton-Roquemaure Group of the study area certainly indicates that calc-alkaline and tholeiitic lavas were extruded simultaneously. The Beatty Township lavas and Porcupine Group sediments may have been deposited well down the slope or adjacent to the active calc-alkalic volcanic pile, centered in Rand Township, far enough from the vent to avoid an interfingering of lavas, but close enough to the volcanic center to be subject to minor flank eruptions.

It should also be mentioned that the dated sample from Rand Township was not from a rhyolite flow, but from a feldspar porphyry dike, part of a 'porphyry complex' assumed by Nunes and Jensen (1980) to have been a center of eruption for the volcano. Since the calc-alkaline lava flows of Rand Township were not dated also, it is possible that the intrusion which was dated, could have been emplaced well after the calc-alkaline lavas were extruded. The lava flows could conceivably be much older than 2710 Ma. An older age for the Hunter Mine Group rocks in general, is further supported by a U-Pb zircon date of 2730 ± 1.4 Ma. for these rocks in the Noranda-Lake Abitibi area (Mortensen, 1987) and by a U-Pb zircon age of 2725 ± 2 Ma. (Nunes and Pyke, 1980) for felsic tuffs at the top of the Lower Supergroup (Upper Formation, Deloro Group) in the Timmins area (Bartlett Township). It should be considered that the dated intrusion may be related to a minor period of calc-alkaline volcanism (2716-2708 Ma.), which post-dates the main period of Hunter Mine Group volcanism, and is only represented in the currently exposed stratigraphy by other feldspar porphyry dikes and the calc-alkaline lavas of the study area.

Whether or not the Rand Township volcanic complex ceased its lava eruptions before or after the commencement of Stoughton-Roquemaure Group volcanism will only be resolved with the dating of the calc-alkaline lava flows in Rand and McCool Townships, but subaqueous calc-alkaline volcanism did occur during the extrusion of the SRG lavas in the study area and, based on the existence of felsic tuffaceous sediments in the stratigraphy, subaerial calc-alkaline volcanism was also occurring somewhere in the region.

4.7.2 Eruption rate indicated by stratigraphic relationships

As mentioned previously in the regional geology section, the wedge of Porcupine Group strata in the south limb of the McCool Hill Syncline is believed to represent a deep basin assemblage deposited during a period when mafic and ultramafic volcanism was more restricted in its distribution. Volcanic rock is not found within the Porcupine Group assemblage which suggests that volcanism did not occur in the deeper basin area during the deposition of the sediment. It is noteworthy that the volcanic succession which is stratigraphically equivalent to the Porcupine Group contains a much greater proportion of interflow sediments than the south limb volcanic successions overlying it. From this, it is proposed that the rate of volcanic eruptions was less than the rate during the period following the deposition of the Porcupine Group. The interflow sediment units are much thicker (1-10 m) than those found higher in the stratigraphy (usually less than 1 m thick) and the type of sediment in these interflow units; chert, finely bedded siltstone and mudstone (Figure 7), is of the type that requires longer periods of deposition between the eruption of lava flows. It could be argued that the eruption rate did not change after the deposition of the Porcupine Group, and that the lack of interflow sediment was due to the reduction in the

Plate 7. Interflow sedimentary unit enclosed by the Munro Lake S.
Laminated silicic and tuffaceous siltstone, north-central
Munro Township.

Plate 8. Pillowed Fe-rich tholeiitic basalt: two lava tubes, one (left)
displaying 'pillow shelves' and the other (right) a
're-entrant' structure indicating a budding pillow. Note that
the 'shelves' are parallel to the elongation direction of the
lava tube. Bedding dips 85° N. Maude Lake Gold Mines Ltd. open
pit, northwest Beatty Township.

supply of sediment; but sediment was still being deposited during this later period, as indicated by thick (up to 300 m thick) units of interflow sediment in the north limb succession. The thickest of these interflow units (approx. 300 m) is in south-central Coulson Township and is contained within a tholeiitic basalt succession which is likely the stratigraphic equivalent of the second tholeiitic succession on the south limb of the syncline. Another thick sedimentary rock unit was probably located where the Munro Lake Sill is in northern Munro Township. The sedimentary rock unit immediately overlying the sill, and the thicker one between the leucogabbro and gabbro portions of the complex were probably part of one or more thicker sedimentary rock units which the sill intruded. In the north limb, interflow sediment units then virtually disappear above a stratigraphic level which corresponds to the onset of komatiitic volcanism in the northern Munro Township stratigraphy. Overall it is proposed that the rate of Stoughton-Roquemaure Group volcanic eruptions increased after the deposition of the Porcupine Group, but initially only locally in the south (south limb succession), with the rate increasing further north after the deposition of the second tholeiitic lava succession.

4.7.3 Syndepositional model for the contact relationships between the Stoughton-Roquemaure and Porcupine Groups

As shown in the south limb stratigraphic columns, there is an angular unconformity between the Porcupine Group and the overlying volcanic rocks westward starting at a point in Beatty Township (column II).

Although the Contact Fault may play some role, it is possible that this is largely a depositional unconformity created by the syndeposition of the Stoughton-Roquemaure and Porcupine Groups. The sedimentary/volcanic rock contact which parallels stratigraphy in the southern half of the

study area and northern Guibord Township, may represent an area where volcanic flows first spread out to cover Porcupine Group sediments, the first flows to advance into the depositional basin being variolitic (Variolitic Marker Horizon). The variolitic lava flows of the first advance covered the largest area of sediments and, to produce an abrupt angular unconformity, successive flows spread the area of volcanic rock coverage more gradually. This slow advance continued until lava flows at the top of the first tholeiitic lava succession covered the Porcupine Group entirely, starting at a point in northwest Carr Township where the contact again parallels the strike of the bedding. The termination of Porcupine Group deposition may have been due to both an increase in the deposition of volcanic rocks, and the filling of a minor, deep submarine basin into which the sediments were being deposited.

4.7.4 Evidence of rifting

Two thick sedimentary rock units within the second tholeiitic lava succession, one located in southern Coulson Township and the other situated at the eastern edge of McCool Township contain beds of pebbly, medium to coarse-grained wacke. These 5 to 15 m thick deposits appear in sharp contrast to the fine-grained wackes and argillites which enclose them. The unsorted deposits appear to consist of more proximal detritus, sub-angular to rounded clasts of chert, silicic siltstone, and argillite in a quartz and plagioclase-rich matrix. The deposition of these beds has caused soft-sediment deformation in the underlying strata and beds of fine-grained sediment drape over irregularities in the upper contact of the deposits. The rock fragment component of the deposits may have been derived from stratigraphically lower Porcupine Group strata or interflow sedimentary units that became uplifted and fragmented during a period of rifting. Considering the sharp contrast between these coarse

unsorted deposits and the fine-grained, well-bedded strata within which they are found, they probably represent sudden periodic dumpings of coarse, immature sediment and fine-grained rock fragments into a submarine graben where normally distal, deep-water sediments (usually distal turbiditic) are deposited.

Another interflow deposit which also appears to have been related to rifting is found enclosed by basaltic komatiite flows of the north limb komatiitic lava succession in northeast Munro Township. The approximately 40 m thick deposit consists of large (up to 4 m long) angular blocks and smaller clasts of white or gray pelite and clasts of tholeiite and komatiite set within a sulphide-rich argillaceous matrix. The pelite is typical of the interflow sediment found within the underlying tholeiitic lava succession, so it is probable that the deposit represents a coarse, mixed debris pile of the type which would be found at the base of a fault scarp.

4.7.5 Basin subsidence

A model of synvolcanic basin subsidence must be considered for the development of the McCool Hill Syncline due to the very low grade of metamorphism evidenced by the alteration mineralogy of the area's rocks (Trowell and Johnstone, 1983). If the lowest exposed strata had been buried to the full depth indicated by the stratigraphic thickness of the Stoughton-Roquemare Group here (10 km) combined with that portion of the upper Stoughton-Roquemare Group and the lower Kinojevis Group, which would likely have been deposited above, a higher grade of metamorphism than sub-greenschist would be expected. Jensen and Langford (1983) have suggested that synvolcanic subsidence was involved in both the development of the Blake River Synclinorium and, on a smaller scale,

the large triangular syncline centered in Frenchville Township, south of Lake Abitibi (see Figure 4). Synvolcanic basin subsidence could produce imbricate rather than vertical stacking of volcanic and sedimentary rock strata if the deposition of sediment and lava flows became progressively more centered within the developing basin. As a result, older strata at the edge of the subsiding basin would not have been buried to the full depth indicated by the thickness of the stratigraphic section exposed within the fold.

The synvolcanic subsidence part of this structural thickening model though, cannot at present be supported by field evidence. If a basin had been actively subsiding during the deposition of the volcanic and sedimentary rocks, individual rock units would be thicker in the center of the basin than at the edge due to a focusing of sediment and lava flow deposition within the depression. Since the McCool Hill Syncline is exposed in longitudinal cross-section, perpendicular to the axial plane of the fold and presumably parallel to the original axis of the proposed elongate basin which preceded it, strata are not exposed in a manner in which rock units could be shown to thicken towards the hinge of the syncline.

It should also be mentioned that the orientation of structures within lava tubes known as 'pillow shelves' were examined to see whether this could indicate synvolcanic basin subsidence, but the results were inconclusive. An indication of the angle of repose relative to horizontal of a lava tube at the time of solidification can be given by the orientation of structures known as 'pillow shelves' (Ballard and Moore, 1977,) within lava tubes. Pillow shelves are thin, planar cavities, usually filled with black chert and/or white quartz, which mark the former positions of lava levels within the lava tube. A flat bottomed cavity is

formed whenever the level of lava flowing in the tube drops to a low position. If the plane of such cavities is not parallel with the plane of the lava tube in longitudinal section, the lava tube formed at other than a horizontal position (Sawyer et al., 1983). Finding a number of lava tubes with non-parallel shelves therefore, could indicate that the pillowed flows within which they are found, were emplaced on an inclined slope. Most of the lava flows in the area do not possess these structures in lava tubes, and those that are found only occur in flows situated in the upper third of the stratigraphy. The lava tubes in these flows have shelves that are oriented parallel to the plane of the lava tubes (see Plate 8), suggesting deposition on a level seafloor. From this, the question of synvolcanic basin subsidence is unresolved; either it did not occur and another tectonic model is required to explain the low grade of burial metamorphism in the area, or synvolcanic subsidence did occur, but not during the deposition of the higher Stoughton-Roquemaure Group stratigraphy. For reasons stated in Chapters 5 and 6 and in the previous section, lava flows of the first komatiitic lava succession and higher in the stratigraphy have likely erupted within an active rift system which would have produced grabens with level seafloors. This however does not indicate whether or not the rifting period was preceded by basin subsidence.

An alternative model which avoids the question of synvolcanic basin subsidence is presented in Figure 34 in Appendix 2 as part of a structural model. This model assumes that fissure eruptions and the deposition of lava flows became progressively focused within the core zone of a developing east-west rift system thorough a succession of graben structures. As with the basin subsidence model, the thickest

accumulation of strata would have been in the center of the volcanic complex. In this model, the McCool Hill Syncline is considered to have largely developed by a flexural-slip process. This would be consistent with two features of the study area's structural geology: a general lack of penetrative deformation within the bulk of the area's rocks, and bedding-parallel shear and fault zones displaying subvertical schistosity and slickensides. Large, upright, east-west-trending flexural-slip folds are also known in the Rouyn-Noranda area (Dimroth et al., 1983). It is proposed that as the McCool Hill Fold tightened, successively younger rock units, slipping along bedding-parallel reverse faults, were translated up-dip, thickening the stratigraphic section now exposed and giving a false impression of the volcanic pile's true thickness.

4.8 Conclusions

Apart from expanding the general stratigraphic knowledge of the Stoughton-Roquemaure Group in the region, this examination of the stratigraphy has also produced hypotheses concerning the deposition of the Stoughton-Roquemaure Group. The total combined stratigraphic section containing the Porcupine Group strata and two komatiitic lava successions alternating with two tholeiitic lava successions is approximately 9 km thick. However, it is possible that the section was structurally thickened slightly through a process of flexural-slip during the development of the McCool Hill Syncline. The volcanic successions lack the small-scale cyclicity (peridotitic komatiite - basaltic komatiite - Mg-rich tholeiite - Fe-rich tholeiite) displayed in the type section of the Stoughton-Roquemaure Group and therefore appear to represent a different style of Stoughton-Roquemaure volcanism involving simultaneous eruptions of Fe-rich tholeiite lava with komatiitic lava accompanied by Mg-

rich tholeiite lava. The presence of calc-alkaline volcanic rock within the mafic and ultramafic lava succession indicates bimodal volcanism, possibly representing the continuation of Hunter Mine Group volcanism during the deposition of the Stoughton-Roquemaure Group. Since the calc-alkaline lava flows are only found within this particular Stoughton-Roquemaure Group succession, and based on the distal nature of the Porcupine Group sediments and the rocks composing the western edge of the Hunter Mine Group volcanic pile underlying the Stoughton-Roquemaure Group succession in McCool Township, it is suggested that the succession represented in Beatty and Munro Township was deposited either lower down the Hunter Mine volcanic pile than the type section assemblage (and probably other SRG assemblages in the region) or adjacent to the calc-alkaline volcanic pile. The suggestion that the study area's rocks represent the initial eruptions of the Stoughton-Roquemaure Group may be further supported by the greater age (S. Marmont, personal communication, 1986) indicated for the succession relative to a controversial date for the Hunter Mine volcanic pile in Rand Township.

Based on the relative proportions of interflow sediments to volcanic rocks in the stratigraphy, it is suggested that the rate of volcanic eruptions locally (south limb succession) increased after the deposition of the Porcupine Group. The angular unconformity between the Porcupine and Stoughton-Roquemaure Groups in Beatty Township is partially structural in nature (Contact Fault) and partially depositional, due to the gradual advance of successive lava flows into a basin during the deposition of the Porcupine Group sediments. Interflow sedimentary deposits in the north limb succession include anomalous mass flow deposits which appear to represent the periodic slumping of coarse material from the

edges of rift valleys.

clast size is 1-2 cm) fragmental exposed along the northwest edge of the complex. Some of the fragments in the coarse breccia drape around adjacent fragments in a manner which suggests that they were still plastic during the formation of the deposit, possibly suggesting proximity to the lava tongues from which the fragments may have been derived. The fine-grained breccia deposit displays a few thin seams of cherty sediment and, in places, a trace of bedding. The finer breccia deposit probably resulted from the sorting action of water.

5.3 Characteristics of layered flows

5.3.1 Structures, textures and petrography of Theo's Flow

Theo's Flow, as described by Arndt (1977) from its northernmost exposure, consists of a 2-10 m thick olivine cumulate base, a 50-55 m thick pyroxene cumulate layer, a 30-35 m thick gabbroic unit and an aphanitic pyroxenite flow top overlain by a flow top breccia. The mineral proportions found in each of these layers is summarized in Figure 14.

The contact between the peridotite and pyroxenite layers is marked by an interlayering of the two rock types. The upper contact of the pyroxenite layer grades into the gabbroic portion of the flow. The flow top and the upper part of the gabbroic portion are penetrated by veins, dikes and irregular patches of reddish breccia of more felsic composition than the flow top breccia unit above. The brecciation likely occurred during the cooling of the flow when seawater accessed fractures to the more felsic residual liquid in the upper part of the flow.

It was also noted by Arndt (1977) that the cumulate layer of Theo's Flow, where it is repeated south of the Warden Hill Fault, is much richer in olivine. The average olivine content of the layer is 70% as opposed to about 30 % in the northernmost exposure of the flow.

Chapter 5: Tholeiites

5.1

It is the intent of this chapter to provide a general description of the petrology of tholeiitic lavas and the physical features of the flows. Detailed petrological descriptions of tholeiitic basalts from several locations in the study area by various authors are available in the literature. The locations covered by these include; north-central Munro Township (Arndt 1975, 1977, Arndt et al., 1977, 1979, Arndt and Nesbitt, 1982), the Potter Mine (Coad, 1976), the Munro Mine (Freeman, 1954, Wicks et al., 1984), Deadman Hill (Canil, 1985), and the Croesus Mine area (MacVeigh, 1978, Saunders, 1982). Their observations were checked during this study, and tholeiitic basalts between these localities were examined to produce a more rigorous characterization applicable over a wider area. Emphasis is placed on describing those petrological and physical features which contribute to a model for lava deposition.

5.2 Physical appearance, petrology, texture and structure of the tholeiitic rocks

5.2.1 General characteristics of tholeiites

Tholeiites include both massive and pillowed flows with compositions ranging from Mg-rich to Fe-rich. Most massive flows are Fe-rich tholeiites as are the tholeiitic layered flows (Section 5.3) Both massive and pillowed flows enclose discontinuous lenses of volcanoclastic rock in the form of hyaloclastite and flow breccia (Section 5.2.4). Section 5.4 describes and discusses the origin of structures commonly found in the tholeiitic flows, varioles.

The two main members of the tholeiitic suite can be easily distinguished in the field. The high-Mg lavas tend to be light gray or

light green, hard, and non-magnetic; and they possess a smooth, light to medium gray or greyish-green weathered surface. The high-Fe tholeiites are medium to dark gray-green or black in colour on fresh surface and dark gray-green or reddish brown on weathered surfaces. They are softer than the high-Mg lavas, and are weakly to moderately magnetic. The darker colour and magnetic properties of the high-Fe tholeiites is due to the combination of the dark green to black colour of the pyroxene and hornblende constituents, and the abundance of titaniferous magnetite, respectively.

Table 2 compares the mineralogy of selected massive, high-Fe and high-Mg tholeiitic basalts. The data are derived from the petrography of thin sections of the central portions of several massive, fine- to medium-grained flows ranging in thickness from 10 m to 50 m.

A gabbroidal texture displayed by thicker flows, is produced by ophitic augite grains, 2mm to 5 mm across, enclosing 0.5 mm to 2 mm plagioclase laths.

5.2.2 Tholeiitic pillowed lavas

Approximately 65 per cent of the Mg-rich tholeiitic flows are pillowed. Pillowed flow units have strike lengths of between 300 m and 700 m, and range in thickness from 10 to 100 m. An exception is a flow unit close to the base of the second tholeiitic succession in west-central Munro Township, which is about 250 m thick and has a strike length of over 2 km. It is possible that this unit may consist of more than one flow, but flow subdivisions, if present, are not well enough defined.

On two dimensional surfaces, most pillows appear as discrete, ellipsoids, 0.3 m to 3 m in length, with convex tops and concave bottoms

Table 2: Petrological descriptions of Mg-rich and Fe-rich tholeiitic basalts*

Fe-rich tholeiitic basalt

40 - 50 % of rock vol. -ophitic, medium to dark gray green augite light to medium green actinolitic hornblende, or medium brown, to green hornblende enclosing laths of plagioclase. The 1 - 5 mm crystals are stubby and prismatic and generally well preserved with clinopyroxene crystals partially altering to chlorite or uraltite and the hornblende showing chlorite fringes.

30 - 40 % of rock vol. -ragged 0.4 - 2.0 mm laths of plagioclase (An₄₀-An₆₀). Crystals may be partially or completely saussuritized, clouded by fine (<0.01 mm) grains of calcite, albite, clinozoisite and epidote.

5 - 7 % of rock vol. -titaniferous magnetite, 0.01 - 0.05 mm subhedral grains occasionally partially altered to leucoxene.

10 - 20 % of rock vol. -fine fibrous uraltite and Fe-rich chlorite, interstitial pumpellyite, anhedral quartz and calcite. Accessory minerals: pyrite, ilmenite. Approximately 1 cm orthopyroxene phenocrysts, replaced by serpentine and chlorite, are present in some flows (2 - 4 % of rock vol.).

Mg-rich tholeiitic basalts

40 - 60 % of rock vol. -medium gray-green ophitic augite (1 - 5 mm) enclosing laths of plagioclase. Crystals are prismatic or occasionally acicular and tend to be altered to fibrous Mg-rich chlorite or uraltite.

30 - 50 % of rock vol. -subhedral to euhedral laths of plagioclase (An₅₀-An₆₅) partially or completely saussuritized. 1 - 2 mm crystals clouded by a fine (<0.1 mm) grains of epidote, clinozoisite and albite.

5 - 10 % of rock vol. -fine (<0.1 mm) grains of magnetite, quartz, calcite and chlorite. Accessory minerals: pyrite, sphene. Approximately 1 cm orthopyroxene phenocrysts, replaced by serpentine and chlorite, are present in some flows (2 - 4 % of rock volume)

* massive, medium-grained, diabasic to gabbroic textured flows.

molded against underlying pillows. When an outcrop has more than one surface orientation, particularly with sections allowing a side and top view of the flow, it becomes apparent that most pillows are either lava tubes, or elongate lobes and pillows that have budded from lava tubes. Pillow shapes can range from small, rounded buds to large (3-5 m) flattened lobes. Selvage widths vary from 0.5 cm to 3 cm. Selvage re-entrants, the two-dimensional expression of a budding pillow (see Plate 8), are more in evidence in stratigraphic sections oriented parallel to bedding. In most cases lava tubes and elongate pillows tend to be oriented in a down-dip direction at a high angle to the strike of the bedding (see Plate 5). This explains why pillow shapes are commonly regular in sub-horizontal exposures, since tubes and pillows are viewed in cross-section.

Mineralogically, the pillow cores generally consist of 0.1 - 0.4 mm clinopyroxene needles (20-30 %), quench-textured, skeletal, 0.1 - 0.5 mm plagioclase laths (60-70 %), and fine disseminated magnetite and pyrite (<3 %) (Plate 14). Pyroxene, particularly in Mg-rich tholeiites, is partially altered to uralite and a light green, Mg-rich chlorite. Plagioclase laths are clouded by very fine epidote and clinozoisite grains. According to Jensen (1978), these are the deuteric alteration products which give the rock a light green colour. The hardness of the rock is attributed to the clinozoisite content. The tops of massive flows also show the effects of deuteric alteration.

5.2.3 Massive tholeiitic flows

Massive flows vary in thickness from 2 m to 75 m, and have strike lengths ranging from 50 m to 1200 m. All of these flows are homogeneous, with the medium-grained cores of thicker flows showing gabbroic to diabasic textures. Orthopyroxene, occurring in hornblende/chlorite

pseudomorphs, can commonly be distinguished on the weathered surface as reddish-brown spots. These equant, 1-2 cm crystals are optically enclosed by plagioclase, and generally do not exceed 15 % of the rock. There are also a number of flows in north-central and southwest Munro Township which contain subhedral plagioclase feldspar phenocrysts up to 4 cm long. (see Plates 9 and 10)

5.2.4 Volcaniclastic deposits

Hyaloclastite and flow breccia units are locally associated with the tholeiitic flows, and occur as hyaloclastite-breccia mixtures and rarely as pure hyaloclastite deposits. Except for an unusual flow breccia exposed at Centre Hill described below, fragment types are compositionally fairly uniform between the different deposits. The breccia units are usually thin, discontinuous deposits commonly composed of lava fragments, usually pillow fragments, in a hyaloclastite matrix (see Plates 11, 12 and 15). Apart from thin (<1 m) flow top breccia layers, there are also 1 m to 10 m thick breccia/hyaloclastite lenses up to 60 m in strike length. It is common to find these deposits with an irregular basal contact and a level top indicating that the material was preferentially deposited in a depression ahead of an advancing flow.

Deposits composed entirely of hyaloclastite are rare. Lava fragments and the occasional fragments of chert and argillite usually make up between 20 % and 80 % of volcaniclastic deposits. Fragments are generally angular to sub-rounded and range in size from 1 cm to a meter. Pillow fragments tend to have curved edges inherited from concentric cooling fractures and occasionally irregular globular fragments are encountered which may have been derived from the fragmentation of a budding pillow or a tongue of lava forcing its way into a breccia pile.

In thin section, 60 % to 80 % of the hyaloclastite consists of distinct globules and granules of chloritized and/or spherulitic tachylite and chloritized glass shards enclosed within a chloritic mesostasis which displays flowage about some of the fragments (Plate 11). The shards 0.5 to 2 mm in size, appear to have formed through 'in situ' rupture of vesicles. The chloritized tachylite shows concentric zoning of iron oxide towards the outer margins of the fragments, a feature attributed to processes of palagonitization and chloritization (Jensen, 1978). Globules and some fractures are filled with fine-grained calcite, quartz, and radial arrays of Mg-rich chlorite and occasionally pumpellyite (see Plate 12).

The high-Mg tholeiite flow breccia exposed at Centre Hill is anomalous. These breccia units consist of sub-angular to rounded, 1 cm to 15 cm fragments of light brown to buff weathering, vesicular lava closely packed in a silty carbonate-rich matrix. The matrix makes up less than 10 per cent of the rock and the composition of the fragments is intermediate between that of a tholeiitic olivine basalt and a picritic basalt (Coad, 1976).

On the basis of fragment size, Coad (1976) subdivided these unique deposits at Centre Hill into hyaloclastite and 'broken pillow breccia' units. No salvaged material was detected in the fragments to confirm that they represent pillow fragments. The fragmental units Coad (1976) referred to as 'hyaloclastite' are not composed of glass shards but small lava fragments. True hyaloclastite does occur locally in the matrix but the material only makes up a small part of the rock. There are however, two types of breccia deposits present in outcrop; (1) a coarse breccia exposed along the northern edge of the Centre Hill Complex (Plate 16), and (11) a relatively well-sorted, fine (average

clast size is 1-2 cm) fragmental exposed along the northwest edge of the complex. Some of the fragments in the coarse breccia drape around adjacent fragments in a manner which suggests that they were still plastic during the formation of the deposit, possibly suggesting proximity to the lava tongues from which the fragments may have been derived. The fine-grained breccia deposit displays a few thin seams of cherty sediment and, in places, a trace of bedding. The finer breccia deposit probably resulted from the sorting action of water.

5.3 Characteristics of layered flows

5.3.1 Structures, textures and petrography of Theo's Flow

Theo's Flow, as described by Arndt (1977) from its northernmost exposure, consists of a 2-10 m thick olivine cumulate base, a 50-55 m thick pyroxene cumulate layer, a 30-35 m thick gabbroic unit and an aphanitic pyroxenite flow top overlain by a flow top breccia. The mineral proportions found in each of these layers is summarized in Figure 14.

The contact between the peridotite and pyroxenite layers is marked by an interlayering of the two rock types. The upper contact of the pyroxenite layer grades into the gabbroic portion of the flow. The flow top and the upper part of the gabbroic portion are penetrated by veins, dikes and irregular patches of reddish breccia of more felsic composition than the flow top breccia unit above. The brecciation likely occurred during the cooling of the flow when seawater accessed fractures to the more felsic residual liquid in the upper part of the flow.

It was also noted by Arndt (1977) that the cumulate layer of Theo's Flow, where it is repeated south of the Warden Hill Eault, is much richer in olivine. The average olivine content of the layer is 70% as opposed to about 30 % in the northernmost exposure of the flow.

FIG. 14. Rock types, chemical and mineralogical variation in Theo's Flow (from Arndt *et al.* 1977).

Theo's Flow shows evidence of a late stage motion of the mafic differentiate. Recent mapping (this study) of this flow at a location along the Munro-Warden Township border turned up a thin, discontinuous, flow top layer, a layer of chilled gabbro within the gabbro portion of the flow several meters below the true flow top. This part of the flow had actually been emplaced in two lava pulses, the second breaking through and flowing out on top of the chilled top of the initial flow.

5.3.2 Structures, textures and petrography of other tholeiitic layered flows;

There is at least one other thick, layered high-Fe tholeiite flow in the study area; an approximately 80 m thick flow exposed in small outcrops located immediately north of Barton Creek at the west Munro Township border and in the Munro Mine area. Due to a lack of exposure, the strike length of the flow is uncertain but it may be over 2.5 km.

In its westernmost exposure the flow is very similar to Theo's Flow in that it consists of a thin (8-10 m) peridotite base, and an 18-20 m thick pyroxenite layer grading into a medium-grained gabbroidal portion above. The pyroxenitic flow top is overlain by a thin discontinuous flow top breccia.

The lack of intervening outcrop and a significant amount of cross-faulting makes it uncertain whether or not the same flow is exposed in the Munro Mine area, but the structural interpretations incorporated in the Munro Township map assume the continuity of the flow on that stratigraphic horizon. In the Munro Mine area, the cumulate portion of the flow thins out leaving just a thick gabbroic textured flow. It is overlain by a thick, massive Mg-tholeiitic flow, and underlain by either another thick tholeiitic flow or the gabbro portion of a layered sill. At one point the layered flow is also intruded by a thin (<10 m thick)

peridotite sill.

Thick, layered flows of tholeiitic affinity in the Stoughton-Roquemaure Group appear to be unique to this area within the Black River-Matheson district. Thick, gabbroidal Fe-rich tholeiite flows are however found towards the base of the Stoughton-Roquemaure Group type-section and in the upper part of the Ghost Range section (Jensen and Langford, 1983).

5.4 Structures, textures and petrographical characteristics of variolites

5.4.1 Characteristics of variolites

Variolites are small spherical bodies generally composed of radiating crystals of plagioclase or pyroxene. The term is usually applied to such structures in basic igneous rocks with the rock bearing variolites being referred to as a variolite (A.G.I., 1980). In this region, these spheroids or ellipsoids occur in both pillowed and massive flows and range in size from a few millimetres to several centimetres. Two types of variolites have been defined (Gelinas et al., 1976): the Kinojevis type and The Blake River Type.

The Kinojevis type is described as small spheroids (0.05 to 2 mm in diameter) confined to the marginal zones of the tholeiitic pillows and composed of a single, radiating intergrowth of acicular clinopyroxene and plagioclase. These intergrowths are either fan-shaped, bow-tie-shaped or spherical and, in some cases, appear to have nucleated on quench plagioclase (see Plate 13).

The Blake River Type variolites are described as being spheroidal or lensoid, white in colour with blue-grey cores varying from 5 mm to 5 cm in size. They consist internally of spherulitic or dendritic textures formed by acicular and skeletal crystals of albite, overprinted by a

younger interlocking mosaic of quartz and albite. Randomly oriented pseudomorphs of skeletal mafic minerals are present and the core of the variole is commonly occupied by a carbonate-filled amygdule or partially resorbed grain of plagioclase or quartz. They can either be dispersed or concentrated in the margins or cores of pillows. In massive flows, the varioles are either dispersed or concentrated in the central plane of the flow or even coalesce to form lenses of low-K rhyolite.

5.4.2 Models for the formation of varioles

Discussions concerning the formation of the Blake River Type varioles have involved considerations as to whether these are primary textures, related to liquid immiscibility (Gelinas et al., 1976) or crystallization processes (Fowler et al., 1987, Philpotts, 1977, Hughes, 1977), or secondary products of devitrification (Dimroth and Lichlbau, 1979). All workers agree that the Kinojevis Type varioles or put more simply 'spherulites', as described by Gelinas et al., 1976), are products of devitrification.

Unlike the Kinojevis Type variolite, the Blake River type displays a sharp chemical contrast between variole and matrix (Gelinas et al., 1976). These varioles typically have a low-K rhyolite composition and the matrix enclosing them is Fe-rich, ranging in composition from felsic to ultramafic. It is the opinion of Gelinas et al. (1976) that Blake River type varioles are the products of the immiscible splitting of a tholeiitic magma during rapid cooling, producing two chemically discrete liquids in contact prior to extrusion. In a liquid state, the varioles are therefore subject to flow differentiation. This is used to explain their concentration in different areas of pillows, lava tubes and tabular flows.

Later discussions (Hughes, 1977, Philpotts, 1977) and a subsequent

reply by Gelinas et al. (1977b) has discredited the devitrification origin for Blake River Type varioles, but it is not as yet clear whether the liquid immiscibility hypothesis is valid.

Based on arguments involving petrology and rare earth element geochemistry, Fowler et al. (1987) dispute the liquid immiscibility hypothesis and support a model involving the direct crystallization of varioles in response to the undercooling of the host liquid. Varioles, referred to as spherulites here, are thus believed to have formed in superheated, nuclei-depleted melts which were erupted from shallow-level magma chambers. Alternatively, rapid cooling after eruption without superheating reduced the rate of nucleation as diffusion slowed due to increased viscosity. Occurring on feldspar microphenocrysts, nucleation was probably heterogenous. The process, referred to by the authors as spherulitic crystallization, is similar to spinifex development in komatiites in that it involves the rapid crystallization in a super-saturated, nuclei-depleted liquid. Fowler et al. (1987) also suggest that the more felsic composition of varioles relative to the matrix was not primary, but due to the albitization of Ca-rich plagioclase.

It is not the purpose of this study to examine the validity of the various theories. It is important to note, though, that Blake River Type varioles have been assumed here to be primary structures for the purpose of stratigraphic correlation. Variolitic lavas can only be considered stratigraphic marker horizons if the varioles formed through a process attributable to the unique properties of a particular lava flow (i.e. nucleated crystal growth in a supersaturated liquid or liquid immiscibility) rather than a secondary process such as devitrification which might have affected all of the extrusive volcanic rocks to a variable

extent.

5.4.3 Characteristics of variolites

Both the Blake River and Kinojevis Type varioles do occur in the study area. For simplicity, the small (<2 mm) radiating masses of skeletal plagioclase (Kinojevis type variole) which are attributable to devitrification, will be referred to as 'spherulites'. These structures are most easily distinguished in chilled pillow rims and massive flow tops, in hyaloclastite and within rhyolite flows defining flow bands. The term 'variole' will only refer to the Blake River Type variole and the term 'variolite' is defined as a rock containing varioles.

Variolitic flows show a broad range of variole sizes, shapes and distribution patterns. Variolitic lavas are mainly Fe-rich tholeiites but they are also commonly Mg-rich tholeiites and occasionally basaltic komatiites. In high-Mg tholeiites, varioles are most commonly found in pillowed flows appearing as 0.5-4.0 cm diameter spheres coalescing into the cores of each pillow (Plate 18). The central regions of the pillows are made light gray or gray-green by the coalesced varioles, and individual varioles can only be distinguished along the outer edge of the mass. Individual or massed varioles should not be confused with light coloured spots or patches produced by incomplete silicification.

The varioles found in tabular komatiitic basalt flows are small (0.4-1.0 cm), and tend to be clustered in small groups along the flow top, immediately above any spinifex zone present. Varioles in marginal to high-Fe tholeiites range in size from 0.4 cm to 6.0 cm with most being 1-2 cm in diameter, and tend to be spherical rather than elliptical in shape. The weathered colour of the varioles is usually white or light gray, but the fresh surface colour varies from light gray-green to dark gray-green and black, making them indistinguishable from the matrix in

many flows. In some of these flows, dark coloured varioles are recognized because of the presence of light gray siliceous rims.

In pillowed flows, varioles can be found dispersed, or concentrated in the pillow margin or core (Plate 18). They tend to be concentrated in the upper halves of lava tubes and along the central planes or within the upper halves of tabular flows. Variole content in a massive flow can vary from 1 % to over 40 % of the flow volume. Many of the flows display progressive concentration and coalescence of varioles upward in the flow. In two flows of the variolitic flow succession, used as a marker horizons in the Croesus Mine area of southwest Munro Township, this has led to the formation of 0.1 m to 4.0 m long rhyolite pods, elongated parallel to bedding (Plate 19). Progressive variole coalescence can clearly be defined along the edges of the pods leaving no doubt that they are composed of varioles, and not a separate felsic liquid incorporated within the mafic lava.

The presence of such pods of coalesced varioles lends further credence to either of the hypotheses that varioles were separate immiscible globules or the product of undercooling and 'spherulitic crystallization' prior to solidification. For it to be the latter, either nuclei grouped together prior to spherulitic crystallization or the matrix to the varioles was plastic enough for the crystallized varioles to coalesce. In support of the spherulitic crystallization model though, it was noted from the microscopic observation of varioles that many were cored by plagioclase fragments and amygdules (see Plate 21) which might represent nuclei.

The migration of varioles in a still plastic 'melt' as they were forming is indicated by individual varioles in a few of the larger

flows, which appear to have been distorted by lava flowage. These varioles, usually of larger size, have been drawn out in a direction parallel to the flow contacts or simply deformed into irregular shapes suggesting that stresses generated by the flowing viscous lava affected the directions in which the variole grew. The deformed varioles could equally support the liquid immiscibility model since felsic liquid globules would have been capable of being carried by mobile lava and plastic enough to be subject to such strain.

5.5 Geochemistry of tholeiites

All the major element geochemical analyses presented (Appendix 3) have been projected on Jensen Cation Plots. This ternary plot of the volume proportion of Al_2O_3 , $\text{Fe}_2\text{O}_3\text{-FeO-TiO}_2$, and MgO , initially developed for the classification of subalkalic volcanic rocks in the Kirkland Lake area, is useful for a stratigraphic study because it recognizes lithological sub-divisions within the tholeiitic, komatiitic and calc-alkalic fields. A description of the Jensen Cation Plot is presented in Appendix 1.

Unless otherwise specified, all samples plotted on the Jensen Cation Plot in Figure 15 are from aphanitic to fine-grained massive tholeiites. On the diagram, most of the samples plot in two clusters, one in the Fe-rich field and the other, in the Mg-rich field. Many samples plot in the low-Fe and low-Mg tholeiite fields forming part of a large cluster including the high-Fe tholeiites. This is why the two tholeiitic rock types referred to in the stratigraphy are Mg-rich tholeiites and marginal to high-Fe tholeiites. As mentioned in Section 5.2, all the samples which plot well within the Fe-rich field are dark gray or black and magnetic, and those within the Mg-rich field are much lighter coloured and non-magnetic. All the rock samples which analysed as Mg-

FIGURE 15 Projections of chemical analyses of tholeiitic volcanic rocks.

rich tholeiites were from lava flows spatially associated with komatiites, confirming the association between these two rock types indicated in an examination of the stratigraphy.

Tholeiitic andesite, dacite and rhyolite, which are light gray-green rocks with a siliceous appearance, are also represented on the diagram. The variolitic tholeiites are from pillowed flows; their positions within the andesite and dacite fields can be explained by chemical inhomogeneities within variolites caused by chemical contrasts between varioles and the enclosing matrix. Research on variolites from southwest Munro Township (Saunders, 1982) has indicated that varioles can have a rhyodacite composition while the matrix has the composition of an Fe-rich basalt.

The tholeiitic rhyolites are from light gray-green or light gray massive, non-variolitic lava flows which interfinger with the calc-alkaline rhyolite and dacite flows in central Beatty Township (black triangles in Figure 15). This suggests a possible magmatic association between the two felsic rock groups, however the association may only be coincidental, because tholeiitic rhyodacites are found elsewhere in the proximity of the study area (southern Wilkie and Coulson Township) without the calc-alkaline lava association (Johnstone, 1986). There is no mention of such lavas occurring elsewhere within the Stoughton-Roquemaure Group, however, they do reappear within the tholeiitic Kinojevis Group (Jensen and Langford, 1983). Two of the tholeiite rhyolites are flow banded, white weathering and porphyritic; indistinguishable from calc-alkalic rhyolites. It is possible that these samples are from calc-alkaline lavas where pyrite content has raised the Fe content of the analyses and produced plots in the tholeiitic field.

5.6 Tectonic setting and environment of deposition of the tholeiitic volcanic rocks

5.6.1 Flow Direction

With most of the stratigraphy dipping vertically or near-vertically, flow direction is difficult to determine without the benefit of more planar exposures of the flows. The direction of flow propagation is determined mainly from the elongation direction of pillows, lava tubes and lava lobes in pillowed flows. Even in exposures allowing for three dimensional views of these structures, care must be taken because pillowed lava piles can be a mass of diverging lava tubes budding pillows of different sizes and shapes in different directions, depending on the topography of the lava plain. Ideally flow direction should be judged from a number of lava tube and pillow elongation direction measurements. The average of these measurements, combined with the direction in which branching lava tubes and budding pillows propagate beyond their point of eruption, give the overall direction of flow movement.

The number of outcrops where enough of these flow structures are exposed in a manner which allows the determination of flow direction is quite limited. Although flow direction can locally be determined for individual flows, there are not enough data available to conclude whether each of the different lava groups have unique flow patterns. Cliff faces can be found in most outcrop areas which expose enough of a flow to judge the direction of lava tube or pillow elongation (Plate 5). In 75-80 per cent of approximately 80 tholeiitic and komatiitic volcanic rock exposures with cliff faces, this elongation direction is within 20° of the down-dip direction of the bedding, indicating that lava flowage was either in a northerly or southerly direction. Most of these sub-

vertical elongation directions (80%) belonged to pillowed tholeiitic flows, reflecting the greater proportion of tholeiitic volcanic rocks (to komatiitic volcanic rocks) in the area; only ten of these tholeiitic flows, six in the north limb lava succession and four in the south limb succession, also display pillows budding from lava tubes which indicates the general direction (north or south) in which the flow was propagating. In all ten cases the general direction of flow movement, indicated by pillow and lava tube elongation direction and the direction in which lava tubes branch and develop pillows, was south.

Another approach to determining flow direction can be made by tracing certain features within a flow which have been identified in various models of flow propagation (Baragar, 1984, Dimroth et al., 1978) as being associated with proximal, medial or distal facies. However, to determine the general direction of proximal to distal progression in a flow, the flow should ideally be exposed in a section which is oriented parallel to the direction of flow movement and, as flow movement is steep, one is not afforded this view.

5.6.2 Lava effusion rate

A large proportion of massive tholeiitic and komatiitic flows, lack the underlying lava tube carpet described in flow propagation models presented by Baragar et al. (1984) and Dimroth et al. (1978). This is attributed to an elevated rate of lava flowage. If lavas migrated quickly due to a steep slope or high effusion rate, lava tubes may not have had enough time to have developed ahead of the advancing flow front, with the lava front propagating as a sheet rather than as channels. Since evidence from 'pillow shelves' does refute a hypothesis of steep depositional slopes in the upper stratigraphy (Chapter 4), a higher rate

of lava flowage is more likely to have been caused by elevated rates of lava effusion. The large numbers of thick, tholeiitic lava flows (approximately 25 % of the massive and pillowed basalt flows exceed 50 m thickness) exposed may be indicative of high rates of lava effusion also, combined in some cases with the effects of ponding.

5.6.3 Centers of eruption

As mentioned in the chapter on stratigraphy, the tholeiitic lava succession on the north limb of the syncline has a greater proportion of interflow sedimentary units than the stratigraphically equivalent second tholeiitic lava succession on the south limb. This could indicate that the eruptive centers for these lavas were not as numerous further north. Therefore, a more proximal area would have a more complete succession of lava flows. Most of the eruptions may have been concentrated along an east-west fissure system which was located closer to the section represented by the south limb succession than that represented by the north limb succession.

The relatively large number of thick gabbroidal flows in the second tholeiitic lava succession of the south limb stratigraphy may also indicate a proximal lava assemblage. Gabbroic-textured massive flows grading laterally into pillowed basalt is recognized as a proximal to distal progression (Dimroth et al., 1974, 1978, 1984, Boivin, 1974). The disproportionately large number of the gabbroidal flows vertically and laterally distributed throughout the succession could indicate both a proximal assemblage and a fixed zone of volcanic eruptions over the period of time represented by the lava flow succession.

In the case of Theo's Flow, the point of extrusion from the Munro Lake Sill can be defined, as being exposed in the fault block south of the Warden Hill Fault. There is a fairly abrupt transition from the sill

to the thick flow westward suggesting the sill broke out of a steep slope or fault scarp, but the orientation of this slope or cliff cannot be judged with a two-dimensional exposure. Based on the second exposure of Theo's Flow north of the Warden Hill Fault, the layered flow thins and narrows northward suggesting proximity to the northern edge of the flow. Like Fred's Flow, Theo's Flow is not exposed on the southern limb of the McCool Hill Syncline suggesting that it does not extend very far south, ponded perhaps against the same east-west trending fault scarp which is proposed (Chapter 6) to have restricted the southern distribution of Fred's Flow.

Feeder dikes for the area's mafic and ultramafic lava flows are rarely identified and when found, they are usually less than a meter wide and cross-cut the stratigraphy at a high angle (north-south). Assuming that most of the lavas extruded by fissure eruptions, the lack of feeder dike exposure is best explained by an east-west orientation to the intrusions. Having originally intruded up vertical east-west fractures, their present orientation would be roughly parallel to the present erosion surface and therefore be less likely to be exposed. Another contributing factor to the apparent lack of feeder dikes is the tendency for flows, as evidenced by Dee's Flow, Fred's Flow, and Theo's Flow, to extrude either from very short dikes tapping shallow level sills or directly from a sill as it broke out of a slope or fault scarp. This, however, appears to be mainly a characteristic of the komatiitic lava flows rather than the tholeiitic lava flows which proportionally, have fewer associated sills of related composition.

5.6.4 Water depth

The volcanic and sedimentary rocks of the area only display chara-

characteristics consistent with deposition under deep-water conditions. Evidence of shallow-water volcanism such as deposits of hyalotuff, the products of phreatomagmatic and phreatic explosions (Honnorez and Kirst, 1975), are absent. Hyaloclastite is the only fine volcanoclastic material found in the breccia deposits (Plate 11); it is considered to be the result of the non-explosive granulation of volcanic glass, and is a feature atypical of shallow-water volcanism (Honnorez and Kirst, 1975).

Brecciated lava deposits account for less than 15 % of the volcanic stratigraphy. A small proportion of breccia relative to massive and pillowed flows is believed to be more typical of deep-water volcanic successions (Dimroth et al., 1985, Ballard et al., 1979).

With rare exceptions, vesicularity is quite low ($< 2\%$) in the flows and vesicle size is usually less than 2 mm. This is typical of basalt erupted at a water depth exceeding 500 m (Moore, 1965, Jones, 1969, Maruyama and Yamazaki, 1978).

The deep-water environment of deposition is also supported by the distal turbiditic deposits of the Porcupine Group and by the nature of most of the sedimentary rocks, which generally display the fine granularity and laminar bedding (see Plate 7) characteristic of quiescent conditions of deposition.

5.7 Conclusions

A number of hypotheses, largely concerning the depositional environment and the nature of lava deposition, have been proposed based on the examination of tholeiitic lava flows and interflow sediments. These hypotheses are:

- (1) There is enough evidence (varirole coalescence, seed crystals coring varioles etc.) to indicate that variolites are the products of unique magmatic processes (either liquid immiscibility or spherulitic

crystallization) and as such represent viable stratigraphic marker horizons.

(ii) A complete tholeiitic suite (basalt, andesite, dacite, and rhyolite) is represented by geochemical analyses. Most tholeiites plot as marginal to high-Fe or high-Mg tholeiites on a Jensen Cation Plot.

(iii) The plot of tholeiite analyses on a Jensen Cation Plot reflects the association of Mg-rich tholeiites with komatiites within the area's stratigraphy.

(iv) The dominant flow direction on both limbs of the syncline was north-south with south being the predominant flow direction.

(v) High rates of lava effusion during the time period beyond the deposition of the Porcupine Group in Munro Township are suspected from the large number of thick, pillowed and massive gabbroidal flows and from the large number of massive flows which lack basal lava tube layers.

(vi) Based on the number and relative thicknesses of interflow sedimentary units in the tholeiitic lava successions, the frequency of volcanic eruptions and the rate of lava deposition increased in the time period beyond the deposition of the Porcupine Group with the tholeiitic volcanic centers concentrated in the southern part of the area (as represented by the south limb stratigraphy).

(vii) Theo's Flow erupted directly from the Munro Lake Sill out of a steep slope or fault scarp and spread north and south. The southward distribution may have been restricted by a developing east-west normal fault and the flow may have ponded against this fault scarp.

(viii) The apparent absence of feeder dikes in the volcanic stratigraphy (apart from the calc-alkaline volcanic rocks) is most

probably due to the original east-west orientation of the dikes and fissure systems and the tendency for both tholeiitic and komatiitic flows to extrude almost directly from shallow level sills.

(viii) The composition of volcanoclastic deposits and sedimentary rocks, the low proportion of breccia units to lavas in the volcanic stratigraphy and the low vesicularity and small size of vesicles within lava flows are all indicative of deep-water deposition.

- Plate 9. Photomicrograph of a fairly 'fresh' fine-grained, massive Fe-rich tholeiite. Subhedral to euhedral plagioclase and augite crystals display little, if any alteration and are unzoned.
- Plate 10. Photomicrograph of a porphyritic Mg-rich tholeiitic basalt. Laths of Ca-plagioclase set within a groundmass of plagioclase microlites, acicular clinopyroxene and opaques. Minor sericitization of plagioclase.
- Plate 11. Photomicrograph of hyaloclastite from a tholeiitic basalt flow top. The devitrified glass shards are enclosed within a recrystallized matrix of chlorite, quartz and carbonate.
- Plate 12. Photomicrograph of a glass shard with pumpellyite and chlorite-filled vesicle (pu) and a mass of fine spherulites (sp). The shard is fringed by feathery aggregates of chlorite.

Plate 13. Photomicrograph of the upper edge of a pillow (tholeiitic basalt). Hyaloclastite marks the border of the pillow (right edge of plate). Spherulites (dark spots), some of them nucleated on plagioclase microlites, coalesce into the interior of the pillow.

Plate 14. Photomicrograph of a pillowed tholeiitic basalt. Quenched 'swallow-tail' plagioclase and sericitized plagioclase phenocrysts in a spherulitic chlorite-rich groundmass.

Plate 15. Flow breccia; tabular lava fragments in a hyaloclastite matrix.

Plate 16. Close-packed picritic breccia at Centre Hill. Rounded, amygduloidal fragments. Many of the irregularly-shaped fragments interlock with deformed edges.

Plate 17. Small, dispersed varioles in a massive Fe-rich tholeiite flow, southeast Beatty Township.

Plate 18. Varioles coalescing into the core of a tholeiitic basalt pillow, Painkiller Lake, north-central Beatty Township.

Plate 19. Massive Fe-rich tholeiite from the variolitic marker horizon. Varioles coalescing to form a small pod of rhyolite.

Plate 20. Photomicrograph of a devitrified variole in a chloritized, ferruginous matrix. Variole displays a dendritic intergrowth of skeletal plagioclase and pyroxene. Variolite sample from massive, Fe-rich tholeiite flow, Lucky Ben Mine, northwest Beatty Township.

Plate 21. Photomicrograph of variolite from same variolite sample as Plate 20. Spherulitic (core) and dendritic (rim) crystal growth with skeletal mafic crystals radiating out from a central vesicle (V) filled with chlorite. Subhedral plagioclase crystals do not appear to have nucleated spherulitic crystal growth like the vesicle.

Chapter 6: Komatiitic lavas

6.1 Introduction

In this chapter, the petrology, geochemistry and physical features of komatiitic lava flows are discussed with emphasis placed on those characteristics which are significant to a model of lava deposition. Specifically, a previously undefined type of peridotitic komatiite flow is described in section 6.4.4 along with a unique olivine spinifex texture ('windblown' spinifex). In section 6.3.2.3 two layered flows, Fred's and Dee's Flows (Arndt, 1975), are described. Dee's Flow has an irregular upper contact which is discussed in section 6.3.2.3.2. In addition, deep flow top fractures in komatiitic flows and 'friction breccia' and deformed clinopyroxene spinifex in Fred's Flow are presented as evidence of synvolcanic tectonism in komatiitic flows (section 6.6). The orientation of pillows, lava tubes and lava lobes has been used to estimate directions of lava flowage (section 6.7.1.) and certain morphological features (i.e. thickness of the cumulate layer along strike) of Fred's Flow have been used to support conclusions concerning source vent location and the direction of lava flowage (6.7.2.). The location of eruption centers for komatiitic lavas in general is discussed in section 6.8 and evidence supporting deposition of the lavas in an east-west rift zone is presented in section 6.9.

The komatiites of Munro Township have attracted much attention, resulting in numerous detailed petrological and geochemical descriptions (Allen, 1986, Arndt, 1975, 1977, Arndt et al., 1977, Arndt and Nesbitt, 1982, 1984, Arndt and Fleet, 1979, Canil, 1985, Pyke et al., 1973, Whitford and Arndt, 1977) and discussions on magma genesis and flow crystallization (Arndt, 1975, 1976, 1977c, Arndt and Nesbitt, 1982,

1984, Arndt and Fleet, 1979, Whitford and Arndt, 1978, Arth et al., 1977, Pyke et al., 1973). Little would be contributed therefore by producing detailed petrological and geochemical descriptions of each komatiitic rock type here. However, most of this previous work is based on only a small number of flows in northern Munro Township, whereas this study provides a much broader picture of komatiites by expanding the examination to many more flows in more than one stratigraphic group, the first and second komatiitic lava successions of Munro Township and the lenses of komatiitic lavas in Beatty Township. The results of earlier work are summarized, but emphasis here is placed on (i) describing komatiite flow types not previously mentioned in the Munro Township literature, and (ii) interpreting certain flow structures and field relationships which could contribute to a volcanogenic model. Where possible the results of earlier work will be commented on in the context of data from the larger area. Due to its controversial nature, komatiite classification is briefly presented in section 6.2.

6.2. Petrographic and petrological classification of komatiites

Komatiitic volcanic rocks were first named and described in the Barberton Mountain area of South Africa by Viljoen and Viljoen (1969). There it was recognized that ultramafic rocks existed as peridotitic lavas. The large, bladed olivine crystals which characterize these flows were interpreted to represent quench textures. These were later referred to as 'spinifex textures' (Nesbitt, 1971) and attributed to rapid crystal growth combined with a slow nucleation rate in a supersaturated magma of a high normative olivine content (Walker et al., 1976, Donaldson, 1982). Viljoen and Viljoen (1969) divided the Barberton lavas into 'peridotitic komatiites,' having more than 20 per cent MgO by weight, and 'basaltic komatiites', with approximately 9 to 20 per cent

MgO by weight (major element percentages presented in this chapter refer to percentage by weight, anhydrous basis). They also subdivided basaltic komatiites on the basis of average MgO content into Barberton (10%), Badplaas (15%), and Geluk (20%) types. The rocks they described were characterized by low alumina content ($\text{Al}_2\text{O}_3 = 4$ to about 12%) and high $\text{CaO}:\text{Al}_2\text{O}_3$ ratios ($\text{CaO}:\text{Al}_2\text{O}_3 > 1.0$, average 1.6). It was implied that a genetic relationship existed between the basaltic and peridotitic komatiites.

In an attempt to quantify the Barberton observations, Brooks and Hart (1974) further defined komatiites as non-cumulate rocks with an SiO_2 content of less than 53 per cent, MgO content of more than 9 per cent, K_2O less than 0.5 per cent, TiO_2 less than 0.9 per cent and $\text{CaO}:\text{Al}_2\text{O}_3$ greater than 1.0. They stressed that the diagnostic geochemistry must be combined with textural criteria (i.e. spinifex, quench textures) which establish the rock as a silicate melt, before it can be referred to as a komatiite. Similar high-magnesium lavas were subsequently then reported from Canada (Munro Township - Pyke et al., 1973), Zimbabwe (Bickle et al., 1975), Australia (Williams, 1972), and India (Viswanathan, 1974), but among these different occurrences, the $\text{CaO}:\text{Al}_2\text{O}_3$ ratio varies from .75 to 1.25 contrary to the >1.0 value of the basaltic komatiites. The term 'komatiite' was extended to these lavas in recognition that alteration may have affected CaO content, and the criterion was modified to $\text{CaO}:\text{Al}_2\text{O}_3$ greater than 0.8 (Nisbet et al., 1977). Later, Nesbitt et al. (1979) proposed that there were two distinctively different types of komatiitic suite, one characterized by high $\text{CaO}:\text{Al}_2\text{O}_3$ ratios and referred to as the 'alumina-depleted suite', and the other with lower ratios, referred to as the 'alumina-undepleted suite'. Komatiites with $\text{CaO}:\text{Al}_2\text{O}_3$

ratios similar to that of the Barberton Mountain Land komatiites have since been found in Western Australia (Nesbitt et al., 1979, but not from anywhere else. $\text{CaO}:\text{Al}_2\text{O}_3$ ratios presented by Arndt et al. (1977) for Munro Township komatiites ranged from about 0.6 to about 1.1. Most of the komatiites analysed in this study produced $\text{CaO}:\text{Al}_2\text{O}_3$ ratios within this range, but four mafic komatiite samples have $\text{CaO}:\text{Al}_2\text{O}_3$ ratios in the range 1.6 to 1.9. (see Section 6.5).

The reason for the existence of two suites is still controversial, involving arguments for variable degrees and different forms of partial melting and perhaps also their derivation from two distinctly different sources (Beswick, 1982). Nesbitt et al. (1982) proposed the existence of local heterogeneities in an upper layer of the Archean mantle in which early magmas (alumina-undepleted suite) possessed a bulk composition approximating that of the mantle, and later magmas tapped anomalous zones lacking in garnet.

6.2.1 Terminology

The Penrose Conference meeting on komatiites in 1979 (see Arndt and Brooks, 1980) elected to modify the komatiite terminology used by Viljoen and Viljoen (1969) by assigning the term 'komatiite' to only the ultramafic members of the komatiitic suite. This convention avoids the use of the term for all the members of a komatiitic rock suite, including a broad range of ultramafic and mafic compositions, and to some degree, the restructuring of the classification makes the identification of the ultramafic komatiite clearer petrologically as well as geochemically. Also, the term 'komatiitic basalt' was chosen at the Penrose Conference to refer to the mafic portion of a komatiitic rock suite with compositions in the range 8 to 18 per cent MgO . This replaced the terms 'basaltic komatiite', as defined by Viljoen and

Viljoen (1969), and 'basaltic komatiite' and 'pyroxenitic komatiite' as defined by Arndt (1975).

Jensen (personal communication, 1985) continues to use the term 'komatiite' to refer to the komatiitic rock suite as it was originally defined. The term 'peridotitic komatiite' is used for the ultramafic portion of the suite and 'basaltic komatiite' is used for the mafic portion. These terms have been used in recent government reports and maps for the Timmins and Kirkland Lake areas and in a recently released lithostratigraphic map of the Abitibi Subprovince, published jointly by the Ontario and Quebec governments. In the interests of regional correlation, the township maps produced for this study will utilise a rock classification based on the Jensen Cation Plot and the nomenclature used with it.

6.2.2 Diagnostic textures and minerals of komatiites

Eighteen per cent MgO was arbitrarily chosen by the Penrose Conference as a boundary between ultramafic and mafic lavas because it falls into the center of an apparent distributional gap between ultramafic and associated mafic lavas. There is a predominance of olivine and pyroxene in the once-glassy groundmass of an ultramafic komatiite. It is estimated that an MgO content of greater than 18 per cent (anhydrous basis) will roughly correspond to 20-35 per cent modal olivine, 15-30 per cent normative olivine, and 65-70 percent normative mafic minerals (Donaldson, 1982). In Munro Township, the corresponding normative olivine range for the komatiites was estimated to be 20-25 per cent (Arndt et al., 1977). Arndt and Nisbet (1982) caution that most komatiites, as defined by the Penrose Conference, are not ultramafic on a normative basis, having between 15 per cent and about 30 per cent norma-

tive feldspar, and even those lavas with 30 per cent MgO could contain up to 20 per cent normative feldspar. These rocks are in fact modally ultramafic, as in most cases the only original crystalline phases are olivine, pyroxene and chromite with the felsic components being contained in the interstitial glass.

Without an extensive geochemical survey, the distinction of high-Mg tholeiites from komatiitic basalts can prove to be difficult, if not impossible, when dealing with highly altered or strongly differentiated flows which lack spinifex textures. The existence of spinifex texture is the most important diagnostic feature: the olivine type in lavas with MgO between 18 and about 12 per cent and the clinopyroxene type in lavas with MgO between 18 and 9 per cent (Arndt and Nesbitt, 1981). Both types of spinifex can be found together in some of the Munro Township flows.

Mineralogically, a highly magnesian variety of pigeonite (Arndt and Fleet, 1979) and an unusually sodic variety of plagioclase (Binns et al., 1982), may also be diagnostic of a komatiitic basalt.

Arndt and Fleet (1979) have also suggested that the simple presence of acicular pyroxene textures denotes a komatiitic basalt. This point should be clarified though because splays of fine acicular clinopyroxene often occupy the interstitial areas between blades of olivine spinifex in ultramafic komatiites. A komatiitic basalt is characterized by pyroxene spinifex texture.

The two most important diagnostic features of komatiitic lavas for the field geologist are polygonal joint patterns and spinifex textures, but there is some confusion over their terminology.

Polygonal jointing refers to the regular pattern of narrow, cooling fractures which separate rounded to polygonal fragments or blocks in both massive and pillowed komatiitic flows. In massive flows the most

intense polygonal jointing occurs at the flow top, where rapid cooling has occurred. With thicker flows the joints become progressively more widely spaced towards the center of the flow. 'Polygonal jointing' is the term used here when referring to this fracture pattern, but it should also be noted that other workers such as Arndt (1975, 1976), Arndt et al. (1977), Pyke et al. (1973), and Pyke (1976, 1982) have used such terms as 'polygonite', 'polyhedral jointing', 'polygonal fracturing' and 'polysuturing' for the same feature.

The term 'spinifex' was originally defined (Nesbitt, 1971) as a texture resembling the appearance of a coarse Australian grass. It results from the parallel growth of olivine grains into large, closely-spaced, plate-like crystals to form booklets or sheafs. Before the general acceptance of the term spinifex, the texture was locally referred to as 'chicken track', 'herring-bone', 'lath', 'feather' or 'quench' (Pyke et al., 1973).

Nesbitt (1971) and Naldrett and Mason (1968) identified three types of olivine spinifex; 'radiating spinifex', 'porphyritic spinifex' and 'plate spinifex', and within the different types, five different olivine crystal forms, recognized in crystallization experiments (Donaldson, 1976), have been assigned. Arndt (1975) also used the term 'microspinifex' to describe a microscopic texture consisting of splays of fine, bladed olivine, and 'criss-cross spinifex' for a pyroxene-rich form of spinifex containing thin, randomly oriented wafers of olivine. Spinifex texture in fact has been used to describe a broad variety of olivine and pyroxene textures in komatiitic lavas, ranging from small, randomly-oriented olivine booklets to large splays of bladed olivine over 20 centimetres in length, or from a mass of fine, acicular pyroxene crystals to zones over a metre thick where masses of parallel crystals

are oriented in a direction perpendicular to the flow top (see Plate 23). The latter texture is referred to as 'stringbeef' spinifex (Arndt, 1975). A discussion of spinifex textures as indicators of the cooling history of a flow is presented in section 6.4.

Table 3 summarizes the main features which characterize komatiitic lavas in general and were emphasized in this study.

6.3 Petrology of basaltic komatiites

6.3.1.1 Properties of basaltic komatiites in general

Basaltic komatiites account for about 70 per cent of the komatiitic lavas exposed within the study area, approximately two-thirds of these being tabular flows. Flow thickness varies from 1 m to 160 m; at least four flows exceeding a thickness of 80 m. The strike lengths of flows generally range from 100 m to 1 km. It is likely that some flows are more extensive than this, but there is a general lack of exposure along strike where komatiitic flows occur in outcrop. As mentioned in Chapter 4 (section 4.4.1) Fred's Flow has a strike length of at least 5 km in the exposure.

Flows of this composition have smooth, rounded weathered surfaces with a distinctive mottled light reddish brown or orange brown colour. The fresh colour of the rock is medium to dark gray-green and the rock is generally softer than tholeiites.

Due to their broad range of chemical composition (i.e. 9-20% MgO, 44-53% SiO₂, CaO:Al₂O₃ = 0.8 - 1.2, see Table 4), the mineralogy and mineral textures of mafic komatiites tend to be quite variable. An indication of this is the original classification of the northern Munro Township komatiites by Arndt et al. (1977). Komatiites were divided into five groups and each komatiitic lava group had its own set of minera-

Table 3: Characteristics of Komatiitic Lavas**Basaltic Komatiites**

Petrology	Pyroxene dominant mafic mineral, aluminous subcalcic pyroxene, pyroxene spinifex + olivine spinifex; olivine type present in lavas with MgO between about 12 % and 18 % only (Arndt and Nisbit, 1982); highly sodic plagioclase (Binns et al., 1982), high Mg pigeonite.
Geochemistry	MgO content (anhydrous basis) 10-20 %, high MgO, Cr_2O_3 ; low alkalis, TiO_2 , Fe:Mg; high SiO_2 at given MgO; $\text{CaO}:\text{Al}_2\text{O}_3 = 0.8 - 1.2$, moderately low Al_2O_3 .
Features	Polygonal jointing.

Peridotitic Komatiites

Petrology	Olivine dominant mafic mineral (very forsteritic, chrome-rich), olivine spinifex texture only, interstitial clinopyroxene, chromite.
Geochemistry	MgO content (anhydrous basis) >18-20 %; NiO, Cr_2O_3 ; low alkalis, TiO_2 (< 1.0 %), Fe:Mg; high SiO_2 at given MgO; $\text{CaO}:\text{Al}_2\text{O}_3 = 0.8 - 1.0$.
Other Features	Polygonal jointing, susceptibility to alteration (serpentinization, carbonatization).

Table 4: Classification of Northern Munro Township Komatiites (modified from Table 2, Arndt, 1975)

	Field Characteristics	Petrological Characteristics	Chemical Parameters
Peridotitic Komatiite	Massive olivine cumulates devoid of conspicuous volcanic features. May be associated with spinifex-textured flowtops.	High modal olivine.	MgO > 30 %
Pyroxene Peridotitic Komatiite	Some flows are made up of spinifex-textured upper zones, cumulate lower zones (Pyke et al., 1973). Others are massive and characterized by polygonite. May contain lava toes.	Lavas rich in skeletal platy grains in spinifex texture; or as equant phenocrysts or skeletal tabular grains in unsettled lava.	MgO between 30 and 20 %
Pyroxenitic Komatiite	Low, flat outcrops. Lava is soft, grey-green, crumbly and breaks with a hackly fracture; may contain clinopyroxene spinifex, slaggy texture ¹ , polygonite, lava toes, varioles.	Poorer in olivine. Massive lava contains equant olivine grains in clinopyroxene/glass groundmass. Spinifex and slaggy texture dominated by clinopyroxene. No plagioclase.	MgO between 20 and 12 %
Basaltic Komatiite	More massive outcrops; harder, paler grey-green lava; may contain lava toes, hyaloclastite flowtops or may be massive. Uncommon examples contain clinopyroxene spinifex and slaggy texture.	No olivine in groundmass; plagioclase instead. Clinopyroxene and plagioclase in spinifex textures; clinopyroxene/plagioclase intergrowths or normal subophitic basaltic textures.	MgO < 12 %
Andesitic Komatiite²	Hard, pale grey-green lava; usually massive with thin hyaloclastite flowtops; rare examples contain clinopyroxene/plagioclase spinifex.	Subophitic, medium to fine-grained. Colour index >50.	SiO ₂ > 54 %

1. Texture characterized by fine radiating arrays of acicular clinopyroxene.
2. Considered an Mg-rich tholeiitic basalt.

logical and field characteristics (see Table 4). The lavas classified as 'andesitic komatiites' in the table are now recognized as Mg-rich tholeiites and pyroxenitic and basaltic komatiites are presently classified as either komatiitic basalts (Arndt and Nisbet, 1982) or basaltic komatiites (Jensen and Langford, 1983). The latter term is used in this study.

Within the basaltic komatiite group a decrease in MgO content from 20 % to 12 % is accompanied by a decrease in modal olivine content from 35 % to nil (Arndt, et al., 1977). The textural characteristics of the lavas at the two ends of this range are quite different. Basaltic komatiites display a full range of olivine and clinopyroxene textures; random olivine spinifex characterizes the Mg-rich (approx. 15 - 20 % MgO), olivine-rich basaltic komatiites, 'stringbeef' clinopyroxene the intermediate basaltic komatiites, and fine, randomly-oriented clinopyroxene needles characterizes low-Mg (approx. 10 - 15 % MgO), pyroxene-rich basaltic komatiites (see sections 6.3.1.2 and 6.3.1.3). The flows can be either massive and homogeneously olivine- or pyroxene-rich, or stratified with olivine-rich or pyroxene-rich layers. Pillowed basaltic komatiite flows are also common. Pillows range from 1 m rounded buns to 4 m long elongate lobes and generally have comparatively thin selvages. Lava tubes and toes are common and, as in the case of the tabular flows, there are some differences between the two types. The olivine-rich flows display polyhedral jointing more commonly than the pyroxene-rich flows, and the weathered colour (reddish brown) of the rock is darker. It is impossible in the field to distinguish a pyroxene-rich komatiitic basalt from a high-Mg tholeiitic basalt in pillowed flows lacking polyhedral jointing.

6.3.1.2 Properties of olivine-rich komatiitic basalts

Most of the olivine-rich komatiitic basalts are massive and granular. Flow tops are locally brecciated, and polyhedral jointing can extend throughout a flow. The otherwise aphanitic flow top contains olivine in the form of small (1-3 mm), randomly-oriented skeletal platelets, discrete prismatic grains, and equant phenocrysts with skeletal overgrowths. The matrix consists of acicular, dendritic or plumose clinopyroxene, sparse minute grains of chromite, and devitrified glass. The olivine grains impart a 'criss-cross' surface texture to the rocks also known as 'chicken track' texture (Dimroth et al., 1973). The central portions of these flows contain solid (non-skeletal), equant olivine grains and clinopyroxene crystals which form discrete skeletal rods and prisms (Arndt et al., 1977); and it is common to find a zone of plate olivine extending down from the flow top through over half the flow thickness. The 1 cm to 3 cm crystals appear as small triangular faces producing a hackly, weathered surface (see Plates 37 and 38). These skeletal crystals may decrease in size as they grade down into the more granular, lower parts of these flows.

There are at least six flows in Munro Township that have a thick (10 cm to 1 m) layer of clinopyroxene spinifex, referred to as 'stringbeef' spinifex (Arndt, 1975), enclosed within a zone of randomly-oriented plate olivine spinifex in the upper half of the flow. These layers are discontinuous along strike, and consist of fine, 1 cm to 10 cm long needles of skeletal clinopyroxene (see Plates 22 and 23). Rare, skeletal olivine blades, aligned parallel to the clinopyroxene, can only be distinguished in sections that cross-cut the clinopyroxene bundles. The upper contact of the 'stringbeef' spinifex with the plate olivine spinifex is sharp whereas the lower contact is gradational. The clinopyroxene

crystals are strongly zoned with cores that are richer in Mg and Al and poorer in Ca than the margins (Arndt et al., 1977). The core zones are now composed of chlorite which is believed to be a pseudomorphous replacement of either Ca-poor clinopyroxene (pigeonite) or orthopyroxene (Arndt, 1975). The clinopyroxene needles lie in a matrix of smaller, prismatic clinopyroxene crystals, chlorite, and devitrified glass (Plate 30). Compositionally these flows represent a group of komatiitic basalts intermediate between the olivine-rich magnesian variety and the pyroxene-rich low-Mg variety as defined by Arndt et al. (1977).

6.3.1.3 Properties of pyroxene-rich komatiitic basalts

The pyroxene-rich komatiitic basalts, making up most of the komatiitic flows in the east Painkiller Lake and Deadman Hill areas (see Beatty and Munro Township maps), tend to be massive and featureless with poorly defined polyhedral jointing. However, a few pyroxene-rich komatiitic basalt flows display a broad range of pyroxene textures. Two of these flows, one east of Painkiller Lake and the other south-southwest of Centre Hill, show thin lenses of 'stringbeef' spinifex, in the upper third of an otherwise massive flow, consisting of masses of sub-parallel acicular clinopyroxene aligned perpendicular to the flow top. The flow near Centre Hill is 30 m thick with a fine- to medium-grained, gabbroic-textured core and a discontinuous spinifex zone consisting of lenses 2-5 m long.

Jensen and Langford (1983) have described the flow tops of flows belonging to this group as consisting of very fine pseudomorphs of randomly oriented olivine or acicular pyroxene set in a matrix of spherulitic pyroxene and devitrified glass. This texture gives way downward to a 'slaggy texture' produced by radial arrays of acicular

clinopyroxene set in a matrix of prismatic clinopyroxene, devitrified glass and possibly plagioclase. In some of the flows, pyroxene becomes more granular towards the base, and elongate to tabular orthopyroxene and clinopyroxene may form a basal cumulate. Arndt (1975) has noted that flows with less than 12 % MgO lack olivine in the groundmass and contain plagioclase in the more slowly cooled portions of the flow.

6.3.2 Petrology and stratigraphy of individual basaltic komatiite flows

6.3.2.1 Introduction

In order to demonstrate the broad variation of basaltic komatiite flows, two layered flows, Fred's Flow (Arndt, 1975) and Dee's Flow (Arndt, 1975), are described. These have been well described petrologically (Arndt, 1975, 1977, Allen, 1986) and, although they are both basaltic komatiite lava flows, they display interesting morphological and petrological differences worthy of comment.

6.3.2.2 Fred's Flow (Arndt, 1975, 1977, Arndt et al., 1977)

Fred's Flow (Figure 16), in north-central Munro Township, is 120-160 m thick in the fault block north of the Warden Hill Fault, rapidly thinning out eastward and thinning only slightly westward (see Munro Township map). Fred's Flow can be classified as a komatiitic basalt of the olivine-rich variety with a bulk MgO content of 16-20 % (Arndt et al., 1977). The rock types, chemical and mineralogical variation within the layered flow are described in Figure 17.

The breccia unit overlying Fred's Flow is similar in appearance to the picritic breccia units found in the Potter Mine area (as described in Chapter 5) except that it consists of fragments representing both basaltic and peridotitic komatiite compositions. This is thought, along with some geochemical features, to be evidence of magma mixing within

Figure 16. Diagrammatic section through Fred's Flow - a komatiitic layered flow (after Årndt 1975).

FIG. 17. Rock types, chemical and mineralogical variation in Fred's Flow (from Arndt *et al.* 1977).

the flow (Arndt and Nesbitt, 1984).

The breccia unit consists of a layer of small (< 1 cm) angular fragments grading downward into larger (5-10 cm) rounded fragments. The fragments of the fine breccia are aphanitic to fine-grained in internal texture and characterized by either olivine microphenocrysts, amygdules, or grains of olivine or pyroxene. The fragments of the coarse breccia are fine-grained and consist of equant solid or skeletal crystals of serpentinized olivine (average size 0.5 mm) in a groundmass of fine-grained skeletal and acicular augite and devitrified glass. The fine breccia fragments are closely packed in a chlorite/carbonate matrix, likely replacing hyaloclastite and detrital material, while the coarser breccia has a matrix similar in mineral composition and texture to that of the fragments and richer in relict glass. The breccia unit also displays small-scale scour structures and traces of fine bedding indicating the influence of sedimentary processes.

The top of the spinifex zone consists of randomly oriented olivine wafers, 10 to 20 mm long and less than 0.1 mm thick (microspinifex), set in a matrix of acicular, skeletal clinopyroxene grains and devitrified glass. Olivine is only present in the upper 30 cm to 2 m of the spinifex zone, replaced downward by the clinopyroxene of a 'stringbeef' spinifex zone. In the latter zone, the acicular augite crystals have chlorite cores (possibly replacing pigeonite), and are set in a matrix of smaller, acicular augite crystals intergrown with plagioclase laths, opaque minerals, quartz and chlorite. The interstitial augite and plagioclase form sheaves that splay downward. Arndt et al., 1977) have suggested that the long, acicular clinopyroxene crystals may actually be part of larger complex crystals 5 mm across and 1-5 cm long, making up even larger sheaves within the spinifex zone. In 'stringbeef' spinifex

throughout the study area, these complex crystals appear as a straight line of dots when the pyroxene needles are viewed end-on (see Plate 22).

The spinifex zone grades into a medium-grained, equigranular gabbroic section of the flow. In the transition zone acicular clinopyroxene decreases in abundance downward in favor of stubbier, spindle-shaped, curved and almost semicircular grains of clinopyroxene. The matrix consists of slightly smaller, prismatic clinopyroxene and plagioclase crystals. The plagioclase and pyroxene occurs as either discrete, subhedral 0.5-4.0 mm grains or complex intergrowths similar to the graphic intergrowths of quartz and feldspar in pegmatites. The pyroxene grains, surrounded by what is believed to be primary hornblende, have augite cores and diopside mantles. Large patches of chlorite, enclosing small euhedral plagioclase crystals, and interpreted as a pseudomorphic replacement of subhedral orthopyroxene grains 5-10 mm in length, occur at the base of the gabbroic zone. With the decreasing abundance of plagioclase near the base of the zone, the proportion of orthopyroxene and clinopyroxene increases along with the size of the crystals.

The cumulate zone is characterized by a crude downward progression in rock types from websterite, through clinopyroxenite to peridotite. Rhythmic banding and layering cause variations in the proportions of orthopyroxene in the upper part of the cumulate zone and olivine in the lower part. Cumulate orthopyroxene forms prismatic, subhedral grains 0.5-0.8 mm in length which are altered to chlorite. The clinopyroxene (augite) crystals are 0.3-0.5 mm in size and are subhedral except in some clinopyroxenite where adcumulus growth has produced an interlocking network of grains. In the peridotite, the olivine (Fo₈₇₋₈₉) occurs as solid, euhedral grains and occasionally as elongate and tabular crystals

0.7-3.0 mm in length and in certain 1-3 m thick layers, as skeletal forms. The intercumulus matrix contains acicular to subhedral prismatic grains of augite and bronzite, small euhedral grains of augite and euhedral chromite grains in a devitrified glass groundmass. The lowermost 10 m of the flow contains roughly equal proportions of olivine, orthopyroxene and clinopyroxene, all occurring as equant, solid grains 0.3 - 0.8 mm across. The olivine is partially to completely serpentinized, the orthopyroxene is completely altered to serpentine and chlorite, and the clinopyroxene is relatively unaltered.

The base contains curious lenses of what Arndt et al., (1977) describes as 'random clinopyroxene spinifex'. If this is indeed spinifex it means that fragments of an underlying komatiitic basalt flow have been picked up and incorporated by Fred's Flow.

6.3.2.3.1 Dee's Flow

Dee's Flow (Arndt, 1975) is an enigmatic layered body situated at the base of the Munro Fault Zone komatiite succession on the west Munro Township border. This peridotite-pyroxenite-gabbro body is up to 120 m thick but only 450 m long, rapidly thinning out at its eastern and western ends. At its thickest point, the body consists of a peridotite (wehrlite) base approximately 10 m thick, a clinopyroxenite layer 4-5 m thick, grading abruptly into about 100 m of fine- to medium-grained gabbro topped by a 'marginal zone' characterized by zones 'slaggy-textured' pyroxene and 'stringbeef' pyroxene spinifex up to 4 m thick (see Figures 18 and 19). It is partially overlain by a mixed breccia deposit up to 10 m thick consisting of tholeiitic and basaltic komatiite lava fragments and a small quantity of sedimentary rock clasts.

Mineralogically, Dee's Flow is similar to Fred's Flow (Allen, 1986). The main difference is the absence of a random olivine spinifex zone,

FIGURE 18. Lithological map of Dee's Flow (modified after Allen, 1986)

FIGURE 19. Mineralogical profile of Dee's Flow. (after Allen, 1986)

but this should not rule out the comparison considering that this zone is discontinuous along the length of Fred's Flow.

6.3.2.3.2 Origin of Dee's Flow

Although mapped as a layered flow of pyroxenitic komatiite composition (or basaltic komatiite composition-Jensen Cation Plot classification) by Arndt (1975), and Johnstone and Trowell (1984), a recent M.Sc. thesis (Allen, 1986) focussing on the petrology and ore mineralogy of Dee's Flow concluded that the body is a pyroxenitic komatiite sill. According to Allen (1986), the main evidence in support of this conclusion is the existence of a 'pendant' or detached block of tholeiitic basalt extending almost 50 m down into the gabbroic portion of the body, bordered by a chilled margin, and a small gabbro dike next to the block which extends from the gabbroic portion of the body into the overlying Mg-rich tholeiite and basaltic komatiite flows and breccia. The dike carries fragments of rock identifying by Allen (1986) as being derived from the upper margin of the body.

The 'sill' also displays signs of an extrusive nature. The thick zones of 'stringbeef' spinifex present are not characteristic of intrusive rock because the development of the texture requires much more rapid and pervasive cooling (Campbell and Arndt, 1982, Barnes et al., 1983). The matrix between the pyroxene throughout the 'marginal zone' of Dee's Flow is aphanitic, with spherulites indicating the devitrification of glass. In addition, the rock exposed at the top of Dee's Flow displays calcite amygdules and some closely-spaced polygonal jointing. The breccia deposit overlying Dee's Flow contains fragments of pyroxene spinifex-bearing fragments which were likely derived from the top of the flow. The basaltic komatiite flows immediately overlying Dee's Flow lack pyroxene spinifex. The basal contact of Dee's Flow, although concave in

aspect, does not truncate the pillowed tholeiitic lava flow underlying it at its westward thinning edge. Instead, the body appears conformable to a paleotopographical low at the edge of a pillowed lava pile. In addition, differentiated sills of greater than 100 m thickness, possessing well developed layering such as this, have much greater strike lengths than Dee's Flow in this region.

The occurrence of a detached angular block of basalt about which the upper contact and 'stringbeef' spinifex zone conforms does not necessarily indicate an intrusive relationship as suggested by Allen (1986). The clinopyroxene crystals in the spinifex zone are aligned perpendicular to the upper chilled contact of the flow against the block as is the case for 'stringbeef' spinifex in any mafic komatiite flow. It is possible that the block dropped onto the flow, deforming the flow's upper margin before the flow had completely crystallized. A layer of mixed breccia consisting of angular to rounded fragments of both sedimentary rock and tholeiitic and komatiitic volcanic rock overlies the block and a portion of Dee's Flow. This breccia could represent a debris flow deposit of which the large block was a constituent. Alternatively, the block protruding into the top of Dee's Flow could also represent a portion of the leading edge of a large, wedge-shaped block of tholeiitic volcanic rock about which the lava flowed, and against which the flow ponded and cooled. If Dee's Flow shared the same down-dip flow direction as the flows of similar composition which overlie it, then the leading edge of such an obstacle at the flow front could appear like this in the cross-section of the flow as it is presently exposed.

The best evidence presented by Allen (1986) for Dee's Flow being an intrusion is the presence of a small gabbro dike which branches off the

'sill'. The fact that the dike carries what appears to be flow top material suggests another possibility. A thick flow, since it takes longer to cool, could still have a liquid core beyond the time that one or more thin flows could be deposited and crystallize above it. With sudden loading, due possibly to a debris flow or a second pulse of lava into the thick flow, the mafic differentiate liquid could have been forced up fractures in the upper margin of the flow and fragmented the flow top as it passed into the rock above.

In conclusion, Dee's Flow is most likely a layered flow, as originally defined. Its irregular upper contact may indicate that the flow had partially pushed its way through a breccia pile and the convex lower contact is probably the result of the flow ponding within a narrow depression. A flow, close to its point of eruption in a breccia pile, could conceivably be overlain by a thin blanket of breccia consisting of fragments transported from the breccia pile and fragments the flow has generated itself.

6.4 Petrology of peridotitic komatiite flows

6.4.1 General properties

Peridotitic komatiites are generally magnetic (unlike the basaltic komatiites), dark green to black on fresh surface, with light to dark gray or chocolate brown weathered surfaces. Pillowed ultramafic flows are not easily distinguished from pillowed basaltic komatiite flows. Generally though, the pillows tend to be smaller, more intensely polygonally jointed and the weathered surface is a slightly darker shade of reddish brown. Also, large sacks of lava or lava lobes are common in pillowed flows and these can contain lenses of olivine spinifex which indicate that the flow is a peridotitic komatiite. Most peridotitic komatiite flows are generally tabular and tend to be thinner (0.5-5.0 m)

than the komatiitic basalt flows. The flows are not fully enough exposed to judge maximum strike length, but most appear to be less than 100 m long. Arndt et al. (1977) note that non-spinifex flows in the northern Munro Township area tend to be thicker, but shorter than flows with spinifex. This generalization does not stand up elsewhere in the study area.

Arndt et al. (1977) suggest that the flows with thick olivine spinifex zones of the form described by Pyke et al. (1973) represent one end-member of a continuum that ranges from flows with thick spinifex-textured zones to flows devoid of spinifex textures. To illustrate this continuum, these workers profiled three flows (Figure 22) which represent the two end-members (A and C) and an intermediate member (B). All three are described from an outcrop, known as Pyke Hill, located immediately east of the Potter Mine (see Munro Township map. In addition, another intermediate member, flow type 'A-B', is proposed from this study. Examples of all four flow types; 'A', 'A-B', 'B', and 'C', are found in the study area but 'A-B' and 'B' type flows and combination flows, which include one or both of these flow classifications at different points along the flow, are the most commonly observed.

6.4.2 Flow type 'A'

The classic peridotitic komatiite flow (Type 'A') described by Pyke et al. (1973) has five distinct zones; A_1 , A_2 , B_1 , B_2 , B_3 , and B_4 . The first zone, A_1 , is characterized by an aphanitic, polyhedral jointed flow top (see Figure 20 and Plate 26). The rock consists of very fine-grained, randomly oriented equant skeletal or thin bladed olivine crystals and rare solid equant olivine phenocrysts in a matrix of glass altered to chlorite and serpentine. The A_2 zone, with a maximum thick-

Figure 20. Diagrammatic section of an ultramafic flow unit. (after Pyke et al., 1973)

ness of 5 m, marks the start of the coarse spinifex zone. At the upper part of the zone the olivine blades are thin and randomly oriented, but lower down they are generally thicker (up to 2 mm) and arranged in books (parallel plates) or sheaves (long slightly diverging plates). These sheaves are oriented subperpendicular to the plane of the flow and commonly appear broader at the base than at the top (see Plate 27). The partially serpentinized olivine blades (up to 1 m long) are set in a matrix of aligned or splayed clinopyroxene, chromite and devitrified glass.

The A₂ zone shows a sharp contact with the B₁ zone, which is a thin, commonly discontinuous layer composed of tabular, skeletal olivine oriented parallel to the plane of the flow. The zone generally has a flat base and an irregular upper contact caused by spinifex growing down into the layer. The contact of the B₁ zone with the B₂ zone is sharp or gradational over a few centimetres. The rest of the cumulate B zone is a gray weathering, fine- to medium-grained peridotite composed of mainly equant, 0.7-1 mm grains of serpentinized olivine (70 to 75 percent of the rock) in a matrix of parallel or stellate arrays of fine clinopyroxene, skeletal chromite and devitrified glass. At the flow base, there is an abrupt decrease in grain size and a strong foliation parallel to the base is observed. A weak to moderate parallel foliation occurs throughout the cumulate zone, caused by the alignment of more elongate olivine crystals.

Only the presence of zone B₃ allows distinction of zones B₂ and B₄. The B₃ zone is also called the 'knobby peridotite' zone and is not always present or continuous. The 15 cm to 35 cm thick zone is characterized by small protuberances, irregular to subrounded in outline, that average 2 mm in size and may form large irregular clots up to 5 cm

across. Microscopically, the clot consists of a rim of olivine, clinopyroxene and interstitial chlorite, and a core of fine tremolite, minor olivine, clinopyroxene, and interstitial chlorite and serpentine.

The upper part of the cumulate zone also contains small lenses and dike-like bodies of olivine spinifex less than a meter long and 2-15 cm wide. These have been referred to as spinifex dikes (Pyke et al., 1973) and hydro line structures (N. Arndt, personal communication, 1984) due to the fact that, like a power line in profile, the lenses are commonly linked end to end in concave-upward segments. The olivine blades are up to 5 cm long, and the contacts with the cumulate rock are sharp with no marginal reduction in grain size. It is possible that these structures formed when fractures opened in the cooling olivine crystal mush and nuclei-depleted liquid was allowed to intrude the cumulate layer and crystallize as spinifex at the same time as the A zone.

6.4.3 Flow type 'B'

As described by Arndt et al. (1977), the intermediate member, Flow 'B', possesses an A_2 zone thinner (approximately 1 m), in proportion to the flow thickness, than that of 'A' type flows, and spinifex texture, usually of the randomly oriented type, is not as extensively developed as in the 'A' type flows. In these flows the B_1 zone is absent and the transition from the spinifex zone to the cumulate base is gradational. The proportion of equant olivine crystals increases downward to a maximum of 60-70 per cent three-quarters of the way through the flow before decreasing to less than 50 per cent at the base. The transition zone can be marked by small, spinifex-textured schlieren 2-10 cm thick and 50 cm to several metres long situated within the cumulate zone immediately below, and occasionally in contact with, the spinifex zone.

The flow base is described as consisting of equant olivine phenocrysts set within a matrix of acicular pyroxene grains, some fractured and bent, some skeletal pyroxene and chlorite after glass.

These 'B' type flows commonly comprise lava tubes or lobes which may or may not display spinifex zones. Non-spinifex lava lobes can be found in pillowed flows in the Potterdoal Mine area and at Pyke Hill in north-central Munro Township. Spinifex-bearing lava lobes can be found immediately east of Dee's Flow at the western edge of Munro Township and exposed in an outcrop group northeast of the Hedman Mine road/Potterdoal Mine road junction (northeast Munro Township). Each of the spinifex-bearing lobes has a basal concentration of equant olivine grains overlain, and to some extent concentrically surrounded by a zone of spinifex below a curved, polygonally-jointed upper crust (Arndt et al, 1977). Each 2-6 m diameter lobe conforms pillow-like to the convex upper surfaces of the underlying lobes but unlike the smaller, generally bun-shaped pillows, the lava lobes are broader.

6.4.4 Flow type 'A-B'

Peridotitic komatiite flows displaying all the features of an 'A' type flow apparently occur only at Pyke Hill. A number of ultramafic flows exposed both at Pyke Hill and elsewhere in the study area, that exhibit thick spinifex zones but lack a knobby peridotite zone (B_3) and possess only a poorly developed, or no B_1 zone have been observed during this study. Such flows, referred to here as 'A-B' type, appear to fall between the 'A' type and 'B' type classifications.

A good example of an 'A-B' type flow is exposed immediately south of Highway 101 at the northeast edge of Guibord Township, stratigraphically close to the base of the first (Munro Fault Zone) komatiitic succession. This flow is twice as thick as the average Pyke Hill flow, having a

thickness of 7.8 m to 8.0 m and almost half the thickness of the flow (3.5 m) is an olivine spinifex zone (see Figure 21).

The base of this flow is quite irregular, resting in one place on the rapidly thinning edge of an underlying 'A-B' type flow. The cumulate zone is similar to that of the 'A' type flow, composed of equant, serpentinized olivine grains averaging 70 model per cent set within a matrix of skeletal pyroxene and chloritized glass. The average grain size is 0.8-1.0 mm throughout most of the layer with a slight increase in size (1.5 mm) within the top 10 cm. The knobby peridotite zone is absent and a foliation caused by the alignment of elongate skeletal olivine parallel to the plane of the flow was observed in the top 20 cm of the peridotite layer. The contact of the cumulate layer with the spinifex zone is sharp, but the B₁ zone is discontinuous, occurring as 2-3 cm thick lenses. As in the Pyke Hill 'A' type flows this layer of skeletal olivine plates has been indented by the downward growth of spinifex.

In most places, the spinifex making contact with the cumulate layer consists of long downward-diverging splays of straight olivine blades within 5-15 cm long sheaves roughly oriented perpendicular to the basal contact (Plate 27). Randomly oriented bladed olivine sheaves form a criss-cross pattern in 5-20 cm wide patches between the subparallel sheaves at the lower contact of the A zone (Plate 34). Sheaves within the spinifex zone can be up to 1 m in length and 1.2 m wide across the base. The sheaves are not however usually oriented perpendicular to the plane of the flow as they are at Pyke Hill. The larger sheaves vary up to within 70° from perpendicular and the smaller sheaves can have any orientation. In the lower third of the spinifex zone a string of

FIGURE 21. Sketch of an 'A-B' type peridotitic komatiite flow, northeast Guibord Township.

spinifex sheaves can be found curving eastward up from the base of the zone producing a 60° change in orientation (Plate 35). Curving masses of coarse spinifex such as this are quite common in the study area. Also common in 'A-B' type flows, observed in a flow overlying this one, is a spinifex zone consisting of coarse (3-10 cm blades) spinifex in the form of randomly oriented booklets. (see Plate 39)

Within 1.8 m of the flow top, shorter groups of sheaves begin to predominate within 1.5 m, small patches of randomly oriented, bladed olivine booklets, 0.4-1 cm wide (Plates 37 and 38), begin to appear and at a point 1 m below the flow top, the coarse spinifex is replaced by the fine randomly oriented form. The average size of the olivine booklets within this upper zone progressively decreases upward towards the flow top which is a light buff weathering zone characterized by equant, 1-2 mm, skeletal olivine crystals and solid olivine microphenocrysts. A flow top breccia layer is absent in the only exposure of the flow.

The upper 1 m of the flow is characterized by rectangular to rounded polygonal jointing. Joints are spaced 5-18 cm apart at the base of this zone, and then become more closely spaced towards the top of the flow. In the coarse spinifex zone (A_2) broadly spaced polygonal joints are imperfectly developed while in the cumulate layer the jointing is much more regular, producing 10-15 cm wide columns of rectangular blocks (Plate 32).

Lack of continuous outcrop makes an estimate of strike length and lateral change for this flow impossible however, based on the evidence of similar flows underlying it, it is reasonable to assume that it has a strike length of less than 250 m, and that a spinifex zone persists for much, if not all, of this distance. This is the case for a 20 m thick

flow which marks the base of the komatiitic lava succession at this location.

6.4.5 Flow type 'C'

The massive, non-spinifex peridotitic komatiites (Flow 'C' -Arndt et al., 1977) are characterized at Pyke Hill by extensive polygonal jointing. At the flow top the joints are closely-spaced and distinctly rectangular or polyhedral, whereas those in the core of the flow are longer, thicker, gently curved and more widely spaced.

A type 'C' flow described by Arndt et al. (1977) consists of 45-55 per cent equant olivine crystals, some with skeletal olivine overgrowths, in a matrix of skeletal, dendritic, radiating and plumose splay of clinopyroxene, cruciform, dendritic and cubic crystals of chromite and chloritized glass. The proportion of olivine in this flow type is much lower than that of the 'B' zones of spinifex-bearing lavas, but the size and habit of the olivine crystals is similar.

6.4.6 Crystallization model for peridotitic komatiite flows

Pyke et al. (1973) were the first workers to suggest a model for the the crystallization of 'A' type flows and, apart from minor additions to the model (Arndt et al., 1977), it remains fundamentally unchanged and unchallenged.

Pyke et al. (1973) suggested that the B zone formed initially by the rapid settling of olivine phenocrysts. Certain features of the B zone have been explained by Arndt et al. (1977) in terms of this settling process. The decrease in the size of the olivine crystals at the base of the flows was thought to be due to the fact that the first phenocrysts to settle have less time, than subsequent phenocrysts, to grow in the melt. Flowage of the cumulate above the flow base was believed to be

responsible for the decrease in olivine content at the base since olivine phenocrysts would tend to migrate away from the stalled margins of a flow. In addition, the chilling of the base, with the associated increase in viscosity, would reduce the rate of phenocryst settling. Flow differentiation is also invoked to explain the development of the B_3 zone in the core of the cumulate layer.

As suggested by Pyke et al. (1973), spinifex formed only after the accumulation of the B zone had depleted the liquid of potential nuclei in the form of olivine phenocrysts. With rapid cooling at the flow top, the resulting supersaturated liquid rapidly crystallized skeletal olivine blades from the top down. The blades progressively increase in size downward in the lower portions of the flow where slower cooling was permitted at the time of crystallization.

The B_1 zone is interpreted (Pyke et al., 1973) as a cumulate layer of the first skeletal crystals to form in the liquid portion of the flow after the settling of the olivine phenocrysts and prior to the crystallization of olivine spinifex. The straight growth of the spinifex suggests that crystallization was static, occurring only after flowage had ceased, and perhaps aided by the damming or ponding of the flow. The downward growth of the spinifex, as noted before, indents the B_1 zone in places, but not the B_2 zone. This suggests that the olivine phenocryst cumulate portion, at that stage in the crystallization of the flow, would have been cohesive enough to develop fractures for the emplacement of spinifex dikes.

The different types of peridotitic komatiitic flows (Figure 22) are explained by Arndt et al. (1977) to be due to the different degrees to which gravitational settling has separated olivine phenocrysts from the liquid lava. Since spinifex texture only develops in liquids essentially

FIGURE 22. Diagrammatic sections through three types of peridotitic lava flows: A, a flow with an upper spinifex zone; B, a flow with limited spinifex texture; C, a flow without spinifex texture.
(after Arndt et al., 1977)

devoid of phenocryst nuclei, the type of flow with a thick spinifex zone ('A') is the result of complete separation, the intermediate flow type ('B') is the result of solidification before complete separation and the spinifex-free flow type ('C') is the result of solidification with little or no gravitational settling.

A single thick flow could possess characteristics of all the flow types along its length. Close to the conduit olivine phenocrysts could settle in hot fluid lava, and thereby permit the development of spinifex. As lava flowed out and spread though, its viscosity would increase with a drop in lava temperature and progressively prohibit the settling of olivine phenocrysts. Ideally a progression from 'A' to 'B' and then 'C' types should be observed in a flow, thus allowing one to estimate proximity to the flow's source vent. Arndt et al. (1977) noted this progression in one of the thicker ultramafic flows in north-central Munro Township, and used it, along with direction of flow thinning and lava lobe orientation, as evidence of flow direction.

Considering the thick spinifex zones and thick, well defined cumulate layers of 'A-B' type flows, complete phenocryst separation is in evidence for the period of flow crystallization, and therefore such flows should not be considered any less proximal to the source vent than the 'A' type flows described by Arndt et al. (1977). The 'A' type flows may in fact represent very unique conditions of static crystallization, whereas the more common 'A-B' type flows represent a more dynamic crystallization process such as current action during spinifex crystallization due to flow remobilization or convective cooling.

6.5 Geochemistry of komatiites

As with the tholeiites, komatiite geochemical data is presented on a Jensen Cation Plot (Figure 23) in order that the two komatiite rock

FIGURE 23. Projections of chemical analyses of komatiitic volcanic rocks.

groups can be distinguished. The line separating basaltic and ultramafic komatiite fields, based on the petrographical differences between the two rock types, corresponds to $\text{MgO} = 10\%$ by weight (anhydrous). Olivine is the major mafic mineral in the ultramafic komatiites, whereas pyroxene is the dominant mafic mineral in the basaltic komatiites (Jensen and Langford, 1983). This petrologically based sub-division of the komatiitic field is confirmed by the samples plotted on the diagram (i.e. If pyroxene was the dominant mafic mineral in the sampled flow, the rock plotted as a basaltic komatiite on the diagram). Despite the name, pyroxene is still the dominant mafic mineral in 'olivine-rich' basaltic komatiites.

Individual spinifex-bearing flows may vary in composition from top to bottom, reflecting the processes of crystallization. This compositional variation can be caused by crystal settling to form cumulates at the base of the flow, 'in situ' crystal growth and accumulation which, in the case of 'stringbeef' clinopyroxene spinifex, can produce spinifex enclosing a cumulus component, and fractional crystallization within the flow which produces more evolved liquids in flow centers (Donaldson 1982, Lesher et al., 1984). Channel sampling from each zone and mass balancing the analyses would correct this problem but this is not practical in regional scale sampling. For the spinifex-bearing flows analysed here, samples were taken from locations close to the flow top, where it is more likely to find a rock which represents a composition approximating that of the lava prior to the settling of olivine microphenocrysts and spinifex crystallization (but not so close to the top of the flow that the rock has been greatly affected by seafloor alteration).

A black triangle on the diagram (Figure 23) represents the composi-

ion of an olivine-rich basaltic komatiite flow which contains both clinopyroxene and olivine spinifex. It has been suggested that the presence of olivine spinifex in an undifferentiated flow is indicative of a peridotitic komatiite composition (Nesbitt et al., 1979). However, this analysis indicates that a flow can have olivine spinifex, and still be of basaltic komatiite composition. Therefore, olivine spinifex-bearing flows which obviously had pyroxene as their dominant mafic mineral, as evidenced by clinopyroxene spinifex zones and clinopyroxenite cumulate layers, were considered basaltic komatiites during mapping.

The analysis of a variolitic basaltic komatiite (black box) is included on the Jensen Cation Plot to indicate that such rocks, although rare, do exist in the study area. This particular sample contained olivine spinifex along with small varioles, so there is some question whether the presence of the varioles has biased the analysis in favor of alumina as in the tholeiitic variolites. This is considered a possibility because other olivine spinifex-bearing samples plot as peridotitic komatiites or Mg-rich (olivine-rich) basaltic komatiites on the diagram.

Figure 23 indicates that the basaltic and peridotitic komatiite analyses of Beatty and Munro Townships, and those of other Stoughton-Roquemaure Group assemblages in the region (Figures 24 and 25 -Stoughton and Roquemaure Townships and southern Lightning River area) produce similar trends on the Jensen Cation Diagram, a trend of aluminum enrichment and magnesium depletion, rather than iron enrichment. Fred's Flow plots within this aluminium enrichment trend on the Jensen Cation Plot (based on the chemical data of Arndt and Nesbitt, 1982). In Figure 23 the circles labelled 2, 3, and 4 represent analyses from the random olivine spinifex layer near the flow top, the olivine porphyritic layer

Figure 24. Projections of the chemical analyses of the volcanic rocks of the Stoughton - Roquemaure Group type section on the Jensen Cation Diagram. (after Jensen and Langford, 1983)

Figure 25. Jensen Cation plots of analyses of the Stoughton - Roquemaure Group along the Destor - Porcupine Fault zone (large black triangles equal 2 overlapping projections). (after Jensen and Langford, 1983)

2 m below the flow top, and the fine-grained flow top respectively. The circle labelled 1 represents the analysis of a sample from the flow's gabbroic layer.

However, what is apparent from the study area projections is a second cluster of komatiitic basalt analyses which are more iron-rich than those within the aluminum enrichment trend. On the basis of the $\text{Al}_2\text{O}_3/\text{TiO}_2$ values, the Fe-rich basaltic komatiites at the lower end of the MgO range for basaltic komatiites appear clearly chemically distinct from other basaltic komatiites having lower average $\text{Al}_2\text{O}_3:\text{TiO}_2$ ratios (7 - 9). These ratios are typical of komatiite-associated Fe-rich tholeiites in both the first (7) and second (7 - 9) komatiitic successions. The $\text{Al}_2\text{O}_3:\text{TiO}_2$ ratios for different rock types (including Fred's Flow) identified by Arndt and Nesbitt, 1984) in north-central Munro Township are compared with those of komatiites and an associated, massive Fe-rich tholeiitic basalt from elsewhere in the study area in Table 5.

Figure 26 display a plot of $\text{CaO}/\text{Al}_2\text{O}_3$ vs. MgO. The diagram clearly shows that five basaltic komatiites and one low-Mg peridotitic komatiite have $\text{CaO}/\text{Al}_2\text{O}_3$ values of approximately 1.6 to 1.9, values typical of the 'alumina-depleted suite' of komatiites (section 6.2). These anomalous values raise questions as to whether alteration (ie. carbonatization) could have sufficiently raised the CaO content of the rocks to produce the values and whether or not, the division of komatiites into alumina-depleted and alumina-undepleted suites is valid.

6.6 Evidence of synvolcanic tectonism in komatiites

Synvolcanic fracturing, other than that caused by contraction during crystallization, is commonly seen in the ponded and non-ponded komatiitic flows. Such fractures within a flow appear as serpentine veins, 1-2 m long, bordered by 3-7 cm wide margins of intense polygonal jointing

Table 5: MgO contents and $Al_2O_3:TiO_2$ ratios for the main magma types in Munro Township

Second komatiitic lava succession (Arndt and Nesbitt, 1985)¹

	Fe-rich tholeiites	Komatiitic basalts	Fred's Flow	Peridotitic komatiites	Olivine porphyry (Mg- rich tholeiite
MgO	5 - 14	7 - 15	16 - 19	22 - 28	7 - 15
Al_2O_3/TiO_2	7 - 9	20	20	20.5	17

First komatiitic lava succession (this study)

	Fe-rich tholeiite (1 sample)	Komatiitic basalts (9 samples)	Fe-rich komatiitic basalts (8 samples)	Peridotitic komatiites (5 samples)	Variolitic komatiitic basalt (1 sample)
Mgo	3	9 - 20	9 - 12	22 - 34	12
Al_2O_3/TiO_2	7	12 - 20	7 - 9	15 - 16	18

1. Based on 24 rock samples.

FIGURE 26. $\text{CaO}/\text{Al}_2\text{O}_3$ vs. MgO plot of komatiite samples.

extending down from the flow top (see Figure 27). In cross-section it appears as if the flow top had tightly folded into the flow. It appears that when the flow top fractured, seawater was allowed to permeate down to the still-liquid portion of the flow and cause rapid cooling and polygonal joint development next to the fracture. These fractures are not likely to be confused with normal cooling fractures because; (i) cooling fractures in a spinifex zone lack chilled margins and, (ii) these fractures extend much deeper (1-2 m) into the flow than individual cooling fractures (<1 m), and (iii) cooling fractures are much thinner (<1 cm).

The development of these deep syn-crystallization fractures could have been caused by tectonism or by intermittent flowage associated with irregular topography or fluctuating lava supply. Only the former cause would apply to ponded flows. For example, Arndt et al. (1977) have suggested that Theo's Flow has been affected by syn-crystallization fracturing. However, such fracturing in tholeiitic lava flows is difficult to distinguish from normal cooling fractures because cooling fractures in tholeiites lack a regular pattern such as that represented by polygonal jointing.

The development of a blockly 'aa-type' flow top breccia from a smooth pahoehoe flow top, more typical of a ponded flow, indicates flow remobilization (Dimroth et al., 1985). The flow top breccia overlying Fred's Flow, referred to by Arndt (1977) as a 'friction breccia' appears to be of this sort (i.e. produced at the flow top by fracturing created by the viscous drag of flowing lava below (autobrecciation). Renewed lava flowage within a ponded lava flow could indirectly indicate tectonic disruption.

The pahoehoe-aa transition is not observed along the exposed length

FIGURE 27. Sketch diagram of a syndepositional fracture in a peridotitic komatiite flow.

of Fred's Flow, which suggests that either lava remobilization affected the entire lava lake or the undisturbed portion of the flow is not exposed.

The remobilization of Fred's Flow may have been caused by two factors: (i) a break-out of lava caused by fracturing or the collapse of a confining levee during a seismic event within the rift system, and (ii) the extrusion of a separate magma into the ponded flow. As mentioned previously (Section 6.3.2.2), a mixed flow top breccia was thought by Arndt and Nesbitt (1984) to have resulted from the mixing of two separate magmas within the flow.

Late stage lava flowage within certain komatiitic flows is also indicated by broad curving arrays of either clinopyroxene or olivine spinifex. In the case of olivine spinifex, the pattern is referred to in this study as 'windblown spinifex'. Windblown spinifex consists of sheaves of coarse skeletal olivine platelets which bend as much as 90° (see Plate 43 and 44). Curvature of the sheaves is produced by slightly curved olivine plates arranged en echelon within booklets progressively reorientated down the length of the sheaf. To form this structure, flowage would have initiated shortly after the start of spinifex crystallization. Coarse spinifex growth requires the settling out of potential nuclei (olivine microphenocrysts carried in the lava) a process aided by the cessation of lava flowage (Pyke et al., 1973). Skeletal crystal growth perpendicular to the flow top would develop in the stagnant liquid, but if flowage resumed in this liquid portion, current action would redirect the growth of new crystals as they nucleated on crystal sheaves along the crystallization front.

In a 'windblown' spinifex zone, the direction of crystal sheaves is not consistent throughout the entire zone, so it is unlikely that the

current which redirects crystal growth is strong or widespread. Weak, localized current action is probably more typical of either thermal convection within the flow or tectonic disruption rather than a renewal of lava flowage. Huppert et al. (1984) have constructed a mathematical model which indicates that rapid cooling within ultramafic flows could have been accomplished by forced convection related to turbulent flow during emplacement and thermal convection currents after the flow settled. If a settled flow was subjected to a second pulse of lava carrying olivine microphenocrysts, it would likely be indicated by a zone of randomly oriented spinifex due to the sudden introduction of many nuclei into a super-saturated liquid, and possibly by a second cumulate layer above the B_1 layer. Some of the peridotitic komatiite flows within the Munro Fault Zone succession have entire spinifex zones consisting of coarse, randomly oriented spinifex (see Plate 39). Unlike the finer-grained random olivine spinifex in 'A-B' and 'B' type flows, this form of spinifex consists of large booklets of coarse, skeletal olivine blades, 5-10 cm across. Such a pattern is likely an example of a flow where a second pulse of phenocryst-bearing lava initiated spinifex crystallization, characterized by simultaneous nucleation occurring throughout the liquid portion of the flow rather than just at the flow top. Therefore, a resumption of lava flowage within a flow as evidenced by 'windblown' spinifex is more likely due to a tectonically induced break-out of lava rather than the introduction of new lava.

From the best available evidence (i.e. deep syn-volcanic fractures in ponded flows, 'windblown' spinifex) the magnitude of tectonic activity cannot be judged, but the evidence is sufficient to confirm that active tectonism accompanied the extrusion of komatiitic lavas.

6.7 Flow direction

6.7.1 Pillowed flows

As is the case of the pillowed tholeiitic flows (section 5.5.1.), pillowed komatiitic flows tend to have pillows, lava lobes and tubes which are elongate in a down-dip direction, but only four flows could be found, two in the north limb succession (north-central Munro Township) and two in the south limb succession (southwest Munro Township), where budding pillows or branching lava tubes indicate flow direction conclusively. In all cases flow direction was determined to be within 10° of south (Plate 40).

6.7.2 Fred's Flow, vent location and flow direction

Fred's Flow, being a layered flow, represents a case where the 'A-C' flow type progression cannot be used to determine flow direction. Arndt (1975) concluded that flow direction for Fred's Flow was from east to west based on thinning of the flow westward in its exposure north of the Warden Hill Fault (north fault block). Actually the flow thins slightly eastward and westward from a point in the Potterdoal mine. Fred's Flow is a ponded flow (Arndt et al., 1977) and as such, changes in its thickness can simply be due to local paleotopographical features and not necessarily to down-flow tapering of the flow. A cumulate and spinifex zone persisting over the entire 7 km strike length of the flow in the north fault block exposure attests to its ponded nature.

If it is assumed that olivine microphenocrysts carried by the magma, along with olivine and pyroxene crystallized within the flow, began to settle out of Fred's Flow while its lava was still being extruded, the cumulate zone should, barring a local topographical effect, be thicker closer to the point of extrusion. If this is the case, then the roughly uniform thickness of the cumulate zone in the flow's northernmost expo-

sure indicates that all points along the flow are equidistant from a point of extrusion, as would be the case if the flow had extruded from an east-west oriented fissure. A comparison of the relative thicknesses of the cumulate layer in the northern and southern exposures of Fred's Flow support the hypothesis that there is an uneven distribution of cumulate material over the length of the flow. The cumulate layer in the southernmost exposure is also of uniform thickness along strike, but at least a third thicker than the cumulate layer in the northern exposure and, as mentioned before, possessing a much higher olivine-to-pyroxene ratio. This evidence would suggest that this southern (down-dip) cross-section of the flow is closer to the point of extrusion than the northern exposure.

If, as suggested, the source fissure was oriented east-west, the lava which is represented in exposures of Fred's Flow would have flowed north. This northward flow direction for Fred's Flow is also supported by two features: (1) the northward-directed deformation the flow's 'stringbeef' clinopyroxene spinifex and, (2) the northward flow indicated by a pillowed flow of the same composition, immediately overlying Fred's Flow. There is evidence that clinopyroxene needles can continue to grow down from the flowtop while the lava is still flowing (Barnes et al., 1983) and it is reasonable to suggest that the liquid movement would have caused the skeletal clinopyroxene crystals to curve in the direction of flowage as they were crystallizing. This is somewhat different from 'windblown spinifex' where the curving of the sheaf is accomplished more from the progressive reorientation of individual olivine blades than by their deformation. Sections of the spinifex zone in Fred's Flow have been deformed in a direction which suggests that lava

was flowing north (up-dip) as the spinifex was crystallizing. In some places crystal masses have been reoriented almost parallel to the plane of the flow, the greatest reorientation having occurred in the center of each deformed section. The clinopyroxene bundles appear to fan out over several meters (see plate 46).

The lava tubes and lobes exposed in the pillowed basaltic komatiite flow directly overlying Fred's Flow are approximately parallel to the dip of the bedding and clearly bud pillows in an up-dip direction, thus indicating northward flowage (see Plate 41). It is suspected from the close association of the two flows over a long strike length (over 5 km) that the pillowed flow extruded from the same place as the basaltic komatiite lava of Fred's Flow. If so, Fred's Flow would have originally flowed north also.

It is also possible that Fred's Flow may have flowed south from its point of extrusion if the source-fissure was in the center instead of along the southern edge of the proposed east-west trending graben. The north-south distance, prior to folding, between Fred's Flow, as it is presently exposed, and a stratigraphically equivalent point on the south limb of the McCool Hill Syncline is not believed to be great. Even if it was assumed that the 60° NW plunge of the syncline (see Appendix 2) did not shallow at depth, this distance would be less than 12 km. Even though Fred's Flow is stratigraphically higher than the Munro Lake Sill and therefore should represent a shorter north limb to south limb distance, the Munro Lake Sill is found on both limbs of the fold and the flow is not. Considering the short distance involved within the fold, it is proposed that the distribution of Fred's Flow was largely north of its point of eruption which is situated somewhere below the present erosion surface in either the north or south limb of the syncline. This

would be the case if the source magma preferentially intruded a fault forming the southern edge of the graben and the lava, confined to the south by a fault scarp, spread north.

6.8 Centers of eruption-komatiitic lavas

The hybrid magmas that Arndt and Nesbitt (1984) believe fed Fred's Flow and a few of the overlying basaltic komatiite lava flows, resulted, from the mixing within the flow of two separate komatiitic magmas of peridotitic and basaltic composition. The two magmas involved are not believed to be related by low pressure fractionation, but are derived either from separate mantle sources or the same mantle source and are the products of high pressure fractionation (Arndt and Nesbitt, 1982). If magma mixing did occur within Fred's Flow and the other flows, a close spacing must have existed between vents erupting ultramafic lava and those erupting basaltic komatiite lava.

The eruption of ultramafic lavas requires; (i) the rapid ascent of magma in order to avoid the contamination of the magma through the assimilation of country rock (Arndt, 1975) and, (ii) the development of a magma chamber where differentiation could evolve a more felsic magma (Arndt and Nesbitt, 1982). The appearance of komatiitic lava flows and related shallow level ultramafic sills in the stratigraphy probably indicates the development of a rift zone where normal faults had expedited the rise of ultrabasic magma. The peridotitic komatiite lavas in particular, are confined to two, approximately 2 km thick stratigraphic intervals indicating two separate periods of ultramafic volcanism and perhaps two periods of fault zone activity. It is proposed that ultramafic intrusions, referred to as 'mantle diapirs' by Arndt (1975, 1976), rose at different points along east-west oriented fracture systems

creating a string of sills and komatiitic lava piles during the two ultramafic eruption periods. In the stratigraphy of the study area, this is indicated by two known komatiitic lava piles in each of two stratigraphic levels (first and second komatiitic lava successions) and possibly a fifth komatiitic lava pile further west in southeast Wilkie Township, indicated on maps produced by Kidd Creek Ltd. (Resident Geologist Files, Kirkland Lake), which may be stratigraphically equivalent to the second komatiitic lava succession.

6.9 Ponded flows and rifting

Komatiitic flows and particularly ultramafic flows are thought to have been much hotter (1600 °C) and more fluid than modern day basalts (Arndt and Nisbet, 1982). From this it is assumed that ultramafic flows would spread out far more than flows of mafic and intermediate composition and therefore, for the same volume of lava extruded, be thinner. Significant thickness in a peridotitic komatiite flow would therefore only be achieved by ponding. Of course, without modern examples of ultramafic flows for comparison, the maximum thickness of a non-ponded flow is unknown, but from the abrupt terminations of many of the thicker ultramafic flows, it is suspected that many are in fact ponded. The best example is a partially exposed flow with an abruptly tapering end, immediately west of the Munro Lake Sill at Centre Hill. Only the eastern end of this flow is exposed, over a strike length of 280 m, but the flow thins from a thickness of approximately 100 m to 20 m within 150 m of the eastern end of the flow. This flow is also unique because the cumulate portion of the flow, characterized by a thick dunitic base and thin, chromite-rich layers, accounts for just over half the thickness of the flow.

Rather than a series of small depressions developing at different

times during the deposition of the komatiitic lavas promoting the ponding of thick, ultramafic lava flows, a more viable hypothesis, consistent with the proposed model of fissure eruptions and extensional tectonics, is that ponding was occurring within graben structures created by the rifting. The predominance of north-south flow directions for tholeiitic and komatiitic flows (Sections 5.6.1, 6.7.1), including Fred's Flow (Section 6.7.2), and the general lack of feeder dikes (Section 5.6.3) in the stratigraphy have been used to suggest that most lavas extruded from east-west fissures in a rift zone. The normal faults of the rift zone would have localized the fissure eruptions and the extruding lava would have ponded within the fault-bounded valleys. The development of an east-west graben system would be indicated by a stratigraphic horizon dominated by ponded komatiitic flows, indicating the simultaneous ponding of lavas within a rift valley. Both komatiitic lava successions within the study area have bases dominated by thick, ponded flows with large strike lengths. This would be expected if rifting was associated with the initial rise and extrusion of komatiitic magma and the rift valleys within which the lava ponded, had an east-west orientation.

6.10 The nature of komatiitic volcanism: conclusions

The following statements can be made concerning the deposition of komatiitic flows and the nature of the depositional environment:

(i) The physical features of Dee's Flow suggest that it is a ponded flow with a flow top which has been deformed by the loading of a mass-flow deposit during the flow's crystallization.

(ii) A komatiitic trend of aluminium enrichment and magnesium depletion noted in the type-section area of the Stoughton-Roquemaure Group

can be defined in the plot of komatiite analyses for the first komatiitic lava succession area, but there is also a distinctive group of Fe-rich basaltic komatiites indicated on the diagram which are distinguished from other basaltic komatiites by lower $\text{Al}_2\text{O}_3:\text{TiO}_2$ ratios (7 - 9) more typical of Fe-rich tholeiites associated with komatiites.

(iii) 'A-B' and 'A' type flows and flows combining both of these flow types are the most common forms of peridotitic komatiite flows. Since these flow types represent proximal facies, this may indicate a general proximity to source vents for most of the flow within the lava assemblage, as would be the case if the centers of eruption remained relatively fixed during the deposition of the komatiitic lava succession.

(iv) Peridotitic komatiite flows commonly display 'windblown' spinifex and coarse, random olivine spinifex. It is proposed that 'windblown' spinifex results from either the resumption of lava flowage due to tectonism or convection currents within the flow during spinifex crystallization and that coarse, random olivine spinifex represents the introduction of new magma bearing olivine microphenocrysts into a previously settled flow.

(v) Renewed lava flowage within the crystallizing Fred's Flow, related either to tectonism or the introduction of a separate magma into the flow, is indicated by flow top 'friction breccia' and deformed 'string-beef' clinopyroxene spinifex. The deformed spinifex zone suggests northward (up-dip) lava flowage.

(vi) Deep fractures extending down into the upper half of flows are believed to be products of syndepositional tectonism.

(vii) The dominant flow direction for komatiites was north-south, but there was not enough evidence available to discern a dominant direction of flow propagation.

(viii) Based on the relative thickness and olivine contents of the cumulate zone of Fred's Flow and the relatively uniform thickness and composition of the flow along strike, it is proposed that the layered flow extruded from an east-west fissure (presently situated within the McCool Hill Syncline) originally situated along the southern edge of an east-west oriented graben structure. The flow ponded within the rift valley.

(ix) Based on stratigraphic relationships and flow morphologies, it is suggested that each komatiitic lava succession represents a period of rifting which aided the rise of ultramafic diapirs and formed east-west graben structures within which komatiitic lavas were contained and flows ponded. Komatiitic lavas would have extruded at different points along the east-west fissure systems.

Plate 22. End-on view of 'string-beef' clinopyroxene spinifex from an olivine-rich basaltic komatiite flow located north of the Munro Mine in southwest Munro Township. Sheaves of acicular clinopyroxene appear as dots arranged in straight, 1 cm long strings.

Plate 23. Longitudinal view of 'string-beef' clinopyroxene spinifex from the same flow (Plate 22).

22

23

Plate 24. Photomicrograph of 'string-beef' clinopyroxene in cross-section. Skeletal clinopyroxene (augite) needles are cored by chloritized pigeonite (arrow). The groundmass consists of finer-grained acicular clinopyroxene, chlorite, plagioclase, and serpentine after olivine plates (dark gray).

Plate 25. Large columnar joints in the base of a ponded, peridotitic komatiite flow, Potter Mine area, central Munro Township.

Plate 26. Type 'A' peridotitic komatiite flow from Pyke Hill, northern Munro Township. Flow divisions are indicated on board.

Plate 27. Coarse olivine spinifex from an 'A-B' type peridotitic komatiite flow in northeast Guibord Township.

Plate 28. Photomicrograph of a 'slaggy' textured basaltic komatiite. Randomly-oriented, acicular augite with chlorite cores in a matrix of fine, radiating acicular clinopyroxene and tremolite. Sample from Painkiller Lake area, north-central Beatty Township

Plate 29. Photomicrograph of a 'slaggy' textured basaltic komatiite. Coarser grained randomly-oriented and radiating interstitial acicular augite in a devitrified glass matrix (dark gray). Sample from southwest Munro Township.

Plate 30. Photomicrograph of olivine spinifex. Sub-parallel, serpentized olivine plates with a matrix of plumose clinopyroxene. Peridotitic komatiite flow, southwest Munro Township.

Plate 31. Photomicrograph of olivine spinifex. Thin olivine plates lying within a matrix of sub-parallel and splayed acicular clinopyroxene.

1.0 mm

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MINICOD

Plate 32. Rectangular jointing in the cumulate zone in an 'A-B' type peridotitic komatite flow, northeast Guibord Township.

Plate 33. Photomicrograph of serpentized olivine crystals from the cumulate zone of the 'A-B' type flow of Plate 32.

Plate 34. Photomicrograph of the B₁ layer (between 4.4 m and 4.5 m) underlying the olivine spinifex zone (left) and overlying the cumulate zone. The foliation is created by sub-parallel platelets of skeletal olivine. Same 'A-B' type flow.

Plate 35. Coarse olivine spinifex in the Guibord Township 'A-B' type peridotitic komatiite flow.

Plate 36. Photomicrograph of coarse olivine spinifex; the leading edge of a diverging olivine plate booklet in cross-section.

Plate 37. Fine, randomly oriented olivine spinifex, Guibord Township
'A-B' type peridotitic komatiite flow.

Plate 38. Photomicrograph of randomly oriented olivine spinifex; coarser
olivine plates and fine, interstitial acicular clinopyroxene
and sub-parallel olivine platelets.

Plate 39. Coarse randomly oriented olivine spinifex, northeast Guilford Township.

Plate 40. Pillowed basaltic komatiite flow overlying Dee's Flow; polygonally jointed lava tube. Subvertical bedding dip, flow direction down dip. Southwest Munro Township.

Plate 41. Pillowed basaltic komatiite flow overlying Fred's Flow; Large lava lobe (left) which has spread out and flattened as it flowed north (up-dip). Next to the lava lobe, a pillow has budded from the end of a lava tube (photo card).

Plate 42. Pillowed basaltic komatiite flow; cross-sectional view of a lava tube. Lobate margins of the tube indicates budding.

Plate 43. 'Windblown' olivine spinifex in an 'A-B' type peridotitic komatiite flow in northeast Guibord Township. Olivine sheaves are reoriented 90 degrees in the central part of the spinifex zone (center of plate). The flow top is parallel to lower edge of the plate.

Plate 44. Photomicrograph of 'windblown' spinifex. Slightly curved olivine plates in en echelon arrays.

Plate 45. Deformed 'stringbeef' clinopyroxene spinifex in Fred's Flow, southwest edge of Warden Township.

Plate 46. Section of deformed 'stringbeef' clinopyroxene spinifex in Fred's Flow in southwest Warden Township. From the flow top (right side of plate), where the acicular crystals are perpendicular to the flow top, crystal masses curve up-dip lower in the flow.

Chapter 7: Calc-alkaline volcanic rocks within the Stoughton-Roquemare Group

7.1 Introduction

As mentioned in the chapter on stratigraphy, calc-alkaline rhyolite, dacite, and andesite are exposed, intercalated with tholeiitic lavas of the first tholeiitic lava succession, in two thin bands at slightly different stratigraphic levels in the Salve Lake area and the Munro Mine-Barton Creek Mine area. The calc-alkaline suite consists of basalt, andesite, dacite and rhyolite. This rock series is chemically distinguished from the tholeiitic rock series by its differentiation trend on an AFM diagram. The calc-alkaline trend reflects an increase in an initial basaltic magma composition of alkalies and silica with a simultaneous decrease in the total iron content (due to a separation of phases having a higher Fe/Mg ratio than the melt). The tholeiitic differentiation trend displays an initial rise in iron content (due to separation of olivine and pyroxene having Fe/Mg ratios lower than the melt) followed by a decrease in the iron content in the more alkalic members of the series (Ringwood, 1974). The calc-alkaline melt also has a higher relative silica content (in the 56-61 % range) at the same Fe/Mg ratio than the tholeiitic parent melt (Peacock, 1931).

Mineralogically, calc-alkaline rocks tend to be porphyritic with the most common phenocrysts in the more basic members (andesite and basalt) being plagioclase (comprising 50 - 70 %), and quartz and plagioclase being more common in the more silicic members (dacite and rhyolite). Phenocrysts of hypersthene, augite and hornblende are also common (Ehlers and Blatt, 1982).

7.2 Characteristics of calc-alkaline volcanic rocks

These deposits consists of massive flows and volcaniclastics. Only

tholeiitic lava flows are pillowed. The rhyolite and dacite flows are commonly characterized by convolute flow banding (see Plate 47) and large numbers of quartz veins and stringers. Rhyolite flows commonly display areas of autoclastic breccia and in one locality, south of Salve Lake, lenses of white, smooth weathering rhyolite are found enclosed within dark gray weathering dacite (see Plate 48).

The calc-alkaline volcanic rocks have an aphanitic to fine-grained spherulitic matrix which encloses fine-grained subhedral to euhedral phenocrysts of quartz and/or plagioclase feldspar, and in dacite, hornblende. Small to moderately sized (0.5-8 mm) amygdules, many of them drawn out in different directions by lava flowage and containing such ~~minerals~~ as microcrystalline quartz, chlorite, epidote and calcite, can account for up to 5 % of the rock volume. Rhyolite generally weathers to a white, light gray, or light yellowish green colour due to sericitization and has a light gray, yellowish, gray-green or black (rare) fresh surface. Dacite has a medium gray, gray-green, or reddish weathered colour, medium to dark gray-green fresh surface. The weathered surface is rougher than that of the rhyolite. Light gray-green weathered ~~the~~ andesite, defined as calc-alkaline on geochemical grounds (Jensen Cation Plot -Figure 28), could not be distinguished from the tholeiitic andesite in the field.

Volcaniclastic deposits tend to be more common towards the ends of the lava units. These deposits consist of flow breccia and tuffaceous sediment (siltstone and fine-grained quartz wacke), but may also include ~~tuff~~ breccia and crystal tuff.

Several, white weathering dikes, 1 - 10 m wide, are exposed intruding tholeiites, 300-500 m below the Salve Lake band at about the same

stratigraphic level as the Munro Township band. The dikes appear identical to the massive rhyolite flows and could be mistaken for flows if they did not cross-cut the stratigraphy by 10-35 %. Some of the dikes display marginal fine flow bands which parallel the contacts of the dike. These are suspected as being part of a series of feeder dikes from which the calc-alkaline lavas extruded.

7.3 Geochemistry of calc-alkaline volcanic rocks

Analysis of rock samples from calc-alkaline flows belonging to both calc-alkaline lava units were projected of a Jensen Cation Diagram (Figure 28) seven analyses confirm the calc-alkaline composition of the flows.

In addition, the analysis of two sedimentary rocks from interflow sedimentary units in north-central Munro Township are plotted. The rocks sampled were white-weathering, finely-bedded to laminated siltstones which are suspected to have originally had a high felsic ash content (see Plate 7). The fact that these tuffaceous sediments have an intermediate to felsic, calc-alkaline bulk composition helps support the hypothesis that tephra from calc-alkaline volcanic activity was being continually introduced during the deposition of the area's volcanic and sedimentary rocks. Since this represents the analyses of sedimentary rocks, geochemistry cannot be relied on to prove this hypothesis.

The existence of calc-alkaline basalts in the study area is uncertain. The three analyses which project into this field of the Jensen Cation Plot (open boxes, Figure 28) are from pillowed, variolitic flows from an outcrop group immediately southwest of Warden Hill. The analyses are suspect because of the presence of varioles. Varioles and the matrix within which they are enclosed, should be analysed separately to judge whether or not the varioles represent domains of alumina enrichment

FIGURE 28. Projections of the chemical analyses of the calc-alkaline volcanic rocks.

which would bias analysis.

7.4 Models for the eruption of calc-alkaline magmas

Since the intercalated calc-alkaline lavas are situated at a stratigraphic level within a few hundred metres below the base of the first komatiitic lava succession, the calc-alkaline lava eruptions occurred shortly before the onset of komatiitic volcanism, a period of extensional tectonics producing rift zones (see Chapter 6). Since there are no modern examples of calc-alkaline rhyolite erupting in mid-oceanic rift zones, questions are raised concerning unique forms of magma genesis. This is beyond the scope of this thesis, but two models, one a modification of the 'megacauldron' theory of Jensen and Langford (1983), are suggested in the interests of further research.

7.4.1 The megacauldron theory (Table 6, Figure 29)

In a model for the evolution of the Abitibi Belt, Jensen and Langford (1983) have proposed that calc-alkaline magmas in the Abitibi Belt were produced by the partial melting of eclogites derived from the conversion, within a large mantle diapir or 'megacauldron', of mafic and ultramafic rocks, drawn down to depth by subsidence and vertical folding and faulting. This is the third stage of a four stage cycle preceded by the initial extrusion of the komatiitic lavas from mantle diapirs and the later extrusion tholeiitic lavas, representing a fractionated magma, and followed by the generation of granitic melts generated from the partial melting of 'eclogized' calc-alkaline volcanic and sedimentary rocks formed during the third stage (Figure 29). In the Kirkland Lake area, the Upper and Lower Supergroups and the two generations of granitic rocks (first generation; Lake Abitibi, Round Lake, and Watabeag Batholiths, second generation; Flavrian Pluton) are each thought to represent a separate three stage cycle, combining the first and second

Figure 29. Diagram displaying the transformation of simatic crust into sialic in a primary megacauldron: A. the eruption of komatiitic magmas from a rising mantle diapir, B. the sinking of the volcanic rocks and the eruption of tholeiitic magmas; C. the partial melting of eclogized metavolcanics to produce calc-alkalic magmas; D. the partial melting of eclogized calc-alkalic volcanic rocks to form trondhjemitic magmas. (after Jensen and Langford, 1983)

stages shown in Figure 29 (Table 6).

Although these authors assumed that the first megacauldron completed its volcanic cycle before the development of the second megacauldron, bimodal volcanism may indicate that the second mantle diapir rose adjacent to the first megacauldron towards the end of its second stage of volcanism, at a time when calc-alkaline magma bodies were still rising through the crust. Megacauldrons, overlapping both in time and spatially, have been considered by Jensen and Langford (1983) to have been a factor in the formation of other greenstone belts.

7.4.2 Localized, high-level partial melting

Ultramafic magma is thought to have been hot enough to melt country rock as it reached the surface (Huppert et al., 1984), so it is possible that these intrusions could have produced partial melting and the generation of magmas at shallow levels in the crust. Since the Porcupine Group sedimentary rocks have a composition which reflects their derivation from the Hunter Mine Group rocks, the partial melting of these rocks could have produced a calc-alkaline magma. In the study area, ultramafic diapirs (Arndt, 1975) which are thought to have fed the komatiitic lava eruptions would have passed into the Porcupine Group strata. Since the calc-alkaline rocks are only between 200 and 700 m below the lower contact of the first komatiitic lava succession, the calc-alkaline magmas reached the surface only a short time before the ultramafic magma. The time lag may simply be due to the greater relative density of the ultramafic magma and perhaps, a delay in the development of normal faults and fractures which were aiding the rise of the magma at the start of a rifting event.

This process, being localized, would not likely have produced large

TABLE 6: THE KIRKLAND LAKE MEGACAULDRONS OF THE ABITIBI BELT.

Stage 1: Extrusion of komatiitic and tholeiitic lavas from the mantle.

Upper Supergroup: Stoughton - Rouquemaure, Harder Lake, Lower Formation of the Tisdale and Kinojevis Groups.

Lower Supergroups: Wabewawa and Catherine Groups and Lower Formation of Deloro Group. As well, komatiitic and tholeiitic lavas are assumed to have existed in basal parts of the volcanic piles represented by the Hunter Mine Group and Pacaud Tuffs.

Stage 2: Development of calc-alkalic volcanic rocks from the partial melting of "eclogized" komatiitic and tholeiitic volcanic rocks.

Upper Supergroup: Blake River Group.

Lower Supergroups: Skead and Hunter Mine Groups and Pacaud Tuffs.

Stage 3: Generation of granitic rocks from the partial melting of "eclogized" calc-alkalic volcanic and sedimentary rocks.

Upper Supergroup: Flavrian Pluton.

Lower Supergroups: Lake Abitibi, Round Lake, and Watabeag Batholiths, and many granitic stocks and dikes.

(after Jensen and Langford, 1983)

volumes of calc-alkaline magma. This may be why such lavas are not found elsewhere in the Stoughton-Roquemaure Group, combined with the fact that the generation of the magma may require a unique set of conditions; a thick, water-saturated stratum of sediments with a proper composition, and an ultramafic magma body to intrude it at a shallow enough depth.

7.4.3 Concluding statement

Any model which is proposed for the development of this part of the Abitibi Belt will have to address the issue of why calc-alkalic lavas occur within the Stoughton-Roquemaure Group in Beatty and Munro Townships. The generation of these lavas may be due to strictly local, high-level magmatic processes or involve much broader-scale magmatic processes affecting the evolution of the Archean crust.

4

Plate 47. Flow banded rhyolite from the calc-alkaline lava flow in southwest Munro Township. Convelute flow bands are defined by strings of white spherulites.

Plate 48. Lenses of white, massive rhyolite enclosed by dark gray dacite, calc-alkaline lava band in central Beatty Township.

Chapter 8: Major Sills

8.1 Introduction

The major sills of the study area are the Munro and Munro-Lake Sills and the Painkiller Lake Complex. These shallow-level, mafic to ultramafic layered intrusions are of interest because they collectively represent a broad range of rock types and display structures which suggest syn-magmatic tectonism.

8.2 Munro Sill

The Munro Sill is a dominantly ultramafic, mafic to ultramafic layered sill exposed in a few small outcrops close to the Beatty/Munro Township border and along the edges of two water-filled open pits in the former Munro Mine site (see Munro Township map). Much of the information about the petrology of the intrusion had to be gathered from studies by Hendry (1951) and Freeman (1954) during a time period when the mine was still operating and exposure was better.

In the area of the largest pit, 'A' pit, the intrusion was described as being 900 feet thick, consisting of an approximately 100 foot thick, medium- to coarse-grained gabbro layer underlain by a thin, discontinuous layer of medium- to coarse-grained pyroxenite, a 500 foot thick peridotite/dunite cumulate zone and a basal layer, approximately 5 feet thick, of pyroxenite. The lower edge of the intrusion contains a 20 m wide xenolith of metabasalt, which is still exposed at the southwestern edge of the 'A' pit, and which was originally mapped as a metasomatically altered dacite by Freeman (1954). Small lenses of pyroxenite occur in the dunite between this block and the base of the intrusion. The pyroxenes found in the pyroxenite are pigeonite, augite and enstatite (largely altered to serpentine).

According to Freeman (1954), the gabbro grades into feldspathic pyroxenite along strike, and contains lenses of pyroxenite. How much of the complex was originally ultramafic was difficult to ascertain due to the intensity of serpentinization. The model composition for a gabbro sample is; 37 per cent pigeonite, augite and enstatite, 51 per cent plagioclase-An₃₅ (mainly replaced by zoisite and albite), 9 per cent amphibole, and 0.5 per cent interstitial micropegmatite and sphene (Freeman, 1954).

The clinopyroxenite base, the peridotite/dunite layer and the pyroxenite layer grading into the gabbro layer of the Munro Sill are exposed around the edge of the 'B' pit, situated immediately north of the western edge of the 'A' pit. Wicks et al. (1984) noted the similarity between this occurrence, simply referred to as the Munro-Beatty Komatiite, and Fred's Flow. Compared to Fred's Flow, the cumulate layer of the Munro Sill here is slightly more olivine-rich and the upper portion lacks a spinifex zone; however the general chemical composition is similar, and there are some notably elongate clinopyroxene crystals in the gabbro portion which, although not representing spinifex, could indicate rapid cooling at the top of a flow of very shallow sill. Pyroxene content increases towards the top of the gabbro layer and it is here that elongate and slightly bent crystals are most common. Skeletal clinopyroxene also occurs in the basal layer and in portions of the olivine cumulate layer. A fine brecciation was observed along the upper contact of the gabbro beneath the brecciated flow base of an overlying lava flow. Wicks et al. (1984) could not conclude whether or not the layered body was a flow or a sill from these features.

If the Munro Sill is in fact a thick, komatiitic layered flow, it would be a particularly complex body. First of all, it is stratigraphi-

cally below the start of the first komatiitic lava succession separated by some 200-300 m of tholeiitic lavas. Secondly, a north-trending peridotite dike extending from the intrusion intrudes the overlying strata, including the base of Dee's Flow, at the west Munro Township border. In addition, the abrupt changes in the thickness of the body along strike would more likely support a model of multiple intrusions. The body is about 200 m thick in the 'B' pit area and between 400 m and 500 m thick north of the former Barton Creek asbestos mine, close to the east Beatty Township border. In this latter area, the complex appears to consist entirely of massive peridotite and dunite and, based on the distribution of a small number of peridotite outcrops, discordancy with the surrounding strata is indicated.

Small blebs of interstitial micropegmatite occur in the pyroxenite of a thin (<50 m), layered, gabbro/pyroxenite body which is separated from the sill by a thin layer of mafic lavas and flow breccia at the northern edge of the 'A' pit. Since micropegmatite is also found within the gabbro of the Munro Sill, Freeman (1954) concluded that this intrusion represented a felsic differentiate derived from the Munro Sill and emplaced stratigraphically above the sill as a separate pyroxenite/gabbro sill. In contrast, Satterly (1952a) interpreted the gabbroic rock to be extrusive. Mapping performed in this study suggests that the rock marks the easternmost exposure of a tholeiitic layered flow. It is possible that this layered flow could have extruded from the pyroxenite/gabbro sill described by Freeman (1954) from the 'A' pit.

The pyroxenite/gabbro intrusion may represent the eastern end of a 75 m thick peridotite-pyroxenite-gabbro flow or sill sinistrally displaced by a north-south fault. The upper contact of this layered intrusion is

not exposed at its westernmost exposure northeast of the Barton Creek Mine. Minor brecciation at the upper contact of the intrusion exposed in the Munro Mine area, suggests that its eastern end is extrusive. Drill core data between the two outcrops verify its position, but are not specific enough to define the true nature of the layered body. In fact, drill core logs show that this layered body and the Munro sill merge smoothly with no distinction between the cumulate portion of the former and the ultramafic rocks of the latter within this interval. Satterly (1952a) interpreted the mafic and ultramafic rocks intersected in these drill holes as belonging to the same intrusion, the Munro Sill. Based on what is exposed, it is estimated that less than 5 per cent of the Munro Sill consists of gabbro and leucogabbro in the form of small lenses confined to the Munro Mine area, while the layered flow/sill consists of at least 80 per cent gabbro. Even if the smaller body only tapped the upper, differentiated portion of the Munro Sill, it is questionable whether enough mafic magma would have been available to form the gabbro dominated sill/flow. If the Munro Sill feed lavas, it is more likely that they were the komatiitic lava flows located a short stratigraphic distance above the sill.

Several observations made here suggest that instead of being the complex differentiated body which early workers (Satterly, 1952a, Hendry, 1951, Freeman, 1954) have maintained, the Munro Sill is a band of layered sills and flows partially intruded by one and possibly more, semi-discordant peridotite-dunite bodies. These observations are: (i) small (<200 m) plugs of peridotite-dunite do occur intruding the strata immediately below the eastern end of the Munro Sill; (ii) large elongate ultramafic intrusions of this nature are certainly common in the region, including two peridotite-dunite bodies of 1 km and 4 km length that

intrude strata immediately below the Munro Lake Sill in McCool and Warden Townships; and (iii) the ultramafic rocks exposed close to the western end of the band apparently belong to a discordant or semi-discordant body, which is supported by their outcrop pattern and also by the presence of a peridotite dike extending from the body and intruding strata above it.

The rhythmically-layered cumulate zones of established differentiated sills in the region are characterized by well-defined clinopyroxenite and peridotite layers not characteristic of the ultramafic rocks of the Munro Sill. A unique feature of the peridotite within such differentiated sills is that small rounded crystals of olivine are poikilitically enclosed within large crystals of pyroxene. In the Munro sill peridotite, pyroxene occurs interstitial to larger equant olivine crystals.

8.3 Munro Lake Sill

The Munro Lake Sill is another mafic to ultramafic layered sill exposed in three areas around the McCool Hill Syncline (see Munro Township and Regional Geology maps). In north-central Munro Township and the bordering edge of Warden Township it is known as the Munro-Warden Complex (MacRae, 1969); at McCool Hill in southern McCool Township it is known as the McCool Hill Complex (MacRae, 1969); and at Centre Hill close to the middle of Munro Township, it is referred to as the Centre Hill Complex (MacRae, 1969). From its westernmost terminus on the north limb of the McCool Hill Syncline in southwest Warden Township to the fold closure at McCool Hill, the sill has a strike length of approximately 12 km. Over most of its extent the sill is about 500 m thick, thinning to 475 m at its western end on the south limb (Centre Hill) and on the north limb, to 400 m in southwest Warden Township and abrupt-

ly thickening to approximately 600 m in north-central Munro Township.

Apart from north-central Munro Township, where the upper 200 m of the complex is taken up by a leucogabbro not seen elsewhere in the sill, the upper half of the sill consists of a fine- to medium-grained gabbro. The lower cumulate portion is characterized by alternating layers of medium-grained clinopyroxenite and medium- to coarse-grained peridotite. Although not all layers are laterally continuous, both the northern and southern limb exposures display at least seven cyclic units (see Figures 30 and 31): five consisting of peridotite (pd) and clinopyroxenite (cpx) layers, the sixth consisting of clinopyroxenite and gabbro (gb), and the seventh defined by a melanogabbro (mgb) layer of a few meters thickness grading into the upper gabbro portion in the sill. The rocks of the last two cycles, marking the transition zone between the ultramafic and mafic halves of the sill, are commonly characterized by small-scale (<3 cm) rhythmic layering (see Plate 49). Clinopyroxenite layers vary in thickness from less than a meter to about 27 meters, and peridotite layers vary from less than a meter to over 35 meters, tending to be thicker in the sill's northernmost exposure. The layering is the result of the interruption of normal gravitational settling of heavier minerals by periodic injections of new magma. Evidence of such current action is given by the preferential orientation, parallel to layering, of plagioclase laths in the gabbro bands of the transition zone.

The clinopyroxenite weathers to a light gray-green colour, whereas the weathered colour of the gabbro is medium to light gray-green or light reddish-gray, depending on the orthopyroxene content of the rock. Groupings of orthopyroxene crystals (partially replaced by hornblende and iron-rich chlorite) impart a reddish pattern to some portions of the gabbro consisting of short curving lines, irregular patches and occa-

Warden-Munro Section

FIG. 31. Stratigraphic correlation diagram between Warden-Munro and Centre Hill sections of the Munro Lake sill. (modified after MacRae, 1969)

sionally dendritic forms. The peridotite is a black rock which weathers to a dark brown colour, with the exception of hornblende peridotite which has a reddish brown weathered colour. Hornblende peridotite is found at the base of the sill at the Centre Hill exposure and towards the middle of the sill's cumulate portion in north-central Munro Township (see Figure 30).

The exposure in north-central Munro Township and the adjacent edge of Warden Township is the most anomalous section of the sill. The fine- to medium-grained leucogabbro at the top of the complex is almost a separate intrusive body since it is separated for much of its extent by up to 20 m of sedimentary country rock. The layer of country rock is truncated in places by protrusions of the leucogabbro and in one location, a section of the layer may be detached within the upper margin of the gabbro as evidenced by the absence of an upper chilled contact next to the sedimentary rock. The sedimentary rock, consisting of pyritiferous chert, light gray or white weathering fine-grained wacke, and finely-bedded to laminated tuffaceous and silicic siltstone, also occurs as xenoliths within the leucogabbro. The xenoliths are arranged in two strings: one located several meters above the base of the intrusion composed of blocks picked up from the underlying layer of country rock, and the other situated immediately below the upper contact of the complex, consisting of fragments derived from a thin succession of similar sedimentary rocks overlying the sill.

The overall thickening of the sill, aside from the approximately 200 m leucogabbro portion at this location, is largely attributable to the addition of more cumulate layers and the thickening of the lowermost peridotite layer.

The small portion of the Munro Lake Sill south of the gabbro

intruding the Warden Hill Fault (see Munro Township map) and west of the Hedman Mine road is represented by small scattered outcrops of gabbro, leuogabbro and minor pyroxenite and peridotite. The correlation of layering is not possible here due to the lack of continuous exposure and it is suspected from the irregular distribution of gabbro in the area that a discordant gabbro body is intruding the sill. As mentioned in section 4.4 of the stratigraphy chapter, this portion of the sill has intruded at a slightly higher stratigraphic level. The intrusive rock here may represent a branch of the Munro Lake Sill which intruded strata immediately above the main body of the sill to extrude laterally westward into Theo's Flow. Almost immediately above this stratigraphic horizon, northwest of Munro Lake, a diamond drill hole intersects with gabbro underlain by peridotite and then country rock. If this is another related layered sill, this stratigraphic section south of the Warden Hill Fault may represent a point where the Munro Lake Sill was beginning to thicken by branching into successively higher strata.

The overall composition of the sill was judged by MacRae (1969) to be that of a tholeiitic basalt. It would be expected that the basal contact layer, if it represents the first formed liquid of the intrusion, should consist of pyroxene and plagioclase rather than hornblende. MacRae (1969) attributed the presence of hornblende to the addition of water from the country rock during emplacement. From its mafic lower contact, the basal layer shows a marked increase in olivine content upward, indicating the early crystallization of olivine. The mineralogy of the main rock types in the Munro Lake Sill at Centre-Hill is presented in Figure 30 and Table 7.

Table 7: Petrological Summary for the Munro Lake Sill (Centre Hill Complex)

<u>Rock Type</u>	<u>Description (summarized from MacRae, 1969)</u>
<u>Gabbro</u>	Subhedral prismatic grains of clinopyroxene (25-50%) orthopyroxene (0-15%), and broad laths of plagioclase (30-40%) in a matrix intergrown clinopyroxene, andesine, plagioclase, quartz and chlorite. The pyroxene is usually mantled by fibrous amphibole and chlorite or by fibrous iddingsite. Plagioclase laths are often saussuritized. Iron sulfide content, including magnetite, ilmeno-magnetite and ilmenite, is as high as 5 %. Texture: subophitic becoming ophitic in patches where quartz becomes more abundant and plagioclase laths are more elongate.
<u>Clinopyroxenite</u>	Subhedral prismatic grains of clinopyroxenite variably altered to tremolite and hornblende. Minor constituents; interstitial (postcumulus) plagioclase and, close to the peridotite contacts, cumulate olivine. The reaction between pyroxene and interstitial plagioclase has formed light green clots of amphibole and chlorite. The proportion of these aggregates increases upsection making the rock higher in the sill a lighter green colour than what is found lower down.
<u>Peridotite</u>	Subhedral to euhedral clinopyroxene grains poikilitically enclosing rounded equant grains of cumulate olivine. Olivine is usually completely replaced by serpentine magnetite and chlorite and occasionally by tremolite Clinopyroxenite crystals are fringed by tremolite or in the case of the uppermost layer, a combination of tremolite and hornblende. The hornblende peridotite consists of primary hornblende, partially altered to actinolite, poikilitically enclosing rounded grains of olivine which are altered to serpentine, magnetite and tremolite-actinolite.

8.3.2 Evidence of synmagmatic tectonism

At the thickest point in the Munro Lake Sill, along the north-central Munro Township border, the cumulate layering is disrupted in a variety of ways. Current action during the emplacement of the sill is evidenced by an interfingering of peridotite and clinopyroxenite layers and by some scoured and fragmented cumulate layers. Tectonic disruption prior to the consolidation of the intrusion is indicated by: (i) detached fragments of peridotite, clinopyroxenite and gabbro, (ii) places where clinopyroxenite has been forced to flow plastically up into fractures in the gabbro, and (iii) minor slump folds and cross-laminated bands caused by local slumping (see Plate 50). MacRae (1969) attributed all the cases of disrupted layering to 'local slumping of the igneous sediments in response to slight tectonic adjustments in the area'. The best evidence for synmagmatic tectonism described by MacRae (1969) was a place where tongues of massive clinopyroxenite had plastically intruded fractures opened up in a gabbro layer and caused detachment of gabbro blocks towards the base of the layer and the disruption of primary textures higher up.

8.4 Painkiller Lake Complex

The intrusive complex exposed in an outcrop group situated between Painkiller Lake and the north-central Beatty Township border contains lithologies similar to the Munro Lake Sill; however, the internal arrangement of the sill is entirely different. Aeromagnetic data (see Figure 13) indicate that the surface expression of the body is elliptical, with the longest axis (approx. 3 km) oriented parallel to bedding. It has an apparent thickness of 600 m at its thickest point within the outcrop area, but with the axial surface trace of the McCool Hill Syncline located along the southern edge of the sill and the dip of the

bedding progressively shallowing from 70°S to 45°S, towards the southern edge of the intrusion, it is estimated that the sill is approximately 500 m thick in its central region, similar to the average thickness of the Munro Lake Sill.

Clinopyroxenite is the dominant rock type, making up approximately 75 % of the exposed rock, and followed by peridotite (15 %), feldspathic pyroxenite (5 %) and gabbro (5 %). A petrological study was conducted on rocks sampled from this sill (Chivers, 1984), and this is summarized as follows:

▲ The pyroxenite is generally light to dark green and fine- to medium-grained. It consists of subhedral to euhedral prismatic augite marginally altered to actinolite, tremolite, hornblende and chlorite. Interstitial plagioclase, when present, occurs within the range An_{41} to An_{65} . The peridotite once again consists of clinopyroxene poikilitically enclosing rounded grains of olivine. The clinopyroxene is completely altered to tremolite, and, to a lesser degree, actinolite, whereas the olivine is replaced by serpentine, iddingsite and magnetite. Tremolite, magnetite and talc occupy interstitial areas. The olivine content of the peridotite was estimated by Chivers (1984) to have been about 60 per cent, similar to that of the Munro Lake Sill peridotite. In fact the lithologies are similar to those found in the Munro Lake Sill.

The distribution of pyroxenite and peridotite is extremely irregular in the complex and continuous cyclic units cannot be clearly defined. The sill has a discontinuous basal peridotite layer up to 50 m thick along an irregular lower contact. The first olivine cumulate appears to have preferentially settled into two low points a kilometer apart at the base of the sill. A fine-grained clinopyroxenite occupies the basal

zone between the two peridotite lenses. .

Peridotite also occurs as a large lens 40-100 m above the base of the sill enclosed by clinopyroxenite. The lens is approximately 500 m long and is 90 m thick at its thickest point, the eastern end. Laterally the peridotite interfingers with the pyroxenite but only the western extension of the lens is exposed. Eastward the unit swings 25 degrees to the southwest as it thins out. In one location the peridotite hosts fragments of clinopyroxenite up to 2 m long and a lens or large block of clinopyroxenite approximately 70 m long and 20-30 m thick. The basal contact of the peridotite lens is sharp, whereas the upper contact is gradational over several centimetres.

A more typical peridotite layer, 3-5 m thick, is situated 20-60 m above the lens. It can be traced for approximately 600 m east and then east-northeast from the center of the outcrop group. The westernmost occurrence of peridotite is the end of the peridotite lense and a small pod a few meters thick immediately below it. The general increase in the amount of peridotite eastward as well as a large magnetic anomaly over the unexposed eastern half of the sill suggests that the main cumulate portion of the sill underlies this area.

The clinopyroxenite is fairly homogenous over most of the outcrop group with only a trace of compositional banding in places. Irregular lenses of feldspathic pyroxenite and pegmatitic patches occur within the upper 200 m of the sill, and lenses and thin layers of gabbro appear at the western edge of the outcrop group. Further west a fine- to medium-grained gabbro is exposed in a small outcrop and it is most likely, since gabbro is found at the western edge of the main outcrop group, that this gabbro represents the differentiated portion of the sill rather than a separate intrusion.

8.4.2 Evidence of synmagmatic tectonism

The unusual distribution of layering within the Painkiller Lake Sill represents a much more extreme example of pre-solidification disruption than the disrupted layering of the Munro Lake Sill. Irregular layering, to a minor degree, could be structural considering the proximity of the intrusion to the axis of a major fold (McCool Hill Syncline) and the uncertain effects of north-south and east-west faults obscured by sets of Matachewan diabase and feldspar porphyry dikes, respectively. Differential erosion at the top of the sill prior to the deposition of overlying strata could be used to explain why there is only a small area of ~~gabbro~~ at one end of the body, but this is not viable since all the exposed contacts of the sill are chilled. Synmagmatic tectonism was most likely responsible for the fragmentation of layers and the off-set of the gabbro portion of the sill relative to the cumulate zone. This arrangement might be expected if the sill was suddenly tilted up at its western end before the magma had completely solidified. Under the force of gravity, cumulate material not yet consolidated would shift east disrupting layering and perhaps brecciating lower, more cohesive clinopyroxenite. Then, less dense mafic differentiate would have migrated west to replace the cumulate material.

The Painkiller Lake Sill is not the only example of a layered sill with a western off-set to its gabbro portion. A sill, possessing similar rock types, is exposed 20 km to the west in Dondonald Township which displays a western thickening of its gabbro portion at the expense of its corresponding thinning of its cumulate layer. Naldrett and Mason (1968) interpreted this arrangement to the progressive migration of residual sill magma during the crystallization of the pyroxenite portion

of the sill. Continued 'on-lap' to the west and 'off-lap' to the east at successively higher levels in the gabbro horizon is used as evidence that this migration continued at a reduced rate until the end of crystal settling. A similar migration of differentiated material may have also occurred in the Painkiller Lake Sill to produce one end of the sill which is dominated by gabbro and the other dominated by peridotite and clinopyroxenite. However, the deformed and fragmented layering also suggests that the movement of liquid involved most of the intrusion and thus was likely related to tectonic instability.

8.5 Summary

The largely unexposed Munro Sill may represent a band of layered sills and flows intruded by either one and possibly more, semi-discordant peridotite-dunite intrusions or a large, dominantly ultramafic, layered sill. In either case, it is possible that the intrusion or intrusions feed komatiitic lavas of the first komatiitic lava succession.

The Munro Lake Sill and the Painkiller Lake Complex have very similar rock types and it is possible that they tapped the same magmas, but the Painkiller Lake Complex has an extremely irregular distribution of rock types which is believed to be largely due to syn-magmatic disruption. It is also suggested that syn-magmatic tectonism effected the Munro Lake Sill on the north limb of the McCool Hill syncline, but here it is only represented by slump folds and fragmented and cross-laminated cumulate layers.

Plate 49. Discontinuous clinopyroxenite layers (light gray) in peridotite (black), Munro Lake Sill, south-central Warden Township.

Plate 50. Rhythmic gabbro (white), leucogabbro (dark gray) and clinopyroxenite (black) layering, Munro Lake Sill, Centre Hill.

Chapter 9: A Depositional Model

The observations and interpretations presented in the preceding chapters dealing with stratigraphy, geochemistry, tholeiites, komatiites, calc-alkaline lavas, and layered sills can be synthesized into the following model for the deposition of the Stoughton-Roquemaure and Porcupine Groups in Beatty and Munro Township area.

Stage 1 (Figure 32 A)

Mafic lavas erupting from broadly spaced volcanic centers build a submarine lava plain adjacent to one or more active calc-alkaline volcanic complexes.

Stage 2 (Figure 32 B)

Loading of the Stoughton-Roquemaure Group lavas leads to subsidence south of the relatively more buoyant felsic volcanic rock areas. A basin develops into which detritus largely derived from the erosion of calc-alkaline volcanic rock was being deposited, expands eastward into the region broadening the distribution of the deep-water Porcupine Group sediments. During this period the rate of mafic volcanic eruption was reduced and the area of lava deposition was limited. Volcanic eruptions were rare or absent in the deepest parts of the basin. Sub-aerial calc-alkaline volcanic eruptions provided a continuing supply of fine tephra for mixing with the sea-floor sediments.

Stage 3 (Figure 32 C)

A general increase in the rate and distribution of volcanic eruptions (including calc-alkalic volcanism) along an evolving east-west fissure system causes a sharp reduction in the amount of interflow sediments and an onlap of the Porcupine Group strata by Fe-rich tholeiitic basalts. An elongate east-west basin, separated from the main area of

→N

FIG. 32A.

FIG. 32B.

FIG. 32C

FIGURE 32: Depositional model for the Stoughton-Roquemaure Group.

subsidence to the south (developing Blake River Synclinorium) by a parallel horst or antiformal structure, marks the first stage in the development of the McCool Hill Syncline.

Stage 4 (Figure 32 D)

Continued tensional fracturing and the rise of dikes expands the rift system. Ultramafic magma is allowed to reach the surface and a submarine lava plain composed dominantly of high-Mg tholeiitic basalt, basaltic komatiite and peridotitic komatiite develops. The main komatiitic lava complex is situated in the southeastern part of the area (southern Munro Township). Graben structures formed by the rifting promote the formation of ponded flows. Many, if not all, komatiitic lavas erupt either directly from shallow-level sills or from feeder dikes intruding subvertical faults and fractures. The Munro Sill and many other smaller sills are emplaced during this period.

Small volumes of Fe-rich tholeiitic basalt continue to erupt but the eruptions are not widespread or numerous.

Stage 5 (Figure 32 E)

Komatiitic volcanism, dominated by basaltic komatiites, dies out in the east and sporadically re-occurs in the west. A thick tholeiitic basalt lava plain builds with most lavas flowing south from an east-west fissure system. Volcanic activity was not as widespread along the northern edge of the basin and this allowed for local deposits of interflow sediment to form within any grabens found there. Distant sub-aerial calc-alkaline volcanic activity continues to provide felsic ash for the sediments.

Stage 6 (Figures 32 F and G)

The Munro Lake and Painkiller Lake Sills, tapping a common magma body, are emplaced and Theo's Flow is extruded from the Munro Lake Sill.

FIG. 32D

FIG. 32E

FIG. 32F

The deposition of Theo's Flow occurred at the start of a second period of east-west rifting which again allowed for the rise of komatiitic magma(s) and extrusion of basaltic and peridotitic komatiites with deposition concentrated within rift valleys. Some of this normal fault development may have been associated with the initiation of vertical motions along the north branch of the Destor-Porcupine Fault Zone.

Most of the komatiitic lavas were again deposited in the eastern part of the area and it was there that the last sporadic basaltic komatiite lava eruptions occurred at the close of komatiitic volcanism. The initial lavas, including Fred's Flow, flowed north, possibly from a fissure system concentrated along the southern edge of a fault-bounded valley. Fred's Flow flooded the valley floor and ponded between the fault scarps.

FIG. 32G

Chapter 10: Summary

10.1 Introduction

Ultramafic to felsic volcanic and subvolcanic rocks of komatiitic, tholeiitic, and calc-alkaline geochemical affinities (Stoughton-Roquemaure, Kinojevis and Hunter Mine Groups) underlie most of Beatty and Munro Townships and the townships immediately surrounding the study area (i.e. Carr, Coulson, Warden, McCool, Guibord and Hislop Townships). Together with another sedimentary unit (Porcupine Group), these rocks represent the westward continuation of a stratigraphy which has been defined and well documented by Jensen and Langford (1983) and Dimroth et al. (1982) in the south-central Abitibi Belt to the east. It has been possible here to map out and describe eight relatively well exposed sections of the stratigraphy in this study area (Chapter 4) which are summarized briefly below.

Because the lithological and geochemical characteristics, origin and tectonic setting of the komatiitic rocks in Munro and Beatty Townships are of potential interest of students of Archean petrogenesis worldwide, much of this thesis has focussed on the komatiites, as well as the associated tholeiites (Chapters 5 and 6).

Internal textures, fabrics and cross-cutting relationships of some of the rocks described, as well as field relations noted among different rock types, suggest mode of emplacement or synvolcanic setting. With timing relationships either deduced from field relationships, or assumed on the grounds, these features assist in envisaging a tentative model for the development of this segment of the Abitibi Belt (Chapter 10), which can be modified when more information (eg. isotopic dating, additional exposures) become available.

The major results of this study are summarized below.

10.2 Summary of stratigraphy

The stratigraphy defined by Jensen and Langford (1983) to the east can validly be extended into the map area. Both the Stoughton-Roquemaure and Porcupine Groups are represented in Beatty and Munro Townships as well as some calc-alkaline volcanic rock which may be related to Hunter Mine Group volcanism. The Stoughton-Roquemaure Group, the predominant unit in the area, consists largely of subaqueous, medial to Fe-rich and Mg-rich tholeiites and to a lesser extent, peridotitic and basaltic komatiites, rare interflow sediments and intercalated calc-alkaline lavas.

Approximately 8-9 km of volcanic and sedimentary strata, underlying three quarters of the study area, is represented in a north facing succession between the west-trending Destor-Porcupine Fault Zone and the axis of the McCool Hill Syncline, a tight, upright fold with a west- to west-northwest striking, steeply south-dipping axial plane. The southern limb of the McCool Hill Syncline is truncated by the sub-vertically dipping Destor-Porcupine Fault Zone, and disrupted by minor parallel-trending, upright isoclinal folds on both limbs of the syncline and in its axial region. The only faults which significantly disrupt the stratigraphy are the east-trending Axis and Warden Hill Faults on the north limb of the McCool Hill Syncline, the Axis Fault reducing the north limb stratigraphic section by at least 100 m and the Warden Hill Fault increasing the section by approximately 900 m.

The stratigraphy on the south limb of the McCool Hill Syncline in Munro Township consists of two tholeiitic lava successions: the first, 1.5 - 2.0 km thick and largely consisting of marginal to high-Fe tholeiites, is underlain conformably by medial to distal turbidites of

the Porcupine Group and separated from the second succession by a 1.0 - 1.2 km thick, komatiitic lava succession. The second tholeiitic lava succession is approximately 3 km thick, and dominantly consists of Mg-rich tholeiites. An approximately 500 m thick succession of komatiitic lavas cores the McCool Hill Syncline. Both komatiitic lava successions contain peridotitic and basaltic komatiites and minor intercalated tholeiites. A thick, layered basaltic komatiite flow, Fred's Flow, marks the base of the second komatiitic succession. The first komatiitic lava succession thins out at the west Munro Township border and the second grades westward into tholeiites (dominantly Mg-rich tholeiites) in northeast Beatty Township.

A structural/depositional angular unconformity is found along the upper contact of the Porcupine Group in Beatty Township and the group thickens from 2 km in Munro and Guibord Townships to over 3.5 km in western Beatty Township, with a corresponding thinning of the overlying volcanic succession. An interval, approximately 200 m thick, of mafic and possibly felsic Stoughton-Roquemaure Group tholeiites occurs between the base of the Porcupine Group in southwest Beatty Township and the Destor-Porcupine Fault Zone, which marks the start of a south-facing succession beginning with the uppermost strata of the Stoughton-Roquemaure Group. The komatiitic lavas in the volcanic succession of Beatty Township occur in only a few thin lenses, largely intercalated with Mg-rich tholeiites. Of these, only one shares the same stratigraphic horizon as the komatiitic lavas of southern Munro Township.

One or more ultramafic sills intrudes the strata immediately underlying every komatiitic lava succession which contains peridotite

komatiites. The largest and most complex of these shallow-level sills is the Munro Sill which consists of either: (i) a series of ultramafic sill-like bodies intruding an interval containing layered sills and flows; or (ii) one large sill, with a semi-discordant western end and a partially differentiated eastern end containing lenses of gabbro and pyroxenite. The largest sill in the area is the Munro Lake Sill in northern Munro Township, a shallow-level layered sill extending to both limbs of the McCool Hill Syncline and consisting of peridotite, clinopyroxenite, gabbro and leucogabbro. The maximum thickness of the sill is approximately 900 m. at a point on the north limb of the syncline, where the sill thickens by intruding successively higher strata. The smaller, layered Painkiller Lake Complex in north-central Beatty Township is dominated by clinopyroxenite, but also contains irregularly distributed peridotite, gabbro and leucogabbro.

The first tholeiitic lava succession in central Beatty and southwest Munro Township contains two thin lenses of calc-alkalic rhyolite and dacite, intercalated with tholeiitic basalt, andesite and possibly rhyolite. Thin porphyritic dikes intruding the strata underlying the lens in Beatty Township, are thought to be part of a series of dikes which feed the calc-alkaline lavas. The rhyolite in the Beatty Township lens has yielded an U-Pb zircon age of 2714 ± 2 Ma. (S. Marmont, personal communication, 1986), thus indicating an age for the Stoughton-Roquemaure Group.

Interflow sedimentary units which largely consist of chert, argillite, fine-grained arenite, and tuffaceous and siliceous siltstone are rare within the Stoughton-Roquemaure Group assemblage, although they are much more common in volcanic strata underlying the Porcupine Group in Beatty Township, adjacent to the eastern end of the Porcupine Group

metasedimentary belt in Guibord Township and in the south facing tholeiitic lava succession in northern Munro and southern Warden Townships.

10.3 Summary of conclusions

The petrological and geochemical examination of the study area's tholeiites has indicated that a large proportion (approx. 20 %) of tholeiites have compositions intermediate between Fe-rich and Mg-rich tholeiites. Such rocks are indistinguishable in the field from the dark gray-green to black, variably magnetic Fe-tholeiites and the light gray-green Mg-rich tholeiites, as a group, possessing characteristics of both. Stratigraphically, Mg-rich tholeiites tend to be spatially associated with komatiites. Most tholeiitic flows, particularly higher in the stratigraphy, flowed either south or north with the dominant flow direction being south. It is suspected from the general lack of exposed feeder dikes that tholeiitic lavas erupted from east-west oriented fissures, or, in the case of Theo's Flow, either from short dikes or directly from high level sills.

The two thickest komatiitic lava successions, the first and second successions of Munro Township, each display an up-section increase in the portion of basaltic komatiites and intercalated Mg-rich tholeiites to peridotitic komatiites, but a volcanic cyclicity typical of the Stoughton-Roquemaure Group type section in the Lake Abitibi area to the east (i.e. peridotitic komatiite-basaltic komatiite-Mg-rich tholeiite-Fe-rich tholeiite) cannot be defined. In addition, isolated Fe-rich tholeiitic flows occur intercalated with peridotitic komatiites, and there are small isolated occurrences of either peridotitic or basaltic komatiite flows in the tholeiitic lava succession in Beatty Township.

Lack of systematic field associations suggest that the two tholeiitic magmas (Fe-rich and Mg-rich) and the two komatiitic magmas (peridotitic and basaltic) erupted independently of each other.

A unique group of Fe-rich basaltic komatiites, characterized geochemically by $\text{CaO}:\text{Al}_2\text{O}_3$ ratios lower than typical other basaltic komatiites, were identified in the study area. They have not been reported elsewhere in the region. In addition, komatiites with MgO contents ranging from 10 to 20 per cent were identified which had anomalous $\text{CaO}:\text{Al}_2\text{O}_3$ ratios of between 1.6 and 1.95.

Based on the large number of thick, ponded flows with excessive east-west strike lengths and the predominance of northerly and southerly flow directions for the flows, it is suggested that komatiite lavas and possibly lavas were deposited in rift valleys along with lavas of the second tholeiitic lava succession. Feeder dikes are also absent from the komatiitic lava successions, and it is suggested that these lavas were fed from east-west dikes and from short dikes branching from shallow-level magma chambers or sills. The intrusive-extrusive relationship is illustrated by an ultramafic sill to peridotitic komatiite flow transition is found at the Maude Lake Gold Mines Ltd. property in northwest Beatty Township. The large proportion of peridotitic komatiite flows with thick spinifex and cumulate zones ('A' and 'A-B' type flows) throughout the komatiitic lava successions indicates: (i) the proximal nature of source vents relative to most of the komatiitic flows and, (ii) that the locations of these vents were fixed during the deposition of the lava successions.

Tectonism within the rift zone produced disrupted layering in the Munro Lake Sill and the Painkiller Lake Complex and possibly initiated lava remobilization within Fred's Flow on the north limb of the Munro

Lake Sill.

The greater proportion of interflow sediments in the volcanic succession of the McCool Hill Syncline's northern limb relative to that of the southern limb, suggests that the increased rate of volcanic eruptions immediately following the final deposition of the Porcupine Group within the study area, was initially higher in the area represented by the south limb succession.

It has been concluded that the Stoughton-Roquemaure Group lavas were deposited on the lower flanks or adjacent to a Hunter Mine Group calc-alkaline volcanic pile centered in Rand Township. This is based on (i) the presence of deep-water wackes and argillites in the Porcupine Group and in interflow sedimentary units within the Stoughton-Roquemaure Group, (ii) the distal nature of flank deposits constituting the western end of this Hunter Mine Group volcanic pile, disconformably underlying at the Stoughton-Roquemaure Group succession in McCool Township, and (iii) the absence of Hunter Mine Group-Stoughton-Roquemaure Group contact in the south limb succession. Intercalated calc-alkaline lavas are unique to the Stoughton-Roquemaure Group succession of the study area, suggesting that the lavas of the study area erupted earlier than the Stoughton-Roquemaure Group lavas of other areas; i.e., early enough for the succession to have included lavas related to late Hunter Mine volcanism. It is possible that the generation of calc-alkaline magma may not have been related to Hunter Mine volcanism, but the presence of felsic tuffaceous interflow sediments indicates continuing sub-aerial felsic volcanic eruptions within the region during the deposition of the Stoughton-Roquemaure Group lavas. This suggests that one or more felsic volcanic complexes of

the same age and geochemical affinity were still active.

10.4 Suggestions for further research

By describing the general geology of Beatty and Munro Township, it has been the intention of this study to re-direct research from northern Munro Township into other equally interesting areas which could expand the general knowledge of Stoughton-Roquemaure Group volcanism and, in particular, help modify theories of komatiite magma genesis and flow emplacement. The study has raised a number of issues worth further investigation.

Although lack of exposure makes a structural study of the major structures (i.e. McCool Hill Syncline, Destor-Porcupine and Munro Fault Zones) difficult, an understanding of the fracture patterns associated with the development of these structures is very important in the targeting of gold exploration efforts. Beatty, northern Hislop and Munro Townships offer the best exposures of these important structures in the region.

The variolitic lavas in the study area of komatiitic, tholeiitic, and calc-alkalic composition display a broad range of variole sizes and distribution patterns. Due to this, along with the excellent preservation of mineral textures in these rocks of low metamorphic grade, the area has a good potential for further research into the nature and genesis of varioles.

Geochemical research directed at the calc-alkaline lavas and the tholeiites enclosing them is important for two immediate reasons: (i) to see if other calc-alkaline volcanic rocks (particularly basalts and andesites) occur within the assemblage, and (ii), to see whether or not these lavas are in some way distinctive from the Hunter Mine Group rocks. Calc-alkaline rhyolite and dacite in tholeiitic and komatiitic

lava succession is a rare occurrence, and it may have significant implications to the development of evolutionary models for Archean greenstone belts.

The dating of extrusive calc-alkaline volcanic rocks in Rand Township could either confirm or refute the age equivalence of Hunter Mine volcanic pile and the calc-alkaline volcanic rocks of the Stoughton-Rouquemaure Group in the study area. In other words, depending on the relative ages, it could be determined whether or not this particular volcano was active during the eruption of the Stoughton-Rouquemaure Group.

This study has described a broad range of mineral textures, all referred to as 'spinifex', and has introduced a term 'windblown spinifex', which describes a texture thought to be caused by liquid movement during the crystallization of olivine spinifex. If there is to be any consistency in the description of komatiitic mineral textures in the literature, much more effort must be put into describing, classifying, and modeling the development of various clinopyroxene and olivine spinifex textures, particularly in the area where this process began.

Arndt and Nesbitt (1984) have presented geochemical and petrological evidence for the production of hybrid basaltic komatiite magmas in northern Munro Township by the mixing of peridotitic and basaltic komatiite magmas during extrusion. There is also evidence of komatiite-tholeiite magma mixing in one basaltic komatiite flow. Magma mixing during lava extrusion could explain why there is such a broad range of chemical compositions and mineral textures associated with basaltic komatiites, and perhaps the spatial association of basaltic komatiites with Mg-rich tholeiites (the generation of basaltic komatiite magma from

the selective mixing of komatiitic magma with Mg-rich tholeiite magma).

Another possibility is that the low $\text{CaO}:\text{Al}_2\text{O}_3$, Fe-rich basaltic komatiites

resulted from the mixing of Fe-rich tholeiite and peridotitic

magmas. The magma mixing model has some potential application in the

study area, but further detailed geochemical and petrological work is

required to investigate whether or not the broad variation in basaltic

komatiite compositions discovered in this study can be explained by the

mixing of basaltic komatiite and different tholeiite magmas with peridotitic komatiite magmas.

Although, northern Munro Township has been and continues to be an important area for research into komatiites, it is hoped that the maps, stratigraphic reconstructions, and the depositional model presented by this study will guide and promote important work in the future, involving a variety of intrusive and extrusive volcanic rocks in Beatty and Munro Township.

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Appendices

Appendix 1: A description of the Jensen Cation Plot

The Jensen Cation Plot (Jensen, 1976) has been developed to geochemically classify subalkalic volcanic rocks primarily classified on the basis of petrography. The ternary diagram (Figure 33) relates volume percentages of Al_2O_3 , $\text{FeO} + \text{Fe}_2\text{O}_3 + \text{TiO}_2$ and MgO . It's main strength over the more widely used AFM diagram is that it more clearly distinguishes between komatiitic, tholeiitic and calc-alkalic chemical trends.

On the Jensen diagram, the boundary between komatiitic and tholeiitic fields corresponds to 10 per cent MgO by weight and the boundary between the komatiitic basalt field and the ultramafic field corresponds to 20 per cent MgO by weight. The 20 per cent division is just slightly higher than that suggested by the Penrose Conference ($>18\%$ MgO), but Jensen (1976) also bases the boundary on a petrological division between komatiites where the dominant mafic mineral is olivine and the komatiitic basalts where pyroxene is the dominant mafic mineral. The

Jensen Cation Diagram also incorporates rock colour divisions, based on petrological studies in the Kirkland Lake area, which subdivide the calc-alkalic and tholeiitic fields for rocks of greenschist grade or lower.

The Jensen Cation Plot was used in this study for two reasons: it distinguishes more geochemical rock divisions and is therefore an important tool for a detailed stratigraphic study, and (ii) it was initially developed and used for the classification of subalkalic volcanic rocks in the Kirkland Lake area and therefore should be used for the sake of regional stratigraphic correlation.

Figure 33. Jensen Cation Plot involving the cation percentages of Al_2O_3 , $\text{FeO} + \text{Fe}_2\text{O}_3 + \text{TiO}_2$, and MgO

Theory and the calculation of the Jensen Cation Plot*

The Jensen Cation Plot is a simple ternary plot of the volume of Al_2O_3 , Fe_2O_3 , FeO , TiO_2 and MgO found in a given rock. The argument for using volumes rather than weights is that it is much more accurate to compare equal volumes of rock than equal weights of rock. Weight percentages cannot show the quantitative relations which petrologists want to see. Cation percentages can be used to represent volume percentages and this can be done by calculating the equivalent molecular proportions of the constituent oxides from their weight percentages (see Table 8). From the molecular proportions one can calculate 'atomic percentages' or 'cation percentages'.

Oxygen (anions) forms 90 to 95 per cent of the volume of a rock. Atoms (cations) of Si, Al, Fe etc. form less than 6 per cent of the total volume of a rock; hence, one molecule of MgO has essentially the same volume as one molecule of FeO . However, one molecule of FeO has nearly double the weight of one molecule of MgO . In other words, in a rock where FeO and MgO form equal percentages by weight, MgO has nearly twice the volume of FeO in the rock.

* Since one wants to retain a volumetric value rather than a weight measure, there is no advantage to breaking the molecules (oxides) into cations and anions (oxygens). It is simpler to calculate the percentage of each cation with its associated anion(s) (oxygen(s)) and retain the volumetric measure caused by the oxygen anion as explained above.

The cation (cation-oxide) percentages are proportional to the equivalent molecular proportions based on units containing one cation. Thus the proportion of Al_2O_3 is doubled, corresponding to $\text{AlO}^{1-1/2}$ as a unit; likewise, $\text{NaO}^{1/2}$ instead of Na_2O . It has been suggested 'molecular' proportion or percentage be used instead of cation

Table 8: Calculation of cation percentages

	<u>weight %</u>	<u>Equivalent molecular weight</u>	<u>Cation Proportions X 1000</u>	<u>Cations Percentage</u>	<u>Jensen Cation Plot</u>
SiO ₂	49.1	60	818	46.0	
TiO ₂	3.59	80	45	2.5	
AlO $\frac{1}{2}$	16.21	51	317	17.9	51.6
FeO $\frac{1}{2}$	2.86	80	36	2.0	
FeO	6.84	72	95	5.3	28.2
MnO	0.05	71	1	0.1	
MgO	5.04	40	125	7.0	20.2
CaO	8.90	56	159	9.0	
NaO $\frac{1}{2}$	3.52	31	114	6.4	
KO $\frac{1}{2}$	2.76	47	59	3.3	
PO $2\frac{1}{2}$	0.54	71	8	.5	
			<u>1777</u>	<u>100.0</u>	<u>100.0</u>

1. The cation % for MnO is added to that of FeO.

2. Cation percentages are based on each oxide having one cation; therefore, for Al₂O₃, Na₂O, K₂O, P₂O₅ etc., one half the molecular weight is used. To calculate the cation percentages the analyses data, is brought to a new total of 100. It is then divided by the corresponding equivalent molecular weight and multiplied by 1000. These figures are added and percentages of each cation is calculated. For the Jensen Cation Plot, Al₁, FeO₁, FeO, MgO and TiO₂ are totaled and brought to a total of 100. Fe₂O₃, FeO and TiO₂ are added to give one value on the cation plot; Al₂O₃ and MgO form the other two values.

3. To separate tholeiitic lavas from calc-alkalic lavas the cation percentages of MgO, FeO $\frac{1}{2}$, FeO, TiO₂, Al₂O₃ are normalized so that; MgO + (FeO $\frac{1}{2}$ + FeO + TiO₂) + Al₂O₃ = 100. The following procedure is taken;

-if Fe + Ti > 30.0, then stop

-if Fe + Ti < 30.0, then proceed

-if MgO > 35.0, then stop

-if MgO ≤ 35.0 then proceed

-if AlO $\frac{1}{2}$ > then use Y = 10 + 1.058824 MgO

-if AlO $\frac{1}{2}$ ≤ 55.0 then use Y = 3.2734754956 X 10⁻⁵ MgO⁵ -

4.579124579 X 10⁻³ MgO + 0.2550626636 MgO³ - 7.0820001496 MgO² + 97.11934904 MgO - 493.4789749.

percentage, but such a term is misleading because $AlO_{1.1-1/2}$ instead of Al_2O_3 , etc. are used. The term 'cation percentage' is used because the reference is to one-cation oxides.

Cation percentages have to be calculated prior to calculating the molecular and weight norms of a rock. Since the cation percentages are usually calculated in any standard computer program designed to calculate norms, it is relatively simple to calculate the ratios of Al_2O_3 , $Fe_2O_3 + FeO + TiO_2$ and MgO and plot them on a ternary plot as one would do using weight percentage of $K_2O + Na_2O$, $Fe_2O_3 + FeO + TiO_2$ and MgO on a standard A.F.M. ternary plot.

Appendix 2: Structural Geology

Introduction

The purpose of this appendix is to present a more detailed description of the study area's major structures, the McCool Hill Syncline, the Destor-Porcupine and Munro Fault Zones, and the Warden Hill, Centre Hill, and Contact Faults, and models describing how the structures may affect the stratigraphy exposed within the study area. The structural geology is then summarized, and subsequently a tectonic history which places the major structural elements of the study area in the context of regional scale tectonic models is discussed.

Folds

Throughout the study area, the strata are deformed by a series of upright to slightly overturned, tight to isoclinal folds. These are arranged en echelon in an fold belt trending west to west-northwest, which terminates eastward as it enters the Destor-Porcupine Fault Zone (DPFZ) in southern Rand Township. Similar east-trending, and doubly-plunging isoclinal folds are common elsewhere in the Kirkland Lake area (Jensen and Langford, 1983) and the Rouyn-Noranda district (Dimroth et al., 1983). The folds plunge more than 60 degrees as in Quebec (Dimroth et al., 1983).

Most of the steeply inclined strata on both sides of the Destor-Porcupine Fault Zone in the study area face south. Nevertheless, a major syncline in the western Black River-Matheson area parallels the fault zone causing a reversal in facing direction from north to south across the southern branch of the DPFZ. This syncline, the McCool Hill Syncline, is the largest fold within the fold belt, and has a length of at least 25 km. The overall structure of the study area therefore, is

that of a major syncline, its southern limb truncated by the Destor-Porcupine Fault Zone and both its limbs and hinge area disrupted by second order, upright isoclinal folds with an easterly trend. The largest of these second order folds is an anticline in the north-central part of the study area (Figure 9) with a half wavelength approaching 2.5 km. For much of its 8 km extent, the subvertical axial plane of the anticline runs parallel to that of the syncline. Based on the sudden convergence of the axial surface traces of the anticline and the McCool Hill Syncline westward and the apparent absence of a rotation of strata indicating a fold closure close to the terminus of the anticline in northwest Beatty Township, it is suspected that the axial plane of the anticline abruptly rotates into the northern limb of the syncline as the fold flattens out westward. If the anticline at its eastern end, where it is obscured by diorite intrusions in central Munro Township, similarly plunges into the southern limb of the syncline, this would produce the observed fold pattern, that of two west- to west-northwest-trending, sub-parallel synclinal axial traces, separated by a short, largely parallel-trending anticlinal axial trace, spatially arranged so that the western end of the northern synclinal axis (McCool Hill Syncline) apparently ends at the western end of the anticline and the southern synclinal axis (northern Beatty Township) ends at the anticline's eastern end. Alternatively, the fold pattern could have been produced by strike-slip faults sinistrally displacing the axial surface trace of the McCool Hill Syncline, but there is no evidence of this either texturally in shear zones or with the displacement of strata or dikes.

Measurements of contacts taken along the Munro Lake Sill where it is folded at McCool Hill, indicate that the syncline here has a vertical to

steeply north dipping axial plane striking 128 degrees and a hinge plunging at about 65° NW. The axial plane orientation is approximately the same as that of the McCool Hill Syncline in northern Beatty Township.

Precise estimates of bedding dips are not possible in much of the study area's rock exposures, but it can be generally stated that the bulk of the Stoughton-Roquemaure Group strata dip steeply (within 10 degrees of vertical) based on numerous observations of bedding contacts and pillow orientations. Relatively shallow dips ($45-60^{\circ}$ S) occur in only outcrop at three locations; (i) within the layered sill north of Painkiller Lake; (ii) immediately south of the synclinal axis in northeast Beatty Township; and (iii) in the area containing a minor asymmetric fold in northeast Munro Township. In northern Beatty Township, the shallow dips indicate proximity to the trough of the McCool Hill Syncline. Both limbs of the McCool Hill Syncline contain a pair of minor upright, doubly-plunging isoclinal folds which trend east-west. A sub-vertical axial plane cleavage, S_1 , is associated with the folds and the McCool Hill Syncline, but it is only sporadically developed, usually within the axial region of the folds. The orientation of the bedding in the Munro Township fold indicates that it is an overturned anticline (possibly a Z-fold) with a hinge that plunges at approximately $290^{\circ} \rightarrow 45^{\circ}$.

Superimposed on the west and west-northwest-trending folds is a set of gentle open folds which plunge 60° SW (J.H. Morris, Stewart-Abate mining property assessment report, Resident Geologist Files, Kirkland Lake, 1972). In the volcanic rocks, the folds are spaced 1-4 km apart, while in the Porcupine Group sedimentary rocks and certain interflow

sedimentary units this generation of folds is represented by smaller scale folds with half wavelengths of 10-100 m (Plate 52). The Preissac and possibly the much younger Abitibi diabase dikes are also affected by broad, southwest-trending open folds but it is cannot be established whether these and the smaller scale folds represent the same deformation period or separate ones broadly spaced in time. A steeply-dipping fracture cleavage, striking 45-70°, is associated with this set of folds, but it tends to be only sporadically developed within sedimentary rocks. It has been suggested that a southwest-striking set of cross-faults (predominantly dextral displacement sense) is associated with the development of these folds (Morris, 1972).

Despite the tight folding of the Stoughton-Roquemaure Group rocks, there is little, if any, evidence of internal deformation unless the rock is very close to a major fault or within the axial region of a F_1 fold. This is characteristic of the region (Jensen and Langford, 1983). Potential strain indicators (vesicles, varioles etc.) are abundant throughout the area but these remain unstrained, even as close as 100 m from an axial surface trace. North-south flattening is expressed by subvertical axial plane cleavage in the axial region of most of the F_1 folds, but this is generally poorly developed and discontinuous along strike.

The lack of significant penetrative deformation can be characteristic of a lack of confining pressure, suggesting shallow tectonic levels, and/or a lack of compressive stress. It has also been attributed specifically to syn-volcanic deformation by Jensen and Langford (1983). However, it is proposed here that the nature of the F_1 folds, such as the McCool Hill Syncline, may be the most important factor. These folds appear to have developed through a process of flexural-slip in which

most of the associated deformation was taken up by thin layers of less competent strata (interflow sediments, serpentized ultramafic rocks, flow breccia units) within the limbs of the fold. Such strata commonly displays sub-vertical schistosity and where slickensides are exposed within bedding-parallel fault planes, sub-vertical orientations predominate. These characteristics and the general lack of axial plane schistosity are also shared by the first generation folds of the Rouyn-Noranda area and this has led Dimroth et al. (1983) to propose a flexural-slip model for this generation of fold. Such a process of flexural-slip would not be expected to produce a pronounced thinning of the stratigraphy, which would throw off estimates of strata thickness. Translation of strata during flexural-slip folding could however, cause the superpositioning of younger strata upon older strata not directly underlying that rock when it was deposited. As shown in Figure 34 this would cause an over-estimate of the depth of burial.

Faults

Introduction

The most significant faults in the study area, as in the region, strike east-west. This includes the Destor-Porcupine Fault Zone, the Munro Fault Zone, the Pipestone Fault, the Painkiller Lake Fault, the Contact Fault, the Centre Hill Fault and the Warden Hill Fault.

The Destor-Porcupine Fault Zone

The Destor-Porcupine Fault Zone is the most important structural element in the Black River-Matheson area, marking the northern edge of a south-facing monoclinial succession within the Blake River Synclinorium. It is generally agreed that the structure developed over a long period during the deposition of the Upper Supergroup (Jensen and Langford,

FIGURE 34. A model for structural thickening during folding.

1983, Hodson, 1983, Dimroth et al., 1983), and it is possible that there are more faults associated with tectonic activity along the fault zone than the three branches of the Destor-Porcupine Fault Zone identified by Jensen and Langford (1983) and the normal faults described in this section. Only two of the branch faults are exposed within the study area; the Middle Branch of the Destor-Porcupine Fault Zone or the Munro Fault Zone, which terminates westward within Beatty Township, and the Southern Branch of the Destor-Porcupine Fault Zone, which continues westward into the Timmins area.

The Southern Branch of the Destor-Porcupine Fault Zone in southwest Beatty, northern Hislop and central Guibord Townships is not well enough exposed to be interpreted structurally. Only a portion of the fault zone is exposed in an outcrop group in northwest Hislop Township and much of the information as to its width and location must be gathered from diamond drill hole data. The fault zone here appears to be about 500-1000 m wide, and is characterized by a series of sub-vertical faults and shears enclosing slices of mildly to moderately deformed mafic volcanic rock. Some of the faults have been intruded by elongate peridotite, gabbro, diorite and feldspar-phyric syenite bodies.

Since the uppermost strata of the Stoughton-Roquemaure Group occurs south of the fault zone, and at least 10 km of stratigraphically lower Stoughton-Roquemaure strata is found north of the fault zone, a downward displacement of at least 10 km of strata south of the southern branch fault zone relative to that north of the fault zone is suggested. An interpretation of the stratigraphic relationships across the southern branch fault zone is shown in Figure 35.

The Munro Fault Zone

The Munro Fault Zone is characterized by a broad (500-900 m) westward

FIGURE 35. Structural/depositional model interpreting stratigraphic relationships across the Dextor-Porcupine Fault Zone.

thinning zone, comprising numerous parallel, discontinuous bands, themselves made up of nearly vertical dipping zones and faults. The core of the fault zone is largely unexposed, therefore its true nature cannot be adequately judged, but some comment can be made on those portions of the fault zone which are exposed.

Apart from two minor deviations, cutting down-section west of Deadman Hill and up-section at the west Munro Township boundary, fault planes are parallel to bedding within the komatiitic lava succession enclosing it. Slickensides within the fault zones consistently have steep plunges. If it is assumed that all the faults in the fault zone are of this nature, structural thickening or thinning of the stratigraphy could be ruled out. As it is, this can only be considered a possibility. Certainly the fault zone does not appear to cause a stratigraphic break, being entirely contained within a komatiitic lava succession. Vertical fault displacements would also explain why the axial surface traces of two isoclinal folds, which predate the Munro Fault Zone, are not significantly disrupted where the fault zone cuts across them in the center of the study area.

The fault zone thins westward along with the komatiitic lava succession, probably reflecting the increase in rock competency westward from strata dominated by serpentinitized ultramafic rock to strata entirely consisting of mafic volcanic rock. The Munro Fault Zone is unexposed from the east Beatty Township border westward, but probably trends due west in the area immediately north of Salvé Lake (see Beatty Township map). Rock has been faulted in this area, as judged from the results of recent diamond drilling conducted there by Maude Lake Gold Mines Ltd. (R. Bennett, Project Geologist, Maude Lake Gold Mines Ltd., personal communication, 1986), and normal strike faults which could be

subsidaries of the Munro Fault Zone are found in outcrop groups north and south of the suspected area. It is possible that the east-west valley found in this area north of Salve Lake, is the result of differential erosion promoted, as is the case in Munro Township, by the presence of the fault zone.

The relationship of the Munro Fault Zone and the Painkiller Lake Fault

Recent regional geology compilation maps (MERQ-OGS, 1983, Malczac, 1985) have interpreted the western extension of the Munro Fault Zone as consisting of the Painkiller Lake Fault in northern Beatty Township, and the Pipestone Fault which borders the northern edge of the Porcupine Group west of the study area. The connection between these three faults could not be established during field mapping.

The linking Painkiller Lake Fault, shown on the Beatty Township map in this study as an independent structural element, is a younger strike-slip fault which cannot be considered part of the long fault represented on the regional maps. Data from the Blue Quartz Mine (Satterly and Armstrong, 1949) on the south shore of Painkiller Lake and a displaced Matachewan diabase dike in the area, indicate that the Painkiller Lake Fault, dipping 80°N , is a strike-slip fault with a significant horizontal (dextral-800 feet) component of displacement. The Pipestone Fault is known not to be a strike-slip fault (Prest, 1952) and there is no evidence of strike-slip faults within the Munro Fault Zone. Unlike the Munro Fault Zone and the Pipestone Fault which roughly trends parallel to the stratigraphy, the Painkiller Lake Fault cross-cuts stratigraphy for most of its length. The Munro Fault Zone is an older structure because it pre-dates the Matachewan diabase dikes (a few intrude for short distances along the fault zone), while the Painkiller

Lake Fault post-dates the dikes, truncating a number of them.

A pair of upright isoclinal folds border the Painkiller Lake Fault in east-central Beatty Township and then extend into west-central Munro Township where they border the Munro Fault Zone for a short distance. Since field relationships indicate that the folds predate the Munro Fault zone, they would not have been related to the development of the younger Painkiller Lake Fault although they border it. The association may simply be due to the availability of axial planar fractures within the folds which could have preferentially directed the development of the fault. It is therefore assumed that the Munro Fault Zone continues to parallel bedding westward, north of Salve Lake.

The Pipestone Fault

The Pipestone Fault borders the northern edge of the Porcupine Group along the northern edge of the western Black River-Matheson area and is last recognized eastward in north-central Carr Township. The fault is important because it is associated with gold mineralization.

The Pipestone Fault was described by Prest (1952) in Carr Township as dipping 65°N, steepening eastward, and characterized by a 'soapstone' band and 'drag folds' which indicate that the sediments have risen relative to the volcanic rocks. Here, the fault follows the contact between the sedimentary and volcanic rocks. A departure from the sedimentary/volcanic contact eastward, perhaps leaving a lesser fault along the contact is suggested by the continuation of a green carbonate zone across the contact eastward into the volcanic rock. Extensive diamond drilling in this poorly exposed corner of Carr Township has not yet been able to identify the Pipestone Fault in the volcanic rock here (Resident Geologist's Files, Kirkland Lake, B. Cook, Exploration Manager, Cominco Ltd, personal communication, 1985). There is no

evidence of the continuation of the fault in the outcrop in either northwest Beatty Township (Trowell and Johnstone, 1983) or southwest Coulson Township (Johnstone, 1986). Therefore, the fault zone may have either continued along the sedimentary contact, which is known to be faulted from diamond drill hole data, or became splayed in Carr Township, with one branch continuing along the contact and the other trending roughly parallel to bedding through the Maude Lake Gold Property. The 'soapstone' mentioned by Prest (1952) could represent the western extension of the serpentinized ultramafic rock sequence found faulted at the gold property.

The Contact Fault

The Contact Fault (see Plate 53) is a bedding-parallel strike fault in the south-central part of the study area, which dies out eastward at the southern edge of Munro Township and cuts up-section in south-central Beatty Township. Based on fracturing and crenulation patterns, Satterly and Armstrong (1949) concluded that the fault had dextral displacement sense. Morris (1972), without indicating a sense of displacement, also refers to the fault as a strike-slip fault, which has re-oriented certain 'D₂ structural elements', and was later broken up by cross-faults related to the same deformation event. The cross-faulting was explained by accumulated strain during D₂, first released by slippage along the sedimentary/volcanic contact, where there is a competency contrast, and when slippage then stalled along the Contact Fault, strain was accumulated and subsequently released by northeast fracturing and faulting.

Within the fault zone, strained varioles flattened parallel to the fault plane have a common axis of maximum extension plunging

approximately 75°, trending 90°. This lineation, combined with sub-parallel slickenslides at one location along the fault, suggest that the overall motion of the fault was steeply oblique-slip rather than strike-slip. There is not enough evidence to suggest that the south fault block has moved up relative to the north block here, but it is likely that the Contact Fault shares this relative motion with the Pipestone Fault in northern Carr Township.

The Centre Hill Fault

The only exposure of this fault in the study area occurs along the southern edge of Centre Hill where there is a narrow, steeply-dipping zone of sheared mafic lava. For much of its length, it runs parallel to the bedding and then gradually cuts up-section truncating the axis of the McCool Hill Syncline in south-central McCool Township. Here the axial surface trace is displaced approximately 3 km sinistrally. This sense of displacement is consistent with the sense of shear indicated by an asymmetric fold in the Centre Hill Complex at a point where the fault begins to gradually cut up-section westward. This vertically to slightly northwesterly reclined anticline forms the western side of a poorly developed box fold within the Centre Hill Complex with a north-south orientation. No other folds in the study area have this orientation, although similar folds associated with west- or northwest-trending sinistral displacement sense strike faults do occur in south-central Coulson Township and east-central McCool Township. The Centre Hill Fault parallels other major faults belonging to the Destor-Porcupine Fault system, so it is conceivable that it is a related, relatively young fault caused by strike-slip displacements along the fault zone. It is unknown whether the Centre Hill fold is related to the deformation period which produced such displacements along the fault zone, but it

should be noted that Hubert et al. (1984) have used the existence of subvertical folds in the Blake River Group of Rouyn-Noranda to support their hypothesis of late strike-slip displacement along the fault zone.

The Warden Hill Fault

This fault is obscured somewhat by a gabbro intrusion, but something about it can be inferred from the adjacent stratigraphy. In fact, the existence of the Warden Hill Fault was only recognized because the base of an approximately 1000 m thick succession of lava flows, including two layered flows (Fred's and Theo's Flows), located north of an elongate gabbro body, reappears south of the gabbro. The gabbro body has an apparent thickness of up to 400 m in north-central Munro Township, so the precise point at which the stratigraphy is truncated by the fault is unknown. The gabbro body (and the fault) strikes parallel to bedding in this central area, and then trends slightly up-section to the east and down-section to the west.

The Warden Hill fault is modelled in Figure 36. This representation of the fault is based on two premises, a moderately shallow north dip (45-60°) to the fault plane and a dextral oblique-slip displacement sense. Considering the steep south dip of the bedding here, a moderately shallow north-dipping fault down-dropping strata north of the fault relative to the strata south of the fault would produce the required repetition of stratigraphy without a large magnitude of displacement. The absence of western and eastern extensions of the Warden Hill Fault in the outcrops of south-central Coulson and east-central McCool Townships suggests that it is not a major fault.

The dextral oblique-slip displacement produces a horizontal displacement of between 400 m and 500 m in the proposed model. This

4

MicroD

- Munro Lake 811 - gabbro
- Theo's Flow
- gabbro
- peridotite/pyroxenite
- Tholeiites
- Interflow sediment and breccia
- Komatiites
- Fred's Flow
- gabbro/spinellex
- peridotite/pyroxenite

→ N

----- Boundary of area obscured
by gabbro

esent state following erosion.

Warden Hill

265.

Folding followed by oblique slippage
along the Axis and Warden Hill Faults.

ne

- Munro Lake Sill-gabbro
- Theo's Flow
- gabbro
- peridotite/pyroxenite
- Tholeiites
- Interflow sediment and breccia
- Komatiites
- Fred's Flow
- gabbro/spinifex
- peridotite/pyroxenite

FIGURE 36. Model for the structural Township area.

Present state following erosion.

: Folding followed by oblique slippage along the Axis and Warden Hill Faults.

following the formation of the McCool Syncline.

lural evolution of the north-central Munro

dextral-sense component of horizontal displacement is suggested by the position of the western end of a layered flow, Theo's Flow, south of the fault relative to its position in the north fault block.

The diagram (Figure 36) also shows the development of a shallow plunging Z-fold which is cut by the Warden Hill Fault. This appears as a small angular syncline which occurs along the northern edge of the gabbro body at a point where the Warden Hill Fault begins to cut down-section at the eastern edge of the large outcrop group in north-central Munro Township (see Munro Township map). The syncline plunges approximately 45° and its sub-vertical axial plane strikes 290° . The fold is not found on the southern fault block, so it is proposed in the model that the fold did not extend deep enough within the up-thrown southern fault block to have been preserved at the present level of erosion. It is also possible that the gabbro body is obscuring the fold.

Also shown in Figure 36 is a north-dipping reverse fault, the Axis Fault, which is shown on the Munro Township map to trend east-west immediately south of the Warden Hill Fault in north-central Munro Township and then converge eastward with the axial surface trace of the McCool Hill Syncline. The existence of the fault is speculative since it is unexposed, but it is included as a possible explanation for the loss of at least 100 m of the stratigraphy in the southern fault block, including the upper half of Fred's Flow. Field relationships indicate that the axial surface trace of the McCool Hill Syncline is displaced dextrally by a strike fault along the projected extension of the proposed fault. This is why a horizontal component of displacement is incorporated in the model along with Munro Township map presented with this study. In Figure 36, the simplest model is assumed whereby the fault plane of the southern fault is parallel to that of the Warden Hill

Fault. With this arrangement, the faults indicate an overall dextral motion to the middle and northern fault blocks relative to the southern fault block. The middle fault block obliquely rose relative to the southernmost fault block.

Arndt's structural model

It should be noted here that Arndt (1975) interpreted the structure of his thesis area (north-central Munro Township) differently. In his model the fold, which this study assumes is related to the Warden Hill Fault, is part of a major west-plunging syncline, unrelated to the development of the fault. The axial surface trace of the syncline on his map trends west-southwest across his thesis area to a second location, at the southwest edge of his map area, where a reversal in facing direction is indicated. In order to reach this point, the fold would have had to cut across the west-northwest-striking stratigraphy at some point. This is not possible since all the strata in north-central Munro Township consistently faces south-southwest. In the map of Munro Township presented with this project, this 'second location' demarks the position of the axial surface trace of the McCool Hill Syncline. This arrangement clearly separates the minor fold in the northeast from the McCool Hill Syncline.

Cross-faults

The study area's cross-faults can be divided into four main groups, based on their cross-cutting relationships with each other and two sets of diabase dikes. These faults do not appear to have greatly disrupted the stratigraphy and stratigraphic correlation is therefore not hindered by their existence. Horizontal displacements of strata tend to be small, usually less than 100 m. When faults are exposed in vertical section

though, it is obvious that many of them are not strike-slip faults and the magnitude of vertical displacement cannot be judged. Since most of the fault planes dip steeply within the steeply dipping stratigraphy, there may be little or no surface expression of vertical displacement.

There is some importance in establishing time frames for the development of the different fault sets in the area from an economic geology viewpoint. The time when gold mineralization occurred within the region's rocks is estimated to have been between the times corresponding to the deposition of the Upper Tisdale and Blake River Group of the Upper Supergroup (approx. 2703 ± 2 m.y., U-Pb zircon date, -Nunes and Jensen, 1982) and the emplacement of the Matachewan Dike Swarm (approx. 2633 ± 93 m.y., Rb-Sr method, Gates and Hurley, 1973) (Hodson, 1983). Based on an established association between a gold mineralization in Garrison Township and the emplacement of a felsic intrusion (Garrison Stock) (Cherry, 1983) emplaced around 2675 ± 2 m.y., U-Pb zircon date, (S. Marmont, personal communication, 1986), many of the auriferous quartz and quartz-carbonate veins may have been emplaced fairly late in this time period in the Black River-Matheson area. The age relationships between different fault sets will become more important as the time of gold mineralization is more clearly defined, allowing explorationists to discount faults and related fracture systems which post-date the mineralization period as potential conduits and traps for mineralizing fluids. At this time, it can be established that two groups of cross-faults in the study area post-date the Matachewan diabase dikes, and are therefore unlikely exploration targets.

All of the cross-faults indicated on the township maps post-date the development of the McCool Hill Syncline and possibly all of the other west- to northwest-trending folds. In decreasing order of age these are;

a north-northwest trending set, a southwest-trending set (dominantly dextral displacement sense), a north-trending set, and a second northeast-trending set (dominantly sinistral displacement sense). Most of the cross-faults are of short extent and cause horizontal displacements of less than 50 m. The largest displacement (400 m -sinistral) is caused by a northeast-trending fault in north-central Munro Township.

The oldest group of cross-faults (NNW-trending) are only found in the northwest corner of Munro Township. Here there are at least four dextral faults displacing two sinistral faults with slightly more southerly orientations. These older sinistral faults disrupt the east-west oriented folds in this area as well as a discordant gabbro body.

The second group of cross-faults (SW-trending), which dominantly display dextral displacements, are the most common faults in the eastern half of the study area and are concentrated mainly in southwest Munro Township. The faults cross-cut the NNW-trending faults and predate the Matachewan diabase dikes. As mentioned before, it is possible that the faults included in this group could have developed during a deformation period which caused folding about northeast-southwest axes in the Porcupine Group sedimentary rocks. If it can be proven that this set of faults are related to these folds in particular, this would support the hypothesis that the northeast folds affecting the sedimentary and the volcanic rocks, as well as the Painkiller Lake Fault which post-dates this set of faults, are broadly spaced in time. The southwest-trending dextral faults predate the Matachewan diabase dikes and the younger Preissac diabase dikes and possibly the much younger Abitibi diabase dikes are affected by northeast folding.

The third group of cross-faults, the north-trending faults (Plate 51) do not have a preferred sense of displacement. Matachewan diabase dikes have been emplaced along most of the faults. The fact that these dikes preferentially intrude these faults suggest that north-south fracturing may have been coeval with the dike swarm. It is noteworthy that the richest gold deposit ever found within the study area, the Croesus deposit in southwest Munro Township, was located at the junction of a north-trending fault and a northeast-trending faults of the second set.

The dextral Painkiller Lake Fault described earlier post-dates the Matachewan Diabase Dike Swarm and is cross-cut by members of a fourth set of northeast-striking cross-faults. Most of these are dextral. These faults also affect a Preissac Diabase dike (2140 ± 20 m.y., $^{40}\text{Ar}/^{39}\text{Ar}$ method, Hanes and York (1979) Fahrig and West, 1986). They are found mainly in Beatty Township and north-central Munro Township.

The southwest sinistral fault with the greatest horizontal displacement (approx. 250 m) occurs along Barton Creek in the south-central part of the study area. Satterly and Armstrong (1949) originally indicated a 2 km sinistral displacement on either side of this fault, based on the apparent displacement of a Preissac dike (referred to as a Keewenawen dike at that time), but stratigraphic measurements indicate a sinistral-sense displacement of only 250 m. This discrepancy can be explained if it is considered that the dike has intruded up two separate fractures arranged en echelon on either side of the fault, creating the illusion of a major fault offset.

Summary

The most significant structures in the study area share a west or west-northwest trend. This includes the McCool Hill Syncline, the minor isoclinal folds disrupting its core and limbs, and a number of

faults possibly related motions along to the Destor-Porcupine Fault Zone. The major faults can be divided into normal, largely bedding parallel faults (Munro Fault Zone, Contact Fault, and Pipestone Fault) and faults which produce either a repetition of stratigraphy (Warden Hill Fault) or major horizontal displacements (Centre Hill Fault).

Minor structures include a sub-vertical asymmetric fold at Centre Hill, a shallow, westerly-plunging angular fold (possibly part of a Z-fold) in north-central Munro Township and a series of open southwest-trending folds which overprint all the east-west structures.

These fault and fold structures define at least two deformation periods, D_1 and D_2 . D_1 , represented by the McCool Hill Syncline and the sub-parallel-trending isoclinal folds and normal faults, would have been a period of vertical tectonism involving the development of an east-west fold belt of tight or isoclinal, upright folds and vertical displacements along the Destor-Porcupine Fault Zone. D_2 would have been a period of east-west or northwest-southeast compression to produce the open southwest-trending folds, cross-faults and possibly the Centre Hill Fault. The Centre Hill Fault truncates the axial surface trace of the McCool Hill Syncline and therefore post-dates the structure. The Warden Hill Fault is assumed to post-date the McCool Hill Syncline in the absence of any evidence of its presence on the southern limb of the syncline. Without a better understanding of the nature of the fault, its tectonic significance cannot be judged. The fold cut by the Centre Hill Fault at Centre Hill and the angular fold cut by the Warden Hill Fault may also be products of D_2 , but apart from their association with faults thought to have developed during D_2 , structural relationships which prove that the folds post-date D_1 structures are not available.

It is possible that D_2 may represent two separate periods of east-west or northwest-southeast compression. However, this relies on whether or not a set of southwest-striking cross-faults, which pre-date the Matachewan, Abitibi and Preissac diabase dikes, can be proven to be related to the open, southwest-trending folds which deforms strata in the study area. Since the Preissac and Abitibi diabase dikes are similarly folded, the deformation would have pre-dated the emplacement of the Matachewan Dike Swarm and post-dated the emplacement of the Abitibi Dike Swarm. The Matachewan Dike Swarm may have represented an intervening period of east-west extension.

Discussion: regional implications

Up to three deformation periods, D_1 , D_2 and D_3 , have been recognized regionally (Dimroth et al., 1983) and it is possible to fit some of the structures in the study area into a regional tectonic model. A general summary of structural features within the study area and how they relate to a compilation of regional tectonic models proposed by Dimroth et al. (1983), Jensen and Langford (1983), and Hubert et al. (1984) is presented in Table 9. D_1 has been interpreted as a result of a period during the Kenoran Orogeny of either north-south compression alone (Dimroth et al., 1983) or, in the Lake Abitibi area, north-south compression preceded by vertical extension caused by the emplacement of the Lake Abitibi Batholith and basin subsidence related to either the rise of the batholith and/or the loading of komatiitic lavas (Jensen and Langford, 1983).

In the Rouyn-Noranda area, large folds interpreted as being developed during D_1 are described by Dimroth et al. (1983) as plunging doubly and trending east, southeast and locally northeast and north. These F_1 folds are also characterized by subvertical axial planes and a general lack of

TABLE 9: Summary of Major Structures Within Beatty and Munro Townships in Relation to Major Regional Tectonic Events

Regional Tectonic Event	Related Structures and Fabric Elements
D ₃ ?: Northwest-southeast compression.	Development of northeast-trending, dominantly sinistral displacement sense faults.
Preissac Diabase Dike Swarm	
	Dextral displacement along the Painkiller Lake Fault.
North-south faulting and the Matachewan Diabase Dike Swarm	
D ₂ ?: Northwest-southeast compression. Emplacement of the Lake Abitibi Batholith ² .	Development of southwest-trending, small-scale open folds, and north-northwest- and southwest-(dextral) trending faults. Spasmodically developed S ₂ sub-vertical foliation striking 45-70°.
D ₁ ?: north-south compression combined with vertical extension-development of F ₁ folds, north and south branches of the Destor-Porcupine Fault Zone act as normal growth faults. ^{1.2.3.}	Initial development of the McCool Hill Syncline.
Continued north-south compression, development of F ₂ folds ^{1.} .	Tightening of the McCool Hill Syncline followed by vertical displacements along the Munro Fault Zone and the Contact Fault. Development of east-trending, upright isoclinal folds within the syncline. Poorly developed axial-plane cleavage (S ₁) confined to axial region of the folds.
Continued north-south compression without vertical extension, Oblique dextral thrusting ^{1.} and/or sinistral transcurrent motion ^{3.} along the Destor-Porcupine Fault Zone, Development of F ₃ folds ^{1.} .	Development of the Centre Hill fold and the angular fold in north-central Munro Township followed by the formation of the Warden Hill Fault, the thrust fault fault paralleling it, and the Centre Hill Fault.

1. Dimroth et al., 1983

2. Jensen and Langford, 1983

axial-plane schistosity. This latter characteristic, shared by the McCool Hill Syncline, was attributed to the folds being flexural in nature. Some of the F_1 folds in the south-central Abitibi Belt curve around the cores of central volcanic complexes which are thought to have been consolidated by synvolcanic plutons prior to the formation of the folds. Based on the fold patterns surrounding these low-strain domains and the metamorphic and stratigraphic evidence supporting synvolcanic subsidence in the formation of the Blake River Synclinorium, these authors have suggested that F_1 folds nucleated in areas of differential subsidence adjacent to the volcanic complexes. Synclinoria nucleated in zones of pre-orogenic subsidence and anticlinoria nucleated in less subsident zones.

If this model for the F_1 folds is applied to the study area, a stable volcanic complex could have been the Hunter Mine Group volcanic complex in the Lake Abitibi area, which is thought by Jensen and Langford (1983) to have existed prior to the emplacement of the Lake Abitibi Batholith during the Kenoran Orogeny. Based on the consistently low grade of metamorphism within the approximately 9 km thick volcanic pile represented within the McCool Hill Syncline and the lack of significant penetrative deformation, it is possible that the fold is flexural in nature also, although there has been no conclusive evidence from the study area's geology of syn-depositional folding. The development of the syncline may have initiated with basin subsidence and then continued with the onset of north-south compression during the Kenoran Orogeny, as suggested from the F_1 fold model, but the basin subsidence may have only occurred after the deposition of the Stoughton-Roquemaure Group strata. In assuming a thin, unstable Archean crust, the basin subsidence was

initiated only after a thick enough pile of mafic and ultramafic rock was deposited in that area. With east-west rifting having focused the eruption and deposition of the lavas, differential subsidence would have created an east-west oriented trough which would have later nucleated the development of the McCool Hill Syncline at its present location during D_1 .

During D_2 , north-south compression continued and the F_1 folds were closed, flattened and overprinted by east-trending F_2 folds also possessing sub-vertical axial planes (Dimroth et al., 1983). The existence of the F_2 folds in the study area is not clearly established since the McCool Hill Syncline has an orientation fairly close to that of the east-trending F_2 folds of Rouyn-Noranda over much of its extent. The small anticline coring the McCool Hill Syncline is the best candidate for an F_2 fold in that it has a sub-vertical axial plane, an easterly trend and post-dates the syncline. The minor isoclinal folds in the limbs of the syncline are not well enough exposed to judge their relative orientations.

Dimroth et al. (1983) also recognized third-order folds within the region's sedimentary rocks with half wavelengths of 1-100 m, steeply-dipping axial planes. These open folds are attributed to continuing north-south shortening which also produced thrusting along the Destor-Porcupine Fault Zone and northeast- and southwest-trending strike-slip faults. The two folds with steeply-dipping axial planes found bordering the Centre Hill Fault and Warden Hill Faults in the study area are the most likely candidates for this third set of folds, but age relationships for these two folds are not established.

The open southwest-trending folds found within the study area are not found in the Rouyn-Noranda area, but second-order, open folds trending

north-south do exist in the Timmins area (Pyke, 1982). These folds are described by Pyke (1982) as plunging 60° in a north or northeast direction and having nearly vertical axial planes. The north- and southwest-trending open folds appear to represent localized deformation events which post-date regional north-south deformation. An example of such a deformation event would be the folding associated with the shallow-level spreading of Lake Abitibi Batholith in the final stages of its emplacement (Jensen and Langford, 1983).

Based on the interpretation of the senses of displacement established for the Middle Branch of the Destor-Porcupine Fault Zone (Munro Fault Zone) in the Lightning River area (Jensen and Langford, 1983) and the faults bordering the northern edge of the Porcupine Group, the Pipestone and Contact Faults as interpreted by Prest (1952) and Morris (1972) respectively, the strata between the Munro Fault Zone and the Contact Fault has dropped relative to the bordering fault blocks. It is conceivable that the area's major west- to north-northwest-trending faults (Munro Fault Zone, Contact Fault, Pipestone Fault), which have fault planes that are generally parallel to bedding, were likely became most active after strata became rotated up to vertical when slippage could occur along beds of less competent rock. Within the study area, sub-vertical shear zones tend to be restricted to beds of less competent material (i.e. interflow sediments, serpentinitized ultramafic rock, breccia units). Based on cross-cutting relationships with other faults, these normal faults and shear zones predate most cross-faults, and are assumed to be related to the development of the Destor-Porcupine Fault System. The orientations of slicksides indicate that sub-vertical displacements were caused by the faults. This is consistent with models

presented by various workers (Hodson, 1983, Jensen and Langford, 1983, Dimroth et al., 1984) for the early development of the fault zone in which normal faulting continued to occur after the rotation of strata to sub-vertical orientations. According to the model of Jensen and Langford (1983), following D_1 , rifting occurred along the southern branch of the Destor-Porcupine Fault Zone during the final stages of subsidence within the Blake River Synclinorium.

If the two parallel-trending faults disrupting the north limb of the McCool Hill Syncline were contemporaneous, and are as represented in Figure 36, (i.e. moderately north dipping and producing oblique-slip senses of displacement), they could be related to the period of oblique thrusting proposed by Dimroth et al. (1983) to have marked the final stages in the development of the Destor-Porcupine Fault Zone.

Hubert et al. (1984) have alternatively proposed that the Destor-Porcupine Fault Zone was reactivated as a sinistral wrench fault. This hypothesis was based on the fold pattern produced by sub-vertically plunging, second order folds in the Blake River Group in Quebec. In support of their oblique thrust model, Dimroth and Rocheleau (1985) have disputed the structural data upon which the strike-slip model is based. It is beyond the scope of this study to present structural evidence from the study area in support of either one of these theories, as the major structures are poorly exposed; however, it is possible that the Destor-Porcupine Fault system in this area includes faults generated by separate periods of late transcurrent (dextral-sense) and oblique thrust motions along the fault zone represented by the Centre Hill and Warden Hill Faults respectively.

51. North-trending normal cross-fault exposed in the northern wall of the 'A' pit, Munro Mine, southwest Munro Township.
52. Small S_2 folds with southwest-striking axial planes within the Porcupine Group sedimentary rocks of southwest Munro Township.
53. The Contact Fault in southwest Munro Township. The associated deformation is largely confined to the Porcupine Group sedimentary rock (right) not the overlying massive basalt (left).

APPENDIX 3: LIST OF GEOCHEMICAL SAMPLES

SAMPLE NUMBER	EASTING	NORTHING	SAMPLE DESCRIPTION	JENSEN PLOT COMPOSITION
82NFT-1158	544669	5382639	BLACK APHANITIC MASSIVE BASALT	FT
82NFT-1171	546857	5383274	GRAY FINE-GRAINED MASSIVE BASALT	MT
82NFT-1180	546857	5383307	DK. GRAY FINE-GRAINED MASSIVE ANDESITE	TA
82NFT-1184	546420	5384043	DK. GRAY-GREEN APHAN. MASSIVE BASALT	FT
82NFT-1190	546272	5384846	GRAY APHANITIC MASSIVE ANDESITE	TA
82NFT-1193	546495	5384846	DK. GRAY APHANITIC MASSIVE BASALT	FT
82NFT-1202	544689	5385451	DK. GRAY APHANITIC MASSIVE BASALT	FT
82NFT-1217	546661	5384725	LT. GRAY-GREEN APHAN. MASSIVE BASALT	MGT
82NFT-1222	546617	5384940	GRAY APHANITIC MASSIVE BASALTIC KOM.	BK
82NFT-1228	547369	5385572	DK. GRAY APHANITIC PILLOWED BASALT	FT
82NFT-1230	546879	5385498	DK. GRAY-GREEN APHAN. MASSIVE BASALT	FT
82NFT-1231	546880	5385453	DK. GRAY-GREEN APHAN. MASSIVE BASALT	FT
82NFT-1294	545159	5385639	DK. GRAY-GREEN APHAN. MASSIVE BASALT	FT
82NFT-1295	545240	5385670	DK. GRAY-GREEN APHAN. MASSIVE BASALT	FT
82NFT-1314	544473	5384214	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT
82NFT-1318	546867	5384449	BLACK MAGNETIC FINE- GRAINED MASS. BASALT	FT
82NFT-1320	546119	5383238	DK. GRAY-GREEN APHAN. BASALT	FT

82NFT-1331	548395	5383070	MED. GRAY-GREEN FINE- GRAINED MASS. BASALT	MT
82NFT-1332	548334	5382916	DK. GRAY MED. GRAINED MASSIVE BASALT	FT
82NFT-1333	548334	5382948	DK. GRAY APHANITIC MASSIVE BASALTIC KOM.	BK
82NFT-1334	548397	5382824	DK. GRAY-GREEN APHAN. MASSIVE BASALT	FT
82NFT-1337	548400	5382423	DK. GRAY APHANITIC MASSIVE BASALT	FT
82NFT-1339	546138	5383423	DK. GRAY-GREEN APHAN. MASSIVE BASALT	FT
83NFT-1008	548600	5382661	MED. GRAY APHANITIC MASSIVE BASALT	MT
83NFT-1009	548500	5382289	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT
83NFT-1012	550022	5381974	DK. GRAY-GREEN APHAN. MASSIVE BASALT	FT
83NFT-1013	550245	5382253	BL.-GRAY-GREEN APHAN. VARIOLITIC ANDESITE	TD
83NFT-1014	550325	5382440	LT. GRAY-GREEN APHAN. MASSIVE BASALT	MGT
83NFT-1021	551456	5381895	DK. GRAY-GREEN FINE- GRAINED MASS. BASALT	FT
83NFT-1025	551066	5381983	DK. GRAY APHANITIC MASSIVE BASALT	FT
83NFT-1028	550856	5382630	DK. GRAY APHAN. MASS. AMYGDALOIDAL BASALT	FT
83NFT-1045	551291	5382139	DK. GRAY-GREEN FINE- GRAINED MASSIVE BASALT	FT
83NFT-1047	551311	5382109	LT. GRAY-GREEN FINE- GRAINED MASS. BASALT	MGT
83NFT-1053	551397	5381708	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT
83NFT-1064	551954	5383474	LT GRAY APHAN. PILLOWED ANDESITE	TA
83NFT-1066	548803	5380883	MED. GRAY APHAN. QTZ	TR

PORPHYRITIC RHYOLITE

83NFT-1068	548845	5380759	WHITE FLOW BANDED QTZ/ PF PORPH. RHYOLITE	CR
83NFT-1069	549541	5380828	LT. GRAY FLOW BANDED APHANITIC RHYOLITE	TR
83NFT-1070	549542	5380701	WHITE FLOW BANDED QTZ/ PF PORPH. RHYOLITE	CR
83NFT-1071	549542	5380734	LT. GRAY FLOW BANDED QTZ/PF PORPH DACITE	TD
83NFT-1076	549585	5380519	MED. GRAY APHAN. QTZ/ PF PORPH. RHYOLITE	TR
83NFT-1077	549602	5380735	LT. GRAY GREEN FINE- GRAINED MASS. BASALT	MT
83NFT-1089	550648	5380775	LT. GREEN-GRAY APHAN. QTZ/PF PORPH. AMYGD. RHYOLITE	CR
83NFT-1091	550690	5380590	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT
83NFT-1093	550549	5380311	MED. GRAY APHAN. QTZ/ PF PORPH. RHYOLITE	CR
83NFT-1107	553115	5379811	DK. GRAY-GREEN APHAN. MASSIVE BASALT	FT
83NFT-1115	549206	5383975	MED. GRAY FINE-GRAIN. ACICULAR PYROX. BASALT	MGT
83NFT-1120	549327	5384098	LT. GRAY-GREEN APHAN. MASSIVE BASALT	MGT
83NFT-1122	549511	5384223	LT. GRAY-GREEN APHAN. PILLOWED BASALT	TA
83NFT-1136	553480	5380308	MED. GRAY-GREEN APHAN. MASSIVE BASALT	FT
83NFT-1141	553500	5380460	BLACK FINE-GRAINED MAGN. MASS. BASALT	FT
83NFT-1146	553313	5380614	MED. GRAY-GREEN APHAN. PILLOWED BASALT	CB
83NFT-1149	553480	5381060	MED. GRAY FINE- GRAINED BASALTIC KOM.	FBK
83NFT-1155	553600	5380020	MED. GRAY-GREEN FINE-	FBK

			GRAINED GABB. BAS. KOM.	
83NFT-1160	553530	5379690	LT. GRAY APHANITIC MASSIVE RHYOLITE	CR
83NFT-1162	553540	5379540	DK. GRAY APHAN. PILLOWED BASALT	FT
83NFT-1206	554400	5384230	MED. GRAY VARIOLITIC PILLOWED BASALT	CB
83NFT-1212	554580	5383480	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT
83NFT-1213	554580	5383480	DK. GRAY-GREEN APHAN. MASSIVE BASALT	FT
83NFT-1214	554580	5383480	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT
83NFT-1215	554580	5383480	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT
83NFT-1219	555000	5383440	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT
83NFT-1228	554650	5385600	DK. GRAY FINE-GRAINED MASS. PERID. KOM.	PK
83NFT-1229	554730	5385800	MED. GRAY FINE- GRAINED BASALTIC KOM.	BK
83NFT-1230	555080	5385520	MED. GRAY FINE- GRAINED BASALTIC KOM.	BK
83NFT-1231	555080	5385520	DK. GRAY FINE-GRAINED OLIV. SPIN. PERID. KOM.	PK
83NFT-1250	552530	5379620	DK. GRAY-GREEN APHAN. PILLOWED BASALT	FT
84NFT-4052	554822	5385606	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT
84NFT-4067	554851	5386418	LT. GRAY APHAN. QTZ/ PF PORPH. RHYOLITE	CR
84NFT-4072	555500	5376600	COALESCED VARIOLES IN MASS. ANDESITE	TA
84NFT-4078	553100	5381500	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT
84NFT-4091	555250	5377500	DK. GRAY-GREEN APHAN. PILLOWED BASALT	FT

84NFT-4174	556300	5380200	DK. GRAY-GREEN FINE- GRAINED GABB. BASALT	FT
84NFT-4225	555739	5385281	MED. GRAY APHAN. MASSIVE BASALT	MT
84NFT-4230	554750	5379400	DK. GRAY GREEN FINE- GRAINED MASS. BASALT	FT
84NFT-4233	558400	5379300	LT. GRAY-GREEN FINE- GRAINED MASS. BASALT	MGT
84NFT-4243	558400	5379650	BLACK MAGNETIC FINE- GRAINED MASS. BASALT	FT
84NFT-4247	558550	5379650	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT
84NFT-4275	560150	5383700	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT
84NFT-4280	560500	5384500	MED. GRAY APAN. BASALTIC KOMATIITE	FBK
84NFT-4301	560100	5385700	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT
84NFT-4302	560100	5385700	BLACK MAGNETIC FINE- GRAINED MASS. BASALT	FT
84NFT-5021	551100	5379050	BLACK FINE-GRAINED MATRIX VARIOLITIC, MASSIVE BASALT	FT
84NFT-5025	550800	5379200	COALESCED VARIOLES IN MASS. FT BASALT	TA
84NFT-5050	555638	5386581	DK. GRAY-GREEN SLIGHT. MAGN. APHAN. MASSIVE BASALT	FT
84NFT-5056	556200	5378000	BLACK MAGNETIC FINE- GRAINED MASS. BASALT HORNBL. PORPHYRY	FT
84NFT-5063	554893	5386696	FINE RANDOM OLIV. SPIN. IN BASALTIC KOM.	BK
84NFT-5064	555165	5386711	WHITE APHAN. QTZ/PF PORPH. RHYOLITE	CR
84NFT-5080	554638	5387149	BLACK MAGNETIC APHAN. MASSIVE BASALT	FT

84NFT-5084	554552	5386815	MED. GRAY-GREEN FINE- GRAINED VARIOLITIC LAVA TUBE	BK
84NFT-5092	553730	5380900	MED. GRAY-GREEN SLIGHTLY MAGN. FINE-GRAIN. BASALTIC KOM.	FBK
84NFT-5094	553750	5380900	BLACK MAGNETIC FINE- GRAINED MASS. BASALT	FT
84NFT-5099	554300	5380500	MED. GRAY-GREEN SLIGHT. MAGN. VARIOLITIC APHAN. MASS. BASALT	MT
84NFT-5104	554658	5387328	DK. GRAY-GREEN APHAN. MASSIVE BASALT	FT
84NFT-5110	555400	5380300	MED. GRAY-GREEN FINE- GRAINED MASS. BASALT	FT
84NFT-5126	554500	5380500	DK. GRAY-GREEN APHAN. MASSIVE BASALT	FT
84NFT-5127	554648	5386827	LT. GRAY-GREEN APHAN. VARIOLITIC PILLOWED BASALT	MT
84NFT-5149	557800	5377350	BLACK MAGNETIC APHAN. PILLOWED BASALT	FT
84NFT-5167	556800	5379150	LT. GRAY-GREEN FINE- GRAINED MASS. BAS. KOM. POLYG. JOINTING	BK
84NFT-5178	554552	5386860	MED. GRAY-GREEN APHAN. VARIOLITIC PILLOWED BASALT	MT
84NFT-5181	554618	5386149	MED. GRAY-GREEN APHAN. MASS. VARIOLITIC BASALTIC KOM. POLYG. JOINTING	FBK
84NFT-5184	558000	5379150	DK. GRAY-GREEN FINE- GRAINED MASS. BASALT HORNBL. PORPHYRY	FT
84NFT-5189	558950	5378500	MED. GRAY-GREEN FINE- GRAINED MASS. BASALT	MT
84NFT-5190	559900	5379900	MED. GRAY-GREEN FINE- GRAINED MASS. BAS. KOM.	FBK
84NFT-5192	560150	5379900	DK. GRAY-GREEN SLIGHT.	FT

			MAGN. MASSIVE APHANITIC BASALT	
84NFT-5194	554816	5386273	DK. GRAY-GREEN APHAN. MASSIVE BASALT	FT
84NFT-5205	558010	5381500	DK. GRAY-GREEN FINE- GRAINED MASS. BASALT	FT
84NFT-5212	554727	5386327	MED. GRAY FINE-GRAINED MASSIVE BASALTIC KOM.	BK
84NFT-5218	559950	5384700	MED. GRAY-GREEN APHAN. VARIOLITIC PILLOWED BASALT	FT
84NFT-5222	558000	5382900	DK. GRAY APHAN. MASSIVE BASALT	FT
84NFT-8001	558000	5377500	MED. GRAY APHANITIC MASSIVE PERID. KOM.	PK
84NFT-8003	556000	5376290	LT. GRAY-GREEN APHAN. PILLOWED BASALT	MT
ABO-1189	555400	5380400	BLACK, MAGNETIC FINE- GRAINED MASS. BASALT	FT
ABO-1192	554600	5380400	MED. GRAY FINE-GRAINED MASSIVE BASALT	FT
ABO-1193	554600	5380400	MED. GRAY FINE-GRAINED MASSIVE BASALT	FT
ABO-1194	554600	5380400	MED. GRAY FINE-GRAINED VARIOLITIC MASS. BASALT	MT
ABO-1195	555000	5377650	DK. GRAY FINE-GRAINED VARIOLITIC MASS. BASALTIC KOM.	BK
ABO-1196	555000	5377650	DK. GRAY COARSE OLIV. SPIN. BASALTIC KOM.	BK
ABO-1197	555000	5377650	DK. GRAY FINE-GRAINED MASS. BASALTIC KOM.	BK
ABO-1198	555000	5377650	DK. GRAY FINE-GRAINED MASSIVE BASALTIC KOM.	BK
DBA-85-63	560100	5376000	COARSE 'STRINGBEEF' SPIN. BASALTIC KOM.	BK
DBA-85-64	560100	5376000	COARSE OLIVINE SPIN. BASALTIC KOMATIITE	BK

DBA-85-65	555200	5379540	COARSE OLIVINE SPIN. PERIDOTITIC KOMATIITE	BK
DBA-85-67	553800	5380550	DK. GRAY FINE-GRAINED MASS. BASALTIC KOM.	BK
DBA-85-70	553800	5380550	BLACK MED.-GRAINED OLIV. CUMULATE PERID. KOMATIITE	PK
DBA-85-71	553650	5380550	DK. GRAY FINE-GRAINED MASSIVE BASALTIC KOM.	BK
DBA-85-72	555500	5379450	COARSE PYROX. SPIN. BASALTIC KOMATIITE	BK
DBA-85-73	548000	5385900	COARSE PYROX. SPIN. BASALTIC KOMATIITE	BK
DBA-85-74	553800	5385055	COARSE 'STRINGBEEF' BASALTIC KOMATIITE	BK
DBA-85-75	553800	5380550	DK. GRAY FINE-GRAINED BASALTIC KOMATIITE	BK

TUFFACEOUS SEDIMENTS

84NFT-5115	558600	5385600	LT. TAN FINE-BEDDED SILTSTONE
84NFT-5222	559000	5385600	WHITE LAMINATED SILTSTONE

ABBREVIATIONS:

FT -Fe-rich tholeiite	AMYGD. -Amigdaloidal
MT -Low Fe/Mg tholeiite	APHAN. -Aphanitic
MGT -Mg-rich tholeiite	BAS. -Basaltic
TA -Tholeiitic andesite	BL. -Bluish
TD -Tholeiitic dacite	DK. -Dark
TR -Tholeiitic rhyolite	GABB. -Gabbroic
CB -Calc-alkaline basalt	GRAIN. -Grained
CA -Calc-alkaline andesite	HORNBL. -Hornblende
CD -Calc-alkaline dacite	KOM. -Komatiite
CR -Calc-alkaline rhyolite	LT. -Light
FBK -Fe-rich basaltic komatiite	MAGN. -Magnetic
BK -Basaltic komatiite	MASS. -Massive
PK -Peridotitic komatiite	MED. -Medium
	OLIV. -Olivine
	PF -Plagioclase feldspar
	POLYG. -Polygonal
	PYROX. -Pyroxene
	QTZ -Quartz
	SPIN. -Spinifex

NOTES:

All the major rock types exposed within the study area and along the adjacent border areas of townships surrounding the study area were sampled for whole rock geochemical analysis. The geochemical sampling was designed to augment stratigraphic analysis; therefore, sample locations are evenly distributed throughout the area, and the frequency with which the rock types were sampled was proportional to the abundance of each rock type. Therefore, tholeiites are represented by the largest number of samples, and the calc-alkalic rocks are represented by the smallest number of samples.

All samples were prepared and analyzed at the Ontario Geological Survey's Geoscience Laboratories, Toronto. "Major" elements were determined by X-ray Fluorescence from fusion discs. The calibration ranges, as percentages in the rock powder sample, and the precision typically obtained at a mid-range value (MRV) are listed below.

	range (%)	precision (%) @ MRV
SiO ₂	30-80	+2.0
Al ₂ O ₃	0-20	0.4
Fe ₂ O ₃	0-15	0.6
MgO	0-20	0.3
Na ₂ O	0-10	0.5
K ₂ O	0-10	0.1
CaO	0-15	0.15
P ₂ O ₅	0-1	0.15
TiO ₂	0-3	0.16
MnO	0-1	0.015

MAJOR OXIDE LISTING

	82NFT-1158	82NFT-1159	82NFT-1171	82NFT-1180	82NFT-1181	82NFT-1184
SiO ₂	43.30	55.20	48.60	64.80	48.60	47.20
Al ₂ O ₃	1.52	1.75	1.46	0.76	1.29	1.74
Fe ₂ O ₃	14.80	13.80	13.20	11.40	14.70	13.10
FeO	4.88	3.35	5.02	3.00	4.02	5.16
MnO	13.60	6.13	10.60	8.18	9.64	11.70
MgO	0.30	0.16	0.24	0.20	0.26	0.22
CaO	6.10	4.22	6.37	1.50	5.81	5.62
Na ₂ O	8.26	8.99	9.43	3.61	8.01	7.96
K ₂ O	1.73	3.78	1.70	2.59	2.84	2.29
P ₂ O ₅	0.31	0.13	0.35	0.66	1.34	0.45
CO ₂	0.03	0.10	0.04	0.08	0.06	0.04
S	0.25	0.33	0.10	0.19	0.20	0.20
H ₂ O+	0.05	0.36	0.07	1.54	0.21	0.10
H ₂ O-	4.26	1.95	2.63	1.59	2.65	3.64
LOI	0.07	0.05	0.04	0.02	0.05	0.03
TOTAL	3.80	1.70	1.60	2.00	2.20	2.40
	99.46	100.00	99.85	100.12	99.68	99.40

TRACE ELEMENT LISTING

	82NFT-1158	82NFT-1159	82NFT-1171	82NFT-1180	82NFT-1181	82NFT-1184
BA	160	110	120	260	590	130
CO	47	42	46	8	43	50
CR	62	156	72	N.D.	119	60
CU	98	74	114	77	130	108
LI	13	10	14	7	12	12
NI	32	39	39	N.D.	64	31
PB	N.D.	N.D.	N.D.	20	N.D.	N.D.
ZN	146	142	133	102	100	146
BE	2	2	2	2	3	4
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	35	25	21	21	30	35
SC	30	30	55	13	22	30
SR	80	145	195	60	100	70
V	365	230	400	12	235	340
Y	25	25	35	100	15	24
ZR	35	75	30	110	90	65
RB	10	N.D.	N.D.	20	60	20

MAJOR OXIDE LISTING

	82NFT-1190	82NFT-1193	82NFT-1202	82NFT-1217	82NFT-1219	82NFT-1221
SiO ₂	47.40	46.70	48.80	52.60	66.00	49.90
TiO ₂	2.12	1.65	1.49	0.64	0.36	0.53
Al ₂ O ₃	16.80	13.00	13.40	13.20	16.70	15.00
Fe ₂ O ₃	2.07	3.41	4.22	2.26	0.71	2.20
FeO	8.69	12.30	8.84	7.74	2.41	6.28
MnO	0.35	0.24	0.27	0.18	0.06	0.16
MgO	2.67	6.11	5.72	8.56	1.69	8.59
CaO	10.90	10.90	10.10	9.13	1.86	10.70
Na ₂ O	1.55	1.50	1.61	2.04	5.25	2.94
K ₂ O	0.59	0.24	0.32	0.33	3.37	0.38
P ₂ O ₅	0.20	0.06	0.04	0.02	0.09	0.02
CO ₂	3.43	0.15	1.72	0.30	0.27	0.22
S	0.02	0.16	0.29	0.14	0.01	0.07
H ₂ O ⁺	2.97	2.63	2.94	2.78	1.09	2.80
H ₂ O ⁻	0.03	0.05	0.06	0.07	0.06	0.10
LOI	5.50	1.70	3.70	2.50	1.00	2.50
TOTAL	99.79	99.10	99.82	99.99	99.93	99.89

TRACE ELEMENT LISTING

	82NFT-1190	82NFT-1193	82NFT-1202	82NFT-1217	82NFT-1219	82NFT-1221
BA	150	90	90	100	1390	120
CD	58	50	45	41	10	36
CR	254	120	111	336	61	795
CW	88	107	104	80	55	64
LI	12	8	16	15	6	17
NI	170	47	43	82	17	90
FB	N.D.	N.D.	N.D.	N.D.	11	N.D.
ZN	124	120	130	83	52	75
BE	2	3	3	3	3	N.D.
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NE	30	35	35	25	15	21
SC	30	30	25	23	5	21
SR	110	95	95	120	820	135
V	185	330	320	160	35	155
Y	30	24	18	12	9	9
ZR	70	65	55	40	125	30
RB	20	N.D.	N.D.	10	60	20

MAJOR OXIDE LISTING

	82NFT-1222	82NFT-1228	82NFT-1230	82NFT-1231	82NFT-1293	82NFT-1294
SiO ₂	45.40	53.60	56.20	54.50	51.30	44.50
TI02	0.89	1.57	2.30	1.79	1.95	1.77
AL2O3	10.70	15.50	14.80	15.20	13.60	13.60
FE2O3	2.97	2.71	1.82	2.34	3.52	4.31
FeO	9.06	6.94	6.35	6.43	7.23	12.60
MNO	0.26	0.15	0.13	0.15	0.28	0.26
MGO	10.30	4.68	4.23	4.43	3.26	6.42
CaO	12.50	6.13	6.58	7.00	10.00	11.60
NA2O	00.00	5.30	3.78	4.53	2.48	0.79
K2O	2.46	0.27	0.05	0.29	0.49	0.08
P2O5	0.38	0.07	0.22	0.19	0.07	0.07
CO2	0.22	0.39	0.16	0.09	3.17	0.12
S	0.20	0.05	0.02	0.08	0.16	0.02
H2O+	3.22	2.63	3.25	2.67	2.74	2.97
H2O-	0.08	0.16	0.10	0.10	0.06	0.06
LOI	2.30	2.20	2.60	2.30	5.00	2.30
TOTAL	98.64	100.15	99.99	99.79	100.31	99.17

TRACE ELEMENT LISTING

	82NFT-1222	82NFT-1228	82NFT-1230	82NFT-1231	82NFT-1293	82NFT-1294
BA	1810	140	50	120	450	80
CD	55	40	36	31	33	51
CR	525	195	96	144	50	126
CU	1570	74	50	51	60	106
LI	24	8	10	6	7	9
NI	89	96	65	70	29	51
PB	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
ZN	210	92	121	130	127	130
BE	5	1	2	2	2	2
MO	10	N.D.	N.D.	N.D.	N.D.	N.D.
NB	30	25	40	35	40	45
SC	30	20	19	16	30	40
SR	580	125	180	155	260	165
V	230	205	165	145	370	340
Y	40	18	24	23	30	30
ZR	190	75	145	140	75	80
RB	60	10	N.D.	10	10	N.D.

MAJOR OXIDE LISTING

	82NFT-1295	82NFT-1314	82NFT-1318	82NFT-1320	82NFT-1331	82NFT-1332
SiO ₂	49.40	50.90	48.90	44.90	44.70	51.90
TiO ₂	1.69	2.15	1.47	1.40	1.87	1.24
Al ₂ O ₃	12.50	11.60	12.70	12.00	15.30	13.30
Fe ₂ O ₃	3.52	7.95	5.14	4.83	3.74	2.52
FeO	11.00	10.50	10.20	10.50	10.70	11.40
MnO	0.23	0.26	0.28	0.33	0.27	0.20
MgO	6.00	3.85	4.88	4.24	6.67	4.85
CaO	10.50	6.43	9.11	11.10	9.12	9.39
Na ₂ O	1.76	3.06	1.43	1.55	2.34	2.22
K ₂ O	0.31	0.12	0.20	0.16	0.31	0.76
P ₂ O ₅	0.05	0.08	0.04	0.02	0.12	0.07
CO ₂	0.31	0.20	1.83	5.23	0.41	0.12
S	0.03	0.01	0.14	0.29	0.17	0.13
H ₂ O+	2.25	2.81	3.44	3.82	3.39	1.85
H ₂ O-	0.07	0.08	0.06	0.08	0.06	0.05
LOI	1.90	2.30	4.20	8.30	3.40	1.40
TOTAL	99.62	100.00	99.82	100.25	99.17	100.00

TRACE ELEMENT LISTING

	82NFT-1295	82NFT-1314	82NFT-1318	82NFT-1320	82NFT-1331	82NFT-1332
Ba	110	70	120	110	120	230
Co	46	42	42	38	50	44
Cr	130	5	69	61	230	71
Cu	90	22	88	103	76	154
Li	8	8	11	13	14	14
Ni	53	N.D.	31	27	115	39
Pb	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Zn	104	117	122	131	124	118
Be	2	1	2	2	1	2
Mo	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
Nb	40	35	45	40	35	40
Sc	40	35	45	35	18	24
Sr	75	11	95	50	150	115
V	315	215	340	310	205	265
Y	30	40	30	25	20	25
Zr	80	80	75	60	110	110
Rb	10	N.D.	N.D.	N.D.	10	30

MAJOR OXIDE LISTING

	82NFT-1333	82NFT-1334	82NFT-1335	82NFT-1337	83NFT-1008	83NFT-1009
SiO ₂	43.90	44.60	42.00	46.20	45.00	49.80
TiO ₂	0.85	2.15	2.36	1.65	2.26	2.14
Al ₂ O ₃	9.92	14.40	15.50	12.70	13.20	12.50
Fe ₂ O ₃	2.85	3.85	3.39	4.41	3.26	6.52
FeO	7.67	11.80	11.80	12.00	11.00	9.82
MnO	0.26	0.21	0.22	0.25	0.22	0.24
MgO	10.60	6.42	7.78	6.54	7.04	3.10
CaO	18.60	10.80	8.99	10.90	9.73	6.41
Na ₂ O	00.00	1.27	1.75	1.01	1.67	3.89
K ₂ O	0.66	0.42	0.75	0.06	0.44	0.11
P ₂ O ₅	0.61	0.21	0.26	0.03	0.35	0.14
CO ₂	0.14	0.07	0.20	0.08	0.48	0.35
S	0.02	0.18	0.03	0.08	0.07	0.10
H ₂ O+	2.96	2.81	3.89	3.03	3.74	3.06
H ₂ O-	0.03	0.04	0.06	0.02	0.11	0.15
LOI	2.30	2.10	3.20	2.20	3.00	2.90
TOTAL	99.07	99.23	98.98	98.96	98.60	98.30

TRACE ELEMENT LISTING

	82NFT-1333	82NFT-1334	82NFT-1335	82NFT-1337	83NFT-1008	83NFT-1009
AU					7	N.D.
BA	170	140	270	80	190	80
CO	45	50	48	50	41	32
CR	267	210	190	120	162	N.D.
CU	126	62	74	102	62	24
LI	28	14	18	12	11	4
NI	167	60	108	54	90	N.D.
PB	N.D.	N.D.	N.D.	N.D.	48	N.D.
ZN	104	134	141	120	143	195
BE	4	8	2	2	1	1
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	30	40	20	45	25	22
SC	17	30	24	40	30	45
SR	420	210	140	140	190	35
V	155	205	225	320	195	185
Y	30	30	25	30	30	60
ZR	265	120	75	80	105	100
RB	10	10	30	N.D.	10	

MAJOR OXIDE LISTING

	83NFT-1012	83NFT-1013	83NFT-1014	83NFT-1018	83NFT-1021	83NFT-1025
SiO ₂	47.30	71.40	52.10	50.00	48.10	49.30
TiO ₂	1.67	0.75	0.86	0.92	1.84	1.78
Al ₂ O ₃	12.30	10.60	14.00	6.97	13.00	13.30
Fe ₂ O ₃	2.13	1.71	3.14	2.20	3.70	3.89
FeO	13.00	4.80	5.60	10.10	11.10	9.53
MnO	0.26	0.16	0.13	0.21	0.26	0.26
MgO	6.34	0.46	6.26	11.00	5.22	4.56
CaO	9.33	2.27	5.62	13.70	10.30	10.80
Na ₂ O	2.58	3.46	2.62	2.47	2.00	1.81
K ₂ O	0.08	0.38	5.08	00.00	0.28	0.45
P ₂ O ₅	0.06	0.09	0.42	0.01	0.09	0.08
CO ₂	0.22	1.78	1.02	0.29	0.47	0.97
S	0.03	0.05	00.00	0.10	0.15	0.08
H ₂ O+	3.31	1.51	2.52	2.08	2.52	2.42
H ₂ O-	0.05	0.04	0.04	0.04	0.07	0.05
LOI	2.40	2.90	3.20	1.80	2.60	2.90
TOTAL	98.70	99.50	99.40	100.10	99.10	98.00

TRACE ELEMENT LISTING

	83NFT-1012	83NFT-1013	83NFT-1014	83NFT-1018	83NFT-1021	83NFT-1025
AU	N.D.	N.D.	2	19	N.D.	N.D.
BA	110	80	1640	60	150	220
CD	45	N.D.	26	52	42	45
CR	115	N.D.	99	328	103	117
CU	94	15	33	535	98	96
LI	8	4	10	4	6	8
NI	50	N.D.	30	220	50	56
PD	38	360	174	34	N.D.	N.D.
ZN	140	175	100	68	170	122
BE	1	1	2	1	2	2
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	30	14	19	23	30	30
SC	45	18	20	45	50	55
SR	125	55	480	40	195	195
V	345	6	145	240	355	375
Y	30	75	21	17	35	30
ZR	70	180	145	45	75	75

MAJOR OXIDE LISTING

	83NFT-1028	83NFT-1029	83NFT-1045	83NFT-1046	83NFT-1047	83NFT-1053
SiO2	46.30	49.70	46.60	51.90	45.40	47.10
TiO2	1.79	0.72	2.08	0.79	2.15	1.87
Al2O3	12.70	11.00	15.10	14.20	14.80	15.00
Fe2O3	3.43	2.19	2.77	2.51	2.00	2.40
FeO	12.10	6.40	10.90	5.96	11.60	10.30
MnO	0.25	0.15	0.28	0.16	0.17	0.27
MgO	6.23	10.00	5.40	5.04	6.79	5.72
CaO	10.40	9.47	10.30	8.22	9.10	9.70
Na2O	2.32	00.00	1.37	2.15	1.99	2.39
K2O	00.00	5.26	0.40	3.25	0.49	0.46
P2O5	0.08	0.61	0.34	0.55	0.36	0.27
CO2	0.21	0.92	0.27	2.38	0.12	0.66
S	0.17	0.07	0.09	0.08	0.03	0.05
H2O+	3.37	2.92	3.23	2.74	3.97	3.70
H2O-	0.13	0.15	0.06	0.22	0.13	0.29
LOI	2.80	3.60	3.10	4.90	3.50	3.70
TOTAL	99.50	99.60	99.20	100.10	99.10	100.10

TRACE ELEMENT LISTING

	83NFT-1028	83NFT-1029	83NFT-1045	83NFT-1046	83NFT-1047	83NFT-1053
AU	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BA	50	1570	220	1200	360	110
CO	48	35	42	26	80	41
CR	121	655	230	184	445	236
CU	96	68	74	54	62	78
LI	6	10	8	9	32	10
NI	57	166	122	46	199	113
PR	51	35	N.D.	170	N.D.	41
ZN	121	84	134	100	134	118
BE	1	2	1	3	1	1
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	30	20	25	20	25	24
SC	45	25	40	25	35	35
SR	160	540	205	855	220	160
V	365	150	220	160	210	210
Y	30	16	35	30	30	30
ZR	65	130	120	190	120	110

MAJOR OXIDE LISTING

	83NFT-1057	83NFT-1060	83NFT-1061	83NFT-1063	83NFT-1064	83NFT-1066
SiO2	46.30	51.30	51.50	50.20	50.10	74.20
TiO2	0.53	0.66	1.66	0.98	2.63	0.48
Al2O3	14.60	12.90	13.00	7.37	16.60	10.60
Fe2O3	2.17	2.02	4.00	1.91	2.44	0.49
FeO	7.64	7.49	11.00	9.96	7.27	2.91
MnO	0.17	0.16	0.24	0.19	0.14	0.14
MgO	10.70	8.37	2.13	11.20	3.69	0.49
CaO	9.50	11.20	8.30	13.30	6.64	2.85
Na2O	2.66	1.70	3.48	2.28	4.63	2.29
K2O	0.86	0.29	0.23	0.01	0.24	1.52
P2O5	00.00	00.00	0.09	00.00	0.42	00.00
CO2	0.07	0.18	0.27	0.12	0.35	2.36
S	0.01	0.04	0.12	0.01	0.04	0.13
H2O+	3.96	3.46	3.39	2.25	3.74	1.39
H2O-	0.14	0.14	0.14	0.13	0.18	0.04
LOI	4.00	3.50	2.80	2.10	3.80	3.70
TOTAL	99.30	99.90	99.50	99.90	99.10	99.90

TRACE ELEMENT LISTING

	83NFT-1057	83NFT-1060	83NFT-1061	83NFT-1063	83NFT-1064	83NFT-1066
AU	5	2	N.D.	N.D.	N.D.	2
BA	170	100	80	50	140	170
CO	44	37	30	51	29	N.D.
CR	600	625	N.D.	605	103	N.D.
CU	61	70	48	59	32	10
LI	20	16	N.D.	6	6	10
NI	143	106	N.D.	177	73	N.D.
PB	15	33	39	N.D.	475	120
ZN	62	76	180	80	56	46
BE	N.D.	N.D.	1	1	2	2
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	14	17	17	22	35	17
SC	22	25	18	35	30	11
SR	125	120	70	45	125	30
V	160	175	75	220	210	16
Y	7	11	45	17	35	85
ZR	30	35	125	40	215	350

MAJOR OXIDE LISTING

	83NFT-1068	83NFT-1069	83NFT-1070	83NFT-1071	83NFT-1076	83NFT-1077
SiO ₂	78.70	73.00	87.40	65.40	78.90	51.70
TiO ₂	0.34	0.29	0.21	0.37	0.30	1.63
Al ₂ O ₃	9.41	12.10	8.35	13.10	10.80	12.90
Fe ₂ O ₃	0.20	1.38	00.00	2.74	0.73	3.23
FeO	3.20	1.89	0.29	7.49	1.82	8.80
MnO	0.05	0.10	0.01	0.10	0.04	0.18
MgO	0.33	00.00	0.02	0.78	0.29	5.91
CaO	0.78	2.20	0.18	0.91	0.78	9.62
Na ₂ O	1.03	5.21	3.42	2.24	2.89	2.03
K ₂ O	4.38	0.44	0.72	2.33	1.27	0.11
F ₂ O ₅	00.00	00.00	00.00	00.00	00.00	0.10
CO ₂	0.59	1.89	0.16	0.84	0.75	0.10
S	0.01	0.01	0.01	0.04	0.08	0.04
H ₂ O+	0.82	0.52	0.09	2.59	1.12	3.09
H ₂ O-	0.05	0.03	0.03	0.09	0.06	0.05
LOI	1.30	2.50	0.20	3.10	1.80	2.80
TOTAL	99.90	99.10	100.80	99.00	99.80	99.50

TRACE ELEMENT LISTING

	83NFT-1068	83NFT-1069	83NFT-1070	83NFT-1071	83NFT-1076	83NFT-1077
AU	9999	2	N.D.	N.D.	N.D.	N.D.
BA	860	130	140	260	140	70
CO	N.D.	N.D.	N.D.	N.D.	N.D.	35
CR	N.D.	N.D.	N.D.	N.D.	7	213
CU	11	18	6	10	12	46
LI	6	6	N.D.	26	7	18
NI	N.D.	N.D.	N.D.	N.D.	N.D.	73
PD	355	1670	10	N.D.	11	N.D.
ZN	112	240	35	415	73	95
BE	4	4	2	5	3	1
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	35	45	30	50	45	24
SC	N.D.	N.D.	N.D.	N.D.	1	30
SR	25	85	35	30	50	225
V	7	2	2	4	5	195
Y	165	245	105	190	205	30
ZR	395	455	340	400	285	85

MAJOR OXIDE LISTING

	83NFT-1089	83NFT-1091	83NFT-1093	83NFT-1107	83NFT-1112	83NFT-1115
SiO ₂	73.80	46.20	80.30	45.70	50.10	51.00
TiO ₂	0.20	1.92	0.26	3.27	0.80	0.80
Al ₂ O ₃	13.80	13.70	10.40	10.90	13.10	14.60
Fe ₂ O ₃	0.69	4.37	0.26	2.81	2.23	2.14
FeO	2.18	9.45	1.53	13.10	8.07	8.65
MnO	0.02	0.18	0.03	0.39	0.23	0.15
MgO	0.67	6.18	0.27	3.19	9.58	8.91
CaO	0.19	5.83	0.29	8.58	9.52	7.61
Na ₂ O	3.08	3.20	0.37	1.74	3.28	2.41
K ₂ O	2.71	0.57	5.41	0.19	0.14	0.09
F ₂ O ₅	00.00	0.16	00.00	0.64	00.00	0.01
CO ₂	0.16	2.93	0.30	4.51	0.19	0.22
S	00.00	0.11	0.01	0.21	0.03	0.01
H ₂ O ⁺	1.42	4.12	0.58	4.10	1.77	1.67
H ₂ O ⁻	0.05	0.05	0.04	0.09	0.19	0.18
LOI	1.70	6.50	1.10	7.10	2.00	1.90
TOTAL	99.00	99.00	100.00	99.40	99.20	98.50

TRACE ELEMENT LISTING

	83NFT-1089	83NFT-1091	83NFT-1093	83NFT-1107	83NFT-1112	83NFT-1115
AU	N.D.	7	N.D.	N.D.	N.D.	N.D.
BA	340	210	670	170	70	120
CO	N.D.	41	N.D.	30	44	40
CR	8	182	12	N.D.	615	274
CU	6	57	6	34	73	86
LI	13	20	18	10	16	12
NI	N.D.	106	N.D.	N.D.	164	96
PB	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
ZN	64	132	102	180	86	95
BE	3	2	3	1	N.D.	N.D.
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	55	24	45	25	18	19
SC	N.D.	35	1	40	24	22
SR	30	110	45	120	150	180
V	4	220	3	105	190	205
Y	135	24	250	70	11	11
ZR	350	75	305	120	45	30

MAJOR OXIDE LISTING

	83NFT-1118	83NFT-1120	83NFT-1122	83NFT-1126	83NFT-1129	83NFT-1136
SiO2	46.40	53.30	48.30	53.00	48.90	47.70
TiO2	0.73	0.79	2.27	1.01	0.97	2.10
Al2O3	5.09	14.50	17.20	13.40	15.30	16.00
Fe2O3	2.51	1.86	2.52	3.28	1.93	2.40
FeO	9.53	6.55	9.38	10.20	9.45	9.02
MnO	0.23	0.20	0.26	0.20	0.19	0.21
MgO	18.50	7.44	5.08	5.32	5.98	4.14
CaO	13.80	7.83	6.08	7.86	10.40	9.05
Na2O	00.00	4.52	4.22	3.10	2.30	4.27
K2O	0.01	0.04	0.27	0.59	1.56	0.26
P2O5	00.00	0.02	0.36	0.03	0.03	0.12
CO2	0.25	0.16	0.33	0.07	0.14	0.77
S	0.02	0.11	0.09	0.12	0.06	0.16
H2O+	2.56	1.41	2.70	1.43	2.06	3.29
H2O-	0.06	0.08	0.13	0.03	0.04	0.03
LOI	2.50	1.40	2.60	1.20	1.60	3.10
TOTAL	99.70	98.80	99.20	99.60	99.30	99.50

TRACE ELEMENT LISTING

	83NFT-1118	83NFT-1120	83NFT-1122	83NFT-1126	83NFT-1129	83NFT-1136
AU	N.D.	N.D.	N.D.	N.D.	3	N.D.
BA	40	100	100	160	200	90
CO	62	41	37	41	39	41
CR	2150	425	200	N.D.	173	366
CU	76	82	52	47	126	70
LI	14	16	34	14	12	8
NI	440	100	104	19	65	114
PB	N.D.	N.D.	755	N.D.	N.D.	N.D.
ZN	76	80	70	80	98	132
BE	N.D.	N.D.	2	1	1	1
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NR	19	17	30	22	22	30
SC	35	25	25	30	35	50
SR	19	140	325	205	175	215
V	170	200	185	255	240	275
Y	10	12	30	17	17	35
ZR	22	30	125	60	65	95

MAJOR OXIDE LISTING

	83NFT-1137	83NFT-1140	83NFT-1141	83NFT-1146	83NFT-1149	83NFT-1152
SiO2	40.90	42.90	49.30	54.00	48.40	39.40
TiO2	0.38	0.46	1.66	1.54	1.00	0.31
Al2O3	6.12	5.98	13.60	14.40	7.24	4.63
Fe2O3	4.23	3.20	2.54	1.52	1.91	4.80
FeO	7.64	9.60	12.20	7.05	10.40	5.45
MnO	0.17	0.19	0.20	0.16	0.22	0.17
MgO	26.10	23.00	4.24	4.35	11.60	30.40
CaO	3.95	4.87	6.67	7.82	13.30	2.74
Na2O	0.21	0.22	4.45	3.58	1.32	00.00
K2O	00.00	00.00	0.46	0.64	00.00	0.01
P2O5	00.00	00.00	0.06	0.09	0.01	00.00
CO2	0.50	0.29	0.21	1.04	0.97	0.25
S	0.51	0.19	0.62	0.56	0.12	0.12
H2O+	8.84	7.56	2.73	2.49	2.52	11.10
H2O-	0.07	0.33	0.05	0.03	0.04	0.19
LOI	9.00	7.70	2.40	3.30	2.80	10.30
TOTAL	99.60	98.70	99.00	99.30	99.10	99.60

TRACE ELEMENT LISTING

	83NFT-1137	83NFT-1140	83NFT-1141	83NFT-1146	83NFT-1149	83NFT-1152
AU	N.D.	N.D.	N.D.	N.D.	2	N.D.
BA	20	10	230	380	40	20
CO	76	82	44	48	62	75
CR	880	1890	11	460	785	935
CU	98	47	112	74	144	8
LI	10	6	6	8	4	6
NI	1450	840	32	151	235	1850
PB	N.D.	N.D.	112	N.D.	N.D.	N.D.
ZN	50	72	130	133	102	40
BE	N.D.	N.D.	1	1	1	N.D.
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	15	18	25	22	22	12
SC	5	7	23	35	40	4
SR	8	6	125	170	50	8
V	115	115	265	225	230	75
Y	5	8	25	23	12	3
ZR	24	30	75	60	35	20

MAJOR OXIDE LISTING

	83NFT-1156	83NFT-1158	83NFT-1158	83NFT-1160	83NFT-1162	83NFT-1187
SiO2	50.30	49.10	51.50	75.80	48.30	56.10
TiO2	1.51	0.51	0.31	0.30	2.70	0.42
Al2O3	12.30	13.40	5.62	13.20	10.20	18.60
Fe2O3	2.41	3.09	0.94	00.00	2.90	1.72
FeO	9.67	7.35	6.47	1.02	14.00	5.09
MnO	0.22	0.19	0.17	0.02	0.33	0.20
MgO	4.68	9.00	19.10	0.97	2.78	3.39
CaO	9.26	9.87	10.40	0.39	7.27	4.62
Na2O	4.41	0.98	0.14	6.71	1.65	4.91
K2O	0.08	0.89	00.00	0.13	0.59	0.34
F2O5	0.05	00.00	00.00	00.00	0.62	00.00
CO2	1.95	1.26	1.05	0.60	3.57	0.82
S	0.33	0.01	0.02	0.01	0.16	0.01
H2O+	1.90	3.32	3.70	0.59	4.07	3.00
H2O-	0.06	0.09	0.07	0.06	0.10	0.07
LOI	2.90	4.40	4.90	1.30	6.00	3.20
TOTAL	99.10	99.30	99.50	99.80	99.20	99.30

TRACE ELEMENT LISTING

	83NFT-1155	83NFT-1156	83NFT-1158	83NFT-1160	83NFT-1162	83NFT-1187
AU	N.D.	N.D.	55	N.D.	N.D.	N.D.
BA	80	300	50	50	130	110
CO	43	43	42	N.D.	29	49
CR	13	775	2500	8	N.D.	605
CU	102	53	180	5	32	32
LI	4	12	14	9	14	10
NI	39	78	195	56	N.D.	215
PB	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
ZN	165	76	56	48	195	48
BE	1	1	1	5	1	N.D.
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	22	19	16	35	24	13
SC	20	35	30	N.D.	35	40
SR	75	125	9	23	95	105
V	240	185	155	11	70	155
Y	24	10	8	120	85	9
ZR	75	30	21	340	130	20

MAJOR OXIDE LISTING

	83NFT-1200	83NFT-1202	83NFT-1205	83NFT-1206	83NFT-1207	83NFT-1209
SiO2	42.70	50.70	48.10	49.40	54.50	51.20
TiO2	0.16	0.36	0.39	0.39	0.82	0.38
AL2O3	20.00	17.80	16.70	16.00	16.30	15.60
FE2O3	2.34	1.60	1.82	2.28	3.26	2.35
FeO	4.36	5.31	6.91	6.98	5.60	6.98
MNO	0.14	0.15	0.21	0.26	0.12	0.22
MGO	9.87	4.85	7.50	5.61	4.11	8.47
CaO	11.90	11.50	10.90	8.78	5.97	8.21
Na2O	1.05	1.36	1.12	2.54	5.39	1.33
K2O	0.01	00.00	00.00	0.27	0.01	0.71
P2O5	00.00	00.00	00.00	00.00	0.13	00.00
CO2	0.37	2.48	1.60	2.96	0.25	0.20
S	0.01	0.02	0.01	0.01	0.18	0.02
H2O+	5.86	3.31	3.98	4.06	2.59	4.12
H2O-	0.37	0.14	0.16	0.15	0.11	0.21
LOI	6.40	5.60	5.30	6.20	2.70	4.10
TOTAL	99.10	99.60	99.40	99.70	99.30	100.00

TRACE ELEMENT LISTING

	83NFT-1200	83NFT-1202	83NFT-1205	83NFT-1206	83NFT-1207	83NFT-1209
AU	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
BA	50	70	50	180	60	300
CO	41	41	49	60	22	57
CR	252	337	575	1090	11	840
CU	24	45	48	48	38	46
LI	14	16	14	14	N.D.	16
NI	325	140	210	375	N.D.	295
PB	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
ZN	51	62	62	66	56	68
BE	N.D.	N.D.	N.D.	N.D.	1	N.D.
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	8	13	13	13	19	13
SC	12	40	35	40	20	30
SR	75	45	50	125	90	35
V	75	55	145	160	195	160
Y	4	9	9	8	16	6
ZR	15	18	23	20	85	22

MAJOR OXIDE LISTING

	83NFT-1212	83NFT-1213	83NFT-1214	83NFT-1215	83NFT-1219	83NFT-1226
SiO2	49.10	49.00	47.60	48.80	50.30	50.60
TiO2	1.08	1.09	1.17	1.50	1.00	0.99
Al2O3	13.00	12.90	12.80	12.50	13.50	13.80
Fe2O3	2.80	3.85	3.63	3.03	3.70	2.29
FeO	10.80	10.70	12.00	12.20	9.89	8.29
MnO	0.23	0.24	0.25	0.28	0.22	0.21
MgO	5.54	5.00	6.42	6.19	5.79	6.16
CaO	10.50	10.40	9.37	8.12	7.55	8.72
Na2O	2.48	1.86	2.01	2.26	1.80	3.83
K2O	0.15	0.05	00.00	0.02	1.39	0.79
P2O5	0.02	0.01	0.02	0.04	0.04	0.02
CO2	0.24	0.17	0.12	0.15	0.26	0.32
S	0.15	0.04	0.10	0.15	0.09	0.02
H2O+	3.04	3.41	4.29	4.10	3.35	2.46
H2O-	0.11	0.08	0.11	0.11	0.11	0.25
LOI	2.60	3.00	3.50	3.50	3.00	2.80
TOTAL	99.20	98.80	99.90	99.50	99.80	98.80

TRACE ELEMENT LISTING

	83NFT-1212	83NFT-1213	83NFT-1214	83NFT-1215	83NFT-1219	83NFT-1226
AU	10	N.D.	N.D.	3	N.D.	N.D.
BA	140	80	40	60	460	160
CO	52	51	56	52	46	41
CR	19	24	32	66	12	265
CU	122	106	128	100	100	59
LI	3	N.D.	N.D.	3	11	6
NI	42	39	40	44	27	75
PB	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
ZN	90	72	91	140	88	54
BE	1	1	1	1	1	1
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	22	23	25	30	22	22
SC	30	35	35	55	35	35
SR	75	140	100	105	120	140
V	265	295	315	345	245	240
Y	17	18	18	30	19	15
ZR	35	40	45	65	55	75

MAJOR OXIDE LISTING

	83NFT-1227	83NFT-1228	83NFT-1229	83NFT-1230	83NFT-1231	83NFT-1232
SiO2	52.20	41.00	52.50	38.50	36.70	53.40
TiO2	1.03	0.37	0.62	0.53	0.22	0.77
Al2O3	13.30	6.05	10.90	8.05	3.53	11.60
Fe2O3	2.90	4.41	2.01	4.90	6.27	2.38
FeO	9.02	6.47	8.36	8.73	5.67	6.11
MnO	0.18	0.18	0.20	0.20	0.16	0.14
MgO	5.26	27.40	8.90	13.50	30.10	4.09
CaO	9.40	5.64	9.45	6.34	2.03	16.60
Na2O	2.12	00.00	3.69	00.00	00.00	00.00
K2O	0.37	0.01	00.00	0.50	00.00	00.00
P2O5	0.02	00.00	00.00	00.00	00.00	0.01
CO2	0.39	0.13	0.45	16.50	0.27	1.13
S	0.10	0.03	0.01	0.10	0.02	0.66
H2O+	2.91	7.85	2.18	3.38	9.85	3.03
H2O-	0.17	0.38	0.14	0.08	0.89	0.11
LOI	2.60	8.50	1.90	19.40	11.50	4.30
TOTAL	99.40	99.90	99.40	101.30	95.70	100.00

TRACE ELEMENT LISTING

	83NFT-1227	83NFT-1228	83NFT-1229	83NFT-1230	83NFT-1231	83NFT-1232
AU	N.D.	7	2	N.D.	2	N.D.
BA	130	40	70	150	30	40
CO	44	84	39	60	113	48
CR	16	1280	150	1040	910	62
CU	59	34	68	54	8	39
LI	9	6	3	24	4	11
NI	31	1500	48	565	1410	59
PR	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
ZN	79	70	86	94	104	86
RE	1	N.D.	N.D.	N.D.	N.D.	1
MO	N.D.	N.D.	N.D.	N.D.	N.D.	13
NB	22	15	15	16	14	18
SC	35	13	25	23	5	40
SR	115	16	45	65	7	13
V	250	120	185	155	65	200
Y	17	4	10	6	2	17
ZR	70	20	35	23	17	55

MAJOR OXIDE LISTING

	83NFT-1249	83NFT-1250	83NFT-1251	84NFT-4052	84NFT-4067	84NFT-4225
SiO2	51.10	50.90	46.80	50.90	75.40	52.20
TiO2	0.86	1.67	0.78	1.86	0.25	1.30
Al2O3	17.20	13.80	14.80	14.50	13.60	10.70
Fe2O3	2.85	3.34	2.49	3.46	0.24	2.24
FeO	7.35	6.55	8.65	9.33	0.43	10.60
MnO	0.15	0.18	0.21	0.34	0.02	0.19
MgO	3.78	4.36	8.65	4.07	0.19	8.16
CaO	9.36	11.90	10.10	6.50	0.38	8.26
Na2O	2.61	3.76	1.97	4.21	4.20	3.12
K2O	0.79	00.00	1.03	0.12	2.80	0.04
P2O5	0.02	0.06	00.00	0.07	00.00	0.03
CO2	0.65	0.40	0.27	0.73	0.21	0.15
S	0.04	0.02	0.03	0.17	0.06	0.23
H2O+	2.39	1.91	3.16	3.51	0.96	2.24
H2O-	0.15	0.21	0.11	0.13	0.04	0.18
LOI	2.80	1.90	3.00	3.70	0.90	2.30
TOTAL	79.30	99.10	99.00	99.90	98.80	99.60

TRACE ELEMENT LISTING

	83NFT-1249	83NFT-1250	83NFT-1251	84NFT-4052	84NFT-4067	84NFT-4225
AU	N.D.	N.D.	11			
BA	200	60	260			
CO	31	28	53	58	6	57
CR	44	113	293	72	N.D.	100
CU	84	14	107	105	9	144
LI	22	34	42			
NI	32	40	133	45	N.D.	86
PB	N.D.	N.D.	N.D.	14	75	10
ZN	86	72	104	220	32	102
BE	1	1	N.D.	3	5	2
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	16	25	18	7	47	8
SC	30	45	30	60	N.D.	24
SR	260	330	160	235	95	50
V	165	335	205	470	11	265
Y	12	30	9	45	150	21
ZR	50	55	35	40	455	75
TH				N.D.	N.D.	N.D.
RB				N.D.	45	N.D.
SR				190	70	48
Y				39	270	18
ZR				115	360	95

MAJOR OXIDE LISTING

	84NFT-4269	84NFT-5008	84NFT-5015	84NFT-5026	84NFT-5050	84NFT-5063
SiO ₂	44.80	81.50	52.20	76.00	47.70	50.20
TiO ₂	0.47	0.31	0.77	0.21	1.41	0.61
Al ₂ O ₃	7.69	7.93	14.40	11.60	13.30	9.43
Fe ₂ O ₃	1.35	0.03	3.07	0.36	3.37	0.64
FeO	8.90	0.68	4.71	2.14	11.00	8.90
MnO	0.18	0.02	0.13	0.04	0.26	0.16
MgO	21.40	0.23	5.98	0.39	5.89	15.30
CaO	7.93	0.33	5.98	0.34	9.82	7.92
Na ₂ O	0.04	3.25	4.05	3.24	1.34	2.15
K ₂ O	0.01	1.02	2.95	3.37	0.40	0.04
P ₂ O ₅	00.00	00.00	0.63	00.00	0.03	00.00
CO ₂	0.41	0.22	2.28	0.27	1.01	0.10
S	0.01	0.02	0.08	0.01	0.13	0.01
H ₂ O+	5.11	1.19	1.85	1.31	3.35	3.21
H ₂ O-	0.27	0.05	0.09	0.05	0.15	0.11
LOI	6.00	0.90	4.60	0.70	4.10	3.60
TOTAL	98.60	98.80	99.20	99.30	99.20	98.80

TRACE ELEMENT LISTING

	84NFT-4269	84NFT-5008	84NFT-5015	84NFT-5026	84NFT-5050	84NFT-5063
CO	78	N.D.	32	N.D.	49	56
CR	2610	12	185	N.D.	136	1390
CU	61	11	53	7	101	49
NI	940	N.D.	60	N.D.	67	335
PB	N.D.	29	36	12	N.D.	N.D.
ZN	84	38	190	67	170	81
BE	N.D.	1	4	6	2	1
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	5	15	6	49	8	N.D.
SC	20	4	17	N.D.	35	30
SR	12	90	1855	40	155	60
V	160	4	145	9	380	200
Y	12	35	25	175	25	12
ZR	30	295	175	375	45	35
TH	N.D.	N.D.	11	N.D.	N.D.	N.D.
RB	N.D.	22	85	38	9	N.D.
SR	13	65	1645	37	145	60
Y	N.D.	75	22	265	33	9
ZR	48	320	195	345	100	60

MAJOR OXIDE LISTING

	84NFT-5064	84NFT-5080	84NFT-5084	84NFT-5104	84NFT-5127	84NFT-5169
SiO2	78.20	51.90	58.60	50.90	50.70	48.40
TiO2	0.20	1.95	0.44	1.71	1.39	0.64
Al2O3	10.90	12.80	8.76	12.80	11.40	13.20
Fe2O3	0.02	4.12	0.69	2.28	2.44	2.17
FeO	0.26	11.40	6.51	12.00	10.80	8.05
MnO	0.01	0.23	0.17	0.20	0.22	0.16
MgO	0.06	3.64	8.82	5.03	7.08	10.50
CaO	0.18	6.79	9.54	6.45	10.00	10.50
Na2O	0.07	2.52	2.94	2.98	2.06	2.74
K2O	8.13	1.64	0.10	0.12	0.63	0.03
P2O5	00.00	0.21	00.00	0.07	0.04	00.00
CO2	0.11	0.55	0.85	0.76	0.12	0.13
S	0.01	0.09	0.07	0.06	0.06	0.02
H2O+	1.24	1.00	1.98	4.01	2.70	3.13
H2O-	0.06	0.16	0.10	0.17	0.06	0.05
LOI	0.40	1.80	2.10	4.00	1.70	2.30
TOTAL	99.50	99.00	99.60	99.50	99.70	99.70

TRACE ELEMENT LISTING

	84NFT-5064	84NFT-5080	84NFT-5084	84NFT-5104	84NFT-5127	84NFT-5169
CO	N.D.	44	42	47	53	52
CR	N.D.	36	760	12	256	900
CU	6	121	58	118	153	66
NI	N.D.	32	179	21	95	265
PB	N.D.	N.D.	19	N.D.	121	N.D.
ZN	29	200	64	170	160	90
BE	2	3	N.D.	2	2	1
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	42	15	5	10	8	N.D.
SC	N.D.	35	20	17	24	25
SR	25	165	50	50	235	230
V	5	375	145	285	260	200
Y	145	50	12	25	22	10
ZR	360	200	25	95	40	40
TH	N.D.	10	N.D.	N.D.	N.D.	N.D.
RB	110	49	N.D.	N.D.	N.D.	N.D.
SR	23	145	45	48	225	230
Y	145	49	N.D.	22	20	8
ZR	315	200	49	120	115	80

MAJOR OXIDE LISTING

	84NFT-5178	84NFT-5181	84NFT-5194	84NFT-5202	84NFT-5212	85NFT-0005
SiO2	51.00	49.30	49.70	55.20	48.70	47.90
TiO2	0.66	1.27	1.54	0.66	0.57	1.24
Al2O3	13.20	9.03	13.20	15.90	11.10	15.70
Fe2O3	1.47	2.34	1.92	1.98	1.45	1.52
FeO	7.53	10.70	12.00	5.74	7.70	7.28
MnO	0.14	0.23	0.27	0.14	0.16	0.14
MgO	10.20	9.29	6.23	5.09	12.30	6.17
CaO	9.67	12.40	8.72	6.72	10.20	8.24
Na2O	3.41	2.70	4.40	3.54	2.41	2.38
K2O	0.06	0.08	0.06	0.84	0.01	0.38
P2O5	00.00	00.00	0.05	0.06	00.00	0.11
CO2	0.08	0.12	0.34	1.28	1.24	5.89
S	0.02	0.01	0.31	0.19	0.33	0.20
H2O+	2.58	1.99	2.80	2.57	3.44	3.59
H2O-	0.04	0.09	0.16	0.05	0.10	0.09
LOI	2.30	1.60	2.50	3.20	4.00	9.90
TOTAL	100.00	99.60	99.70	99.90	99.70	100.80

TRACE ELEMENT LISTING

	84NFT-5178	84NFT-5181	84NFT-5194	84NFT-5202	84NFT-5212	85NFT-0005
AU						4
CO	49	59	59	31	123	49
CR	895	93	151	164	2360	253
CU	71	325	96	46	82	74
NI	255	131	74	21	1640	176
PB	13	N.D.	13	N.D.	N.D.	13
ZN	75	132	106	82	125	120
BE	1	2	2	1	1	2
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	N.D.	8	8	5	5	7
SC	30	40	35	19	30	25
SR	125	65	60	280	30	185
V	200	310	360	170	200	200
Y	10	22	25	12	14	10
ZR	45	65	50	75	30	45
TH	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
RB	N.D.	N.D.	N.D.	17	N.D.	6
SR	120	70	60	265	34	145
Y	6	20	27	8	9	18
ZR	70	90	105	105	55	120

MAJOR OXIDE LISTING

	85NFT-0008	85NFT-0012	85NFT-0014	85NFT-0016	85NFT-0017	85NFT-0019
SiO2	53.00	64.60	51.80	55.70	51.70	67.60
TiO2	2.38	0.55	0.78	0.65	0.92	0.54
Al2O3	15.00	15.00	13.30	12.00	13.60	16.80
FE2O3	1.95	1.31	2.73	1.84	3.03	0.60
FeO	7.79	4.19	7.36	5.82	5.48	1.88
MnO	0.15	0.06	0.15	0.12	0.17	00.00
MgO	4.56	2.97	9.36	7.26	6.15	1.46
CaO	6.24	1.91	6.00	7.10	8.05	0.72
Na2O	5.28	4.73	2.64	3.50	4.67	7.86
K2O	0.06	1.35	0.84	0.65	0.91	0.82
P2O5	0.19	0.16	0.08	0.11	0.26	0.08
CO2	0.82	1.27	1.43	2.90	3.68	0.07
S	0.42	0.24	0.01	0.01	0.01	0.04
H2O+	2.63	2.53	3.91	3.00	2.71	1.51
H2O-	0.09	0.07	0.13	0.06	0.03	0.05
LOI	3.10	3.50	5.00	5.70	6.10	1.40
TOTAL	100.50	100.90	100.50	100.70	101.30	100.00

TRACE ELEMENT LISTING

	85NFT-0008	85NFT-0012	85NFT-0014	85NFT-0016	85NFT-0017	85NFT-0019
AU	N.D.	7	2	4	3	2
CO	44	20	39	31	28	11
CR	234	162	383	336	268	98
CU	61	44	26	150	35	16
NI	121	72	94	86	63	61
PB	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
ZN	135	80	112	88	116	30
BE	2	2	2	1	2	2
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	10	5	N.D.	N.D.	6	5
SC	35	10	35	30	25	9
SR	200	495	245	225	290	145
V	305	100	235	175	190	95
Y	30	7	17	18	15	N.D.
ZR	65	115	70	70	125	135
TH	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
RB	N.D.	40	6	N.D.	9	15
SR	155	370	190	175	270	140
Y	24	5	11	8	14	5
ZR	140	140	100	95	145	130

MAJOR OXIDE LISTING

	85NFT-0021	85NFT-0023	84NFT-4038	84NFT-4069	84NFT-4072	84NFT-4078
SiO ₂	86.40	65.40	65.60	47.00	58.20	48.50
TiO ₂	0.22	0.52	0.51	1.65	1.36	1.21
Al ₂ O ₃	3.49	14.40	16.30	13.70	11.70	15.00
Fe ₂ O ₃	0.66	1.56	0.90	4.00	1.80	2.70
FeO	1.88	3.60	2.57	10.60	9.16	9.93
MnO	00.00	0.04	0.03	0.23	0.20	0.24
MgO	4.35	2.82	1.59	6.13	2.41	5.58
CaO	0.76	1.82	1.52	9.32	4.73	8.78
Na ₂ O	0.46	5.61	6.87	2.20	3.77	2.06
K ₂ O	0.02	1.20	1.90	0.25	0.35	1.72
P ₂ O ₅	0.03	0.13	0.09	0.10	0.21	0.12
CO ₂	0.73	0.56	0.21	0.30	3.40	0.48
S	0.01	0.86	0.11	0.06	0.07	0.06
H ₂ O+	2.16	0.54	1.57	3.24	3.10	2.97
H ₂ O-	0.04	0.02	0.05	00.00	00.00	0.11
LOI	2.50	2.30	0.90	2.40	5.00	2.30
TOTAL	101.20	99.10	99.80	98.80	100.40	99.50

TRACE ELEMENT LISTING

	85NFT-0021	85NFT-0023	84NFT-4038	84NFT-4069	84NFT-4072	84NFT-4078
AU	9	100	4	N.D.	2	N.D.
CO	39	20	13	46	19	44
CR	1290	175	51	142	15	162
CU	8	48	12	82	28	131
NI	695	69	21	70	8	67
PB	N.D.	11	N.D.	N.D.	N.D.	N.D.
ZN	36	96	40	147	144	134
BE	N.D.	2	2	2	2	2
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	N.D.	5	N.D.	9	13	9
SC	14	10	5	40	25	25
SR	13	795	275	315	135	220
V	75	110	65	370	140	305
Y	N.D.	7	10	30	40	23
ZK	7	115				
TH	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
RB	N.D.	55	40	N.D.	N.D.	60
SR	11	635	245	295	115	210
Y	N.D.	8	N.D.	26	75	25
ZR	29	160	125	125	260	115

MAJOR OXIDE LISTING

	84NFT-4091	84NFT-4174	84NFT-4230	84NFT-4233	84NFT-4243	84NFT-4247
SiO2	46.20	51.00	47.10	50.90	48.00	44.40
TiO2	1.62	1.23	1.66	0.76	1.45	1.62
Al2O3	12.60	13.40	14.00	14.50	13.30	11.70
Fe2O3	2.80	3.00	4.10	1.67	3.30	5.00
FeO	11.00	11.00	11.30	8.13	12.00	11.50
MnO	0.22	0.24	0.20	0.15	0.23	0.25
MgO	5.88	4.53	4.13	6.89	5.72	4.01
CaO	8.58	9.90	5.37	9.75	8.77	10.30
Na2O	1.21	1.97	3.69	3.23	2.48	2.64
K2O	0.02	0.15	0.45	0.17	0.50	0.25
P2O5	0.14	0.09	0.07	0.07	0.07	0.13
CO2	4.10	0.21	3.37	0.24	0.08	3.80
S	0.03	0.11	0.02	0.07	0.16	0.16
H2O+	4.60	3.04	3.96	3.00	3.19	3.27
H2O-	0.06	0.06	0.10	0.08	0.07	0.09
LOI	7.80	2.00	7.10	2.30	2.10	5.60
TOTAL	99.10	99.90	99.50	99.60	99.30	99.90

TRACE ELEMENT LISTING

	84NFT-4091	84NFT-4174	84NFT-4230	84NFT-4233	84NFT-4243	84NFT-4247
AU	N.D.	N.D.	N.D.	3	N.D.	N.D.
CO	42	44	48	39	52	46
CR	140	14	N.D.	279	71	21
CU	76	40	40	90	126	97
NI	64	21	28	58	42	19
PB	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
ZN	146	144	175	107	185	180
BE	2	2	2	1	2	2
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	8	11	9	N.D.	9	9
SC	40	45	19	30	35	45
SR	85	115	235	210	120	115
V	350	350	300	215	390	395
Y	30	40	25	15	25	35
TH	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
RB	N.D.	N.D.	10	N.D.	9	N.D.
SR	80	110	210	190	120	110
Y	24	37	20	6	25	31
ZR	105	115	120	80	95	115

MAJOR OXIDE LISTING

	84NFT-4260	84NFT-4275	84NFT-4280	84NFT-4285	84NFT-4301	84NFT-4302
SiO ₂	48.70	51.30	49.10	86.00	44.60	51.00
TiO ₂	1.85	1.07	1.14	0.26	1.76	2.00
Al ₂ O ₃	12.20	14.70	9.75	6.11	11.80	15.00
Fe ₂ O ₃	4.00	3.76	2.60	0.51	3.10	1.90
FeO	12.00	7.96	10.20	1.28	18.30	11.50
MnO	0.24	0.19	0.17	00.00	0.57	0.23
MgO	5.56	5.04	8.47	0.79	3.51	4.02
CaO	9.72	7.92	12.10	1.12	8.80	5.16
Na ₂ O	1.51	2.76	1.29	2.57	2.71	3.14
K ₂ O	0.27	0.49	0.04	0.01	0.38	0.96
P ₂ O ₅	0.13	0.11	0.12	0.01	0.13	0.13
CO ₂	0.24	0.29	0.33	0.23	0.13	0.21
S	0.17	0.04	0.05	0.01	0.01	0.01
H ₂ O+	2.46	3.38	3.08	0.95	3.09	3.53
H ₂ O-	00.00	0.07	00.00	00.00	0.09	0.07
LOI	1.80	2.70	2.10	0.60	1.50	2.10
TOTAL	99.10	99.10	98.40	99.80	99.00	98.90

TRACE ELEMENT LISTING

	84NFT-4260	84NFT-4275	84NFT-4280	84NFT-4285	84NFT-4301	84NFT-4302
AU	N.D.	5	N.D.	2	N.D.	N.D.
CO	47	41	52	10	50	49
CR	99	10	605	N.D.	20	22
CU	112	20	125	56	30	46
NI	39	27	131	10	26	29
PB	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
ZN	160	85	91	42	185	165
BE	2	2	1	N.D.	2	2
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	11	7	9	7	12	9
SC	40	35	40	4	50	35
SR	110	180	150	18	145	205
V	415	300	235	20	405	470
Y	35	20	24	25	55	40
TH	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
RB	N.D.	N.D.	N.D.	N.D.	19	27
SR	115	160	135	16	135	195
Y	39	13	17	15	48	45
ZR	130	90	90	130	130	140

MAJOR OXIDE LISTING

	84NFT-4310	84NFT-4311	84NFT-5013	84NFT-5021	84NFT-5025	84NFT-5029
SiO ₂	50.40	48.00	42.70	57.80	64.80	42.60
TiO ₂	0.72	1.45	0.73	1.65	0.72	0.54
Al ₂ O ₃	15.00	13.40	13.90	13.10	11.60	8.05
Fe ₂ O ₃	1.28	3.60	1.70	7.99	2.10	2.12
FeO	8.48	11.10	9.16	5.14	9.50	8.90
MnO	0.17	0.21	0.21	0.16	0.13	0.10
MgO	7.60	5.89	6.02	2.51	1.14	20.80
CaO	9.61	8.74	7.50	2.46	1.87	8.08
Na ₂ O	3.08	2.61	2.17	4.71	3.02	0.31
K ₂ O	0.27	0.29	1.06	0.34	0.01	0.04
P ₂ O ₅	0.08	0.11	0.04	0.20	0.11	0.03
CO ₂	0.12	0.16	11.10	0.39	1.17	0.20
S	0.01	0.19	0.02	0.02	0.03	0.05
H ₂ O+	3.50	4.04	3.03	2.69	2.70	6.66
H ₂ O-	00.00	0.06	0.05	0.11	00.00	0.24
LOI	2.10	2.50	13.30	2.40	2.60	6.30
TOTAL	100.30	99.80	99.40	99.30	98.90	98.70

TRACE ELEMENT LISTING

	84NFT-4310	84NFT-4311	84NFT-5013	84NFT-5021	84NFT-5025	84NFT-5029
AU	N.D.	N.D.	15	N.D.	N.D.	N.D.
CO	40	49	40	26	N.D.	88
CR	232	89	230	10	N.D.	3680
CU	88	128	60	19	18	36
NI	60	43	103	N.D.	N.D.	1200
PR	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
ZN	99	160	92	125	190	89
BE	1	2	1	2	2	N.D.
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	6	10	5	14	22	5
SC	35	40	30	30	18	23
SR	160	130	245	75	40	10
V	220	315	215	160	6	180
Y	16	40	7	75	135	13
TH	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
RB	N.D.	N.D.	50	N.D.	N.D.	N.D.
SR	145	120	205	70	40	16
Y	10	33	8	75	145	5
ZR	75	115	70	240	465	48

MAJOR OXIDE LISTING

	84NFT-5037	84NFT-5040	84NFT-5056	84NFT-5058	84NFT-5070	84NFT-5092
SiO ₂	37.30	44.50	48.30	44.90	39.60	49.70
TiO ₂	0.21	1.60	2.09	1.70	0.49	1.01
Al ₂ O ₃	2.88	13.50	12.70	14.70	7.54	7.27
Fe ₂ O ₃	6.74	4.40	5.90	3.00	3.30	3.40
FeO	4.02	10.40	10.90	13.90	8.73	9.42
MnO	00.00	0.15	0.22	0.27	0.13	0.24
MgO	35.40	5.44	4.46	4.95	25.00	10.50
CaO	0.12	9.67	7.50	6.75	4.34	11.90
Na ₂ O	0.16	3.13	3.05	3.34	0.16	1.89
K ₂ O	00.00	0.35	0.10	0.31	0.04	0.14
P ₂ O ₅	00.00	0.13	0.15	0.16	0.04	0.02
CO ₂	0.16	2.91	0.40	0.16	0.24	0.27
S	0.15	0.01	0.15	0.14	0.05	0.06
H ₂ O+	11.50	3.22	3.01	4.12	9.23	2.43
H ₂ O-	0.16	0.12	0.15	0.13	0.37	0.09
LOI	11.90	5.80	3.10	3.60	9.20	2.30
TOTAL	98.80	99.50	99.10	98.50	99.30	98.30

TRACE ELEMENT LISTING

	84NFT-5037	84NFT-5040	84NFT-5056	84NFT-5058	84NFT-5070	84NFT-5092
AU	N.D.	2	N.D.	N.D.	N.D.	3
CO	94	52	43	51	91	60
CR	2400	28	27	14	2510	203
CU	58	124	83	184	24	415
NI	2400	60	27	46	1500	192
PB	N.D.	10	N.D.	N.D.	N.D.	N.D.
ZN	51	95	185	170	78	121
BE	N.D.	2	2	2	N.D.	2
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	N.D.	9	11	11	N.D.	6
SC	7	23	45	20	20	65
SR	7	130	240	210	11	30
V	60	290	520	320	160	355
Y	N.D.	30	45	30	12	21
TH	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
RB	N.D.	16	N.D.	5	N.D.	N.D.
SR	7	110	210	195	12	34
Y	N.D.	22	43	29	N.D.	13
ZR	26	125	135	135	44	65

MAJOR OXIDE LISTING

	84NFT-5094	84NFT-5099	84NFT-5110	84NFT-5115	84NFT-5126	84NFT-5149
SiO2	47.40	53.10	48.40	53.10	51.60	51.20
TiO2	2.14	1.20	1.46	0.74	1.36	1.40
Al2O3	13.10	11.30	13.10	16.50	12.40	11.00
Fe2O3	6.18	1.90	4.30	4.35	3.30	4.20
FeO	8.48	9.16	9.50	4.88	10.40	10.20
MnO	0.20	0.18	0.22	0.15	0.21	0.22
MgO	3.97	5.77	5.19	5.06	5.26	6.06
CaO	5.54	9.47	9.12	8.54	6.81	10.50
Na2O	4.47	3.99	3.95	3.35	2.86	1.18
K2O	0.48	0.12	0.28	0.10	0.76	0.08
P2O5	0.08	0.11	0.11	0.12	0.09	0.10
CO2	2.39	0.64	0.12	0.13	0.25	0.66
S	0.01	0.07	0.11	0.01	0.11	0.10
H2O+	3.84	2.32	2.69	2.90	2.81	2.85
H2O-	0.06	00.00	0.05	00.00	0.23	0.12
LOI	6.00	1.90	2.20	2.40	2.50	2.50
TOTAL	98.30	99.30	98.60	99.90	98.50	99.90

TRACE ELEMENT LISTING

	84NFT-5094	84NFT-5099	84NFT-5110	84NFT-5115	84NFT-5126	84NFT-5149
AU	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CD	49	47	45	26	43	47
CR	N.D.	100	64	138	61	79
CU	18	194	130	38	94	120
NI	37	79	38	29	36	76
PB	N.D.	N.D.	N.D.	11	N.D.	N.D.
ZN	142	126	137	100	142	155
BE	2	2	2	1	2	2
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	9	8	8	5	6	9
SC	24	30	50	30	45	30
SR	65	65	160	660	60	335
V	445	240	405	215	365	265
Y	24	22	35	16	30	25
TH	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
RB	16	N.D.	N.D.	N.D.	23	N.D.
SR	60	60	140	565	60	285
Y	18	15	30	9	22	18
ZR	95	95	105	115	85	115

MAJOR OXIDE LISTING

	84NFT-5167	84NFT-5184	84NFT-5189	84NFT-5190	84NFT-5192	84NFT-5196
SiO ₂	45.90	46.70	48.30	50.40	50.20	68.70
TiO ₂	0.64	1.89	1.20	0.82	1.46	0.33
Al ₂ O ₃	12.20	13.90	14.80	6.48	12.80	15.20
Fe ₂ O ₃	3.00	4.00	4.01	2.90	3.50	1.01
FeO	9.25	13.10	8.90	9.33	9.93	2.05
MnO	0.15	0.19	0.20	0.20	0.28	0.03
MgO	14.30	4.07	6.01	11.70	3.91	1.28
CaO	7.18	7.09	8.99	14.20	9.26	2.87
Na ₂ O	1.66	4.19	2.51	1.70	1.78	6.19
K ₂ O	0.06	0.20	0.17	0.03	0.12	0.54
P ₂ O ₅	0.03	0.10	0.13	0.04	0.15	0.07
CO ₂	0.57	0.09	0.28	0.19	2.60	0.18
S	0.03	0.02	0.06	0.02	0.11	0.02
H ₂ O ⁺	4.50	3.22	3.52	1.66	3.04	1.34
H ₂ O ⁻	0.20	0.20	0.14	0.06	0.12	0.08
LOI	5.10	2.40	3.00	1.50	5.00	1.10
TOTAL	99.70	99.00	99.20	99.70	99.30	99.90

TRACE ELEMENT LISTING

	84NFT-5167	84NFT-5184	84NFT-5189	84NFT-5190	84NFT-5192	84NFT-5196
AU	N.D.	N.D.	N.D.	28	N.D.	N.D.
CO	70	55	43	57	44	9
CR	1600	12	272	320	27	34
CU	70	86	91	535	92	8
NI	570	26	62	265	27	11
FB	N.D.	N.D.	N.D.	N.D.	N.D.	11
ZN	112	200	116	110	144	65
BE	1	2	1	1	2	1
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	6	10	8	8	9	N.D.
SC	30	23	40	55	45	7
SR	55	165	90	50	160	240
V	190	305	285	275	320	50
Y	12	30	35	17	45	6
TH	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
RB	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
SR	55	150	80	55	140	185
Y	N.D.	20	28	10	36	N.D.
ZR	60	115	105	60	130	100

MAJOR OXIDE LISTING

	84NFT-5200	84NFT-5205	84NFT-5218	84NFT-5222	84NFT-5231	84NFT-5232
SiO2	51.60	49.40	47.10	48.30	64.40	48.10
TiO2	0.63	1.46	1.67	2.01	0.43	1.53
Al2O3	17.90	13.20	13.90	12.10	16.20	14.20
Fe2O3	1.77	3.60	2.80	4.40	1.44	3.70
FeO	5.22	10.40	16.10	13.80	2.48	13.80
MnO	0.14	0.29	0.19	0.27	0.07	0.21
MgO	4.66	4.90	2.74	3.52	2.29	3.66
CaO	9.19	8.38	6.94	7.29	4.03	7.24
Na2O	4.77	2.44	3.48	2.52	4.79	3.44
K2O	0.27	0.35	0.21	0.04	0.75	0.15
P2O5	0.21	0.10	0.19	0.14	0.09	0.14
CO2	0.17	1.60	0.13	0.37	0.16	0.45
S	0.01	0.10	0.01	0.19	0.01	0.07
H2O+	1.76	3.47	3.42	3.47	1.75	3.32
H2O-	0.08	0.13	0.18	0.13	0.05	0.10
LOI	1.50	3.80	2.10	2.90	1.50	1.90
TOTAL	98.40	99.80	99.10	98.60	98.90	100.10

TRACE ELEMENT LISTING

	84NFT-5200	84NFT-5205	84NFT-5218	84NFT-5222	84NFT-5231	84NFT-5232
AU	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
CO	25	49	51	48	13	47
CR	159	115	N.D.	N.D.	79	17
CU	5	106	14	100	8	44
NI	30	109	N.D.	11	22	46
PB	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
ZN	58	170	122	210	63	118
BE	1	2	2	2	1	2
MO	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
NB	6	8	13	11	N.D.	10
SC	22	55	17	50	9	25
SR	475	90	230	120	390	120
V	170	420	80	425	85	300
Y	19	40	45	55	8	30
TH	N.D.	N.D.	N.D.	N.D.	N.D.	N.D.
RB	N.D.	N.D.	N.D.	N.D.	12	N.D.
SR	420	80	220	110	320	115
Y	10	30	37	44	N.D.	22
ZR	115	95	155	135	110	120

MAJOR OXIDE STATISTICS

318.

TOTAL NUMBER OF SAMPLES:

54

	MEAN	STD. DEVIATION
SI02	50.12	8.64
AL2O3	12.36	3.31
FE2O3	3.18	1.57
FeO	9.28	3.66
MgO	7.30	7.56
CaO	7.43	3.45
Na2O	2.74	1.57
K2O	0.37	0.44
TiO2	1.15	0.56
P2O5	0.10	0.05
MnO	0.19	0.10
CO2	1.30	2.55
S	0.07	0.06
H2O+	3.58	2.06
H2O-	0.10	0.08
LOI	4.03	3.37
TOTAL	99.26	0.54

TRACE ELEMENT STATISTICS

319.

	NO. OF SAMPLES	MEAN	STD. DEVIATION
AU	56	-0.30	4.85
CO	56	45.82	20.96
CR	56	429.04	913.46
CU	56	83.50	89.82
NI	56	236.96	533.58
PB	56	-8.89	4.70
ZN	56	122.64	45.87
BE	56	1.37	1.00
MO	56	-10.00	0.00
NB	56	6.52	6.06
SC	56	30.36	14.64
SR	56	160.50	125.03
V	56	251.98	130.18
Y	56	27.84	21.30
TH	56	-10.00	0.00
RB	56	3.71	16.97
SR	56	144.77	106.28
Y	56	22.32	24.98
ZR	56	112.09	63.69

MAJOR OXIDE LISTING

	DBA-85-62	DBA-85-63	DBA-85-64	DBA-85-65	DBA-85-LF8	DBA-85-67
SiO2	50.40	50.40	46.40	51.90	49.30	49.50
AL2O3	10.40	11.40	9.12	9.80	9.80	9.38
FE2O3	0.50	0.70	0.70	0.90	0.60	0.80
FeO	9.30	9.50	10.10	9.00	9.50	8.80
MGO	14.00	11.70	18.10	12.80	15.30	16.40
CAO	6.32	6.44	7.16	7.62	6.68	7.52
NA2O	2.61	3.35	1.03	2.86	2.10	1.77
K2O	0.07	0.08	0.05	0.06	0.06	0.06
TiO2	0.55	0.62	0.44	0.52	0.56	0.52
P2O5	0.06	0.06	0.05	0.08	0.05	0.05
MNO	0.18	0.19	0.18	0.18	0.19	0.17
CO2	0.10	0.30	00.00	0.10	0.10	0.20
S	00.00 .01	0.18	0.01	0.06	0.01	00.00
H2O+	4.30	4.00	5.30	3.59	4.60	4.70
TOTAL	98.90	99.10	98.90	99.69	99.10	100.10

TRACE ELEMENT LISTING

	DBA-85-62	DBA-85-63	DBA-85-64	DBA-85-65	DBA-85-LF8	DBA-85-67
BA	60.00	60.00	40.00	40.00	50.00	50.00
CO	65.00	72.00	110.00	110.00	75.00	76.00
CR	600.00	620.00	1300.00	1100.00	880.00	1200.00
CU	81.00	91.00	59.00	70.00	78.00	59.00
NI	220.00	230.00	620.00	290.00	240.00	440.00
ZN	85.00	96.00	85.00	120.00	100.00	100.00
BE	0.50	0.60	0.40	0.80	0.40	0.40
V	210.00	230.00	200.00	200.00	220.00	210.00
YB	2.20	2.40	1.90	1.90	2.10	1.80

MAJOR OXIDE LISTING

	DBA-85-68	DBA-85-69	DBA-85-70	DBA-85-71	DBA-85-72	DBA-85-73
SiO ₂	42.90	41.80	43.10	48.00	49.20	48.60
Al ₂ O ₃	9.10	4.38	8.29	9.39	11.10	10.80
Fe ₂ O ₃	0.50	3.50	1.10	1.20	0.20	1.20
FeO	9.70	5.60	9.50	9.30	9.60	10.00
MgO	21.10	31.30	22.70	17.00	11.80	13.30
CaO	8.05	2.93	6.22	8.42	5.93	7.28
Na ₂ O	0.14	0.12	0.13	1.11	2.88	2.17
K ₂ O	0.03	0.04	0.03	0.07	0.11	0.09
TiO ₂	0.52	0.23	0.42	0.50	0.66	0.50
P ₂ O ₅	0.07	0.01	0.03	0.02	0.11	0.04
MnO	0.18	0.13	0.17	0.18	0.16	0.19
CO ₂	00.00	0.20	00.00	00.00	0.50	0.60
S	0.04	0.07	0.01	0.01	0.09	0.07
H ₂ O+	6.30	9.70	7.10	4.70	4.20	3.60
TOTAL	99.00	100.40	99.20	100.10	96.70	98.60

TRACE ELEMENT LISTING

	DBA-85-68	DBA-85-69	DBA-85-70	DBA-85-71	DBA-85-72	DBA-85-73
BA	40.00	30.00	30.00	50.00	100.00	30.00
CO	100.00	99.00	90.00	81.00	70.00	69.00
CR	2200.00	1700.00	2200.00	1500.00	770.00	740.00
CU	140.00	20.00	43.00	55.00	77.00	65.00
NI	1000.00	1600.00	820.00	400.00	240.00	220.00
ZN	93.00	68.00	81.00	80.00	85.00	87.00
BE	0.50	0.20	0.30	0.40	0.40	0.50
V	210.00	110.00	190.00	190.00	230.00	230.00
YB	1.90	1.30	2.00	2.00	2.20	2.80

MAJOR OXIDE LISTING.

	DBA-85-74	DBA-85-75	DBA-85-76	AB01187	AB01188	AB01189
SiO2	47.80	47.60	92.00	47.09	49.70	54.59
AL2O3	10.60	9.45	3.00	12.80	11.80	14.89
FE2O3	0.50	0.60	00.00	15.80	18.60	9.18
FeO	9.70	9.80	2.60	00.00	00.00	00.00
HgO	15.29	17.10	1.29	7.51	4.21	3.08
CAD	6.36	7.94	0.14	9.52	5.78	11.69
NA2O	1.95	0.95	0.11	1.87	3.25	1.96
K2O	0.06	0.05	0.24	0.57	0.54	0.14
TiO2	0.54	0.51	0.06	1.21	1.92	0.72
P2O5	0.04	0.06	0.03	0.09	0.15	0.15
MNO	0.18	0.18	0.03	0.25	0.23	0.18
CO2	0.30	0.30	00.00	00.00	00.00	00.00
S	0.03	0.02	0.01	00.00	00.00	00.00
H2O+	5.20	5.10	1.40	00.00	00.00	00.00
LOI	00.00	00.00	00.00	2.80	2.70	3.20
TOTAL	98.70	99.90	101.40	99.59	99.00	100.00

TRACE ELEMENT LISTING

	DBA-85-74	DBA-85-75	DBA-85-76	AB01187	AB01188	AB01189
AG	0.00	0.00	0.00	34411.00	0.50	0.00
AS	0.00	0.00	140.00	0.00	-2.00	0.00
AU	0.00	0.00	0.00	0.00	-20.00	0.00
BA	40.00	50.00	80.00	0.00	300.00	0.00
BI	0.00	0.00	0.00	0.00	-0.50	0.00
CO	78.00	78.00	73.00	0.00	53.00	0.00
CR	990.00	1500.00	170.00	0.00	29.00	0.00
CU	51.00	68.00	52.00	0.00	94.00	0.00
NI	400.00	400.00	66.00	0.00	21.00	0.00
FB	0.00	21.00	26.00	0.00	14.00	0.00
RB	0.00	0.00	10.00	30.00	40.00	30.00
SB	0.00	0.00	0.00	0.00	-0.20	0.00
U	0.00	0.00	5.00	0.00	-0.50	0.00
ZN	130.00	110.00	34.00	0.00	150.00	0.00
MO	0.00	0.00	8.00	0.00	-5.00	0.00
BE	0.40	0.50	0.50	0.00	0.00	0.00
NB	0.00	0.00	18.00	30.00	20.00	10.00
SC	0.00	0.00	0.00	0.00	50.00	0.00
SR	65.00	27.00	6.00	180.00	120.00	1320.00
V	220.00	210.00	39.00	0.00	0.00	0.00
Y	12.00	5.00	20.00	30.00	30.00	-10.00
ZR	33.00	27.00	100.00	60.00	110.00	80.00
W	0.00	0.00	0.00	0.00	-3.00	0.00
CE	0.00	0.00	0.00	0.00	22.00	0.00
LA	0.00	0.00	0.00	0.00	6.60	0.00
ND	0.00	0.00	0.00	0.00	10.00	0.00
CS	0.00	0.00	0.00	0.00	6.40	0.00
TH	0.00	0.00	7.00	0.00	0.60	0.00
TA	0.00	0.00	0.00	0.00	-1.00	0.00
SM	0.00	0.00	0.00	0.00	4.70	0.00
EU	0.00	0.00	0.00	0.00	1.40	0.00
YB	1.90	2.20	2.60	0.00	0.00	0.00
LU	0.00	0.00	0.00	0.00	0.78	0.00

MAJOR OXIDE LISTING

	ABO1191	ABO1192	ABO1193	ABO1194	ABO1195	ABO1196
SiO2	66.00	50.90	46.90	49.30	44.70	50.20
AL2O3	17.79	12.10	12.40	10.80	12.80	11.10
FE2O3	2.47	16.60	16.50	14.70	17.20	12.00
MGO	1.77	4.13	4.87	7.38	8.72	11.70
CAO	0.73	8.52	9.75	11.20	7.14	7.75
NA2O	9.27	3.30	3.07	1.28	2.53	3.18
K2O	0.50	0.31	0.33	1.48	0.18	0.05
TiO2	0.25	1.58	1.46	1.29	1.78	0.66
P2O5	0.05	0.14	0.11	0.10	0.14	0.06
MNO	0.07	0.21	0.25	0.22	0.23	0.18
LOI	1.10	2.40	3.30	2.10	00.00	3.00
TOTAL	100.09	100.30	99.10	100.00	99.00	100.10

TRACE ELEMENT LISTING

	ABO1191	ABO1192	ABO1193	ABO1194	ABO1195	ABO1196
AG	-0.50	-0.50	0.50	0.50	0.50	-0.50
AS	-2.00	-2.00	2.00	-2.00	-2.00	-2.00
AU	-20.00	0.00	-20.00	0.00	-20.00	-20.00
BA	200.00	200.00	200.00	900.00	-150.00	-150.00
BI	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
CO	13.00	51.00	51.00	58.00	75.00	52.00
CR	110.00	54.00	85.00	140.00	89.00	1100.00
CU	38.00	110.00	110.00	200.00	280.00	76.00
NI	55.00	30.00	41.00	95.00	110.00	180.00
PB	0.00	18.00	16.00	20.00	60.00	18.00
RB	10.00	30.00	20.00	20.00	10.00	20.00
SB	-0.20	-0.20	0.30	0.70	0.40	0.30
U	-0.50	-0.50	17.00	-0.50	-0.50	-0.50
ZN	51.00	120.00	130.00	130.00	280.00	95.00
MO	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00
NB	20.00	30.00	20.00	20.00	20.00	10.00
SC	4.80	51.00	58.00	34.00	43.00	45.00
SR	110.00	100.00	130.00	120.00	40.00	80.00
Y	-10.00	20.00	20.00	20.00	30.00	30.00
ZR	40.00	100.00	0.00	80.00	120.00	10.00
W	0.00	-3.00	70.00	3.00	4.00	-3.00
CE	11.00	21.00	17.00	19.00	21.00	9.00
LA	4.20	5.90	4.70	6.20	7.50	2.80
ND	-10.00	10.00	10.00	10.00	20.00	10.00
CS	-0.60	5.90	3.30	1.10	1.00	202.00
TH	0.50	-0.50	-0.50	0.70	0.70	-0.50
TA	0.00	-1.00	-1.00	-1.00	-1.00	-1.00
SH	0.80	4.20	3.50	3.70	4.60	1.90
EU	0.40	1.20	1.50	1.60	1.40	0.60
YB	-1.00	0.00	4.00	2.00	4.00	2.00
LU	-0.05	0.78	0.61	0.37	0.46	0.30
CD	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20
MN	390.00	1200.00	1300.00	1300.00	1400.00	1100.00
SE	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

MAJOR OXIDE LISTING

	ABO1197	ABO1198	ABO1219	ABO1220	ABO1221	ABO1222
SiO2	49.80	55.10	50.60	48.50	63.70	57.60
AL2O3	11.40	10.40	13.60	13.10	17.10	15.00
FE2O3	12.60	7.87	10.80	11.80	4.26	8.71
MGO	12.10	11.80	9.22	10.10	2.12	4.79
CAO	7.35	6.23	9.29	10.20	4.33	6.39
NA2O	2.80	4.30	2.77	1.85	5.24	4.20
K2O	0.11	0.04	0.19	0.39	1.18	0.84
TiO2	0.65	0.59	0.66	0.66	0.36	0.55
P2O5	0.05	0.05	0.07	0.07	0.14	0.12
MNO	0.17	0.14	0.20	0.20	0.07	0.15
LOI	3.30	3.30	2.00	2.00	1.60	1.60
TOTAL	100.40	100.10	99.00	99.00	100.20	100.10

TRACE ELEMENT LISTING

	ABO1197	ABO1198	ABO1219	ABO1220	ABO1221	ABO1222
AG	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
AS	-2.00	5.00	3.00	3.00	-2.00	-2.00
AU	-20.00	-20.00	-20.00	-20.00	-20.00	-20.00
BA	-150.00	-150.00	-150.00	-150.00	400.00	400.00
BI	-0.50	-0.50	-0.50	-0.50	-0.50	-0.50
CO	63.00	53.00	54.00	54.00	10.00	31.00
CR	830.00	1800.00	760.00	760.00	160.00	190.00
CU	56.00	120.00	38.00	38.00	26.00	170.00
NI	160.00	260.00	200.00	200.00	26.00	25.00
PB	14.00	12.00	20.00	20.00	16.00	16.00
RB	20.00	10.00	30.00	30.00	40.00	30.00
SB	0.30	1.00	0.50	0.50	-0.20	0.20
U	-0.50	-0.50	-0.50	-0.50	-0.50	0.60
ZN	77.00	75.00	85.00	85.00	37.00	64.00
MO	-5.00	-5.00	-5.00	-5.00	-5.00	-5.00
NB	20.00	10.00	10.00	10.00	20.00	20.00
SC	46.00	41.00	38.00	38.00	9.50	35.00
SR	70.00	10.00	260.00	260.00	720.00	500.00
Y	10.00	20.00	20.00	20.00	10.00	20.00
ZR	20.00	10.00	30.00	30.00	110.00	50.00
W	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00
CE	10.00	9.00	17.00	17.00	22.00	24.00
LA	2.80	1.70	4.40	4.40	12.30	11.00
ND	10.00	-10.00	-10.00	-10.00	10.00	10.00
CS	1.00	-0.70	-0.50	-0.50	1.20	-0.70
TH	-0.50	-0.50	-0.50	-0.50	1.70	1.60
TA	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
SM	1.80	1.30	1.70	1.70	1.90	2.20
EU	0.90	0.40	1.30	1.30	-0.40	0.80
YB	2.00	1.00	2.00	2.00	1.00	2.00
LU	0.30	0.23	0.27	0.27	0.22	0.28
CD	-0.20	-0.20	-0.20	-0.20	-0.20	-0.20
MN	820.00	730.00	1300.00	1300.00	590.00	1100.00
SE	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00

TRACE ELEMENT STATISTICS

	NO. OF SAMPLES	MEAN	STD. DEVIATION
AG	15	2295.93	8892.67
AS	15	9.13	36.29
AU	12	-20.00	0.00
BA	29	79.31	220.21
BI	14	-0.50	0.00
CO	29	66.10	24.10
CR	29	817.83	658.26
CU	29	86.03	56.27
NI	29	297.66	343.84
PB	15	20.47	11.47
RB	17	21.18	14.53
SB	14	0.26	0.37
U	15	1.18	4.60
ZN	29	98.72	44.60
MO	15	-4.13	3.36
RE	15	0.45	0.14
NB	17	18.71	6.96
SC	14	39.09	15.29
SR	19	225.68	318.45
V	15	193.27	51.71
Y	19	16.16	11.81
ZR	18	59.44	37.03
W	13	3.62	20.09
CE	14	16.71	5.20
LA	14	5.67	2.99
ND	14	5.00	10.19
CS	14	15.59	53.71
TH	15	0.59	1.94
TA	13	-0.85	0.55
SM	14	2.66	1.29
EU	14	0.99	0.57
YB	27	2.08	0.97
LU	14	0.39	0.24
CD	14	-0.20	????????
MN	14	1080.71	317.96
SE	14	-3.00	0.00

MAJOR OXIDE STATISTICS

TOTAL NUMBER OF SAMPLES:

31

	MEAN	STD. DEVIATION
SI02	51.41	9.13
AL2O3	11.14	3.00
FE2O3	6.71	6.67
FeO	4.26	4.68
MGO	11.22	6.87
CAO	7.13	2.60
NA2O	2.44	1.79
K2O	0.26	0.35
TiO2	0.74	0.47
P2O5	0.08	0.04
HNO	0.18	0.05
CO2	0.09	0.16
S	0.02	0.04
H2O+	2.38	2.80
H2O-	0.00	0.00
LOI	1.17	1.33
TOTAL	99.50	0.85

GEOCHEMICAL SAMPLE LOCATION MAP

FIGURE 8. Sketch map of the ge

N

McCOOL HILL SYNCLINE

FIGURE 10. South limb stratigraphy

- Peridotitic komatiites
- Mg-rich tholeiites
- Medial to high-Fe tholeiites
- Calc-alkalic volcanic rocks
- Porcupine Group metasedimentary rocks

igraphic columns.

5 of/de 5

7b
4a
4ad
6aljt
4d
4ad
3d
4akht

7ab fine
rhyth. layering

2c, 3s, breccia
2c, pits
(papy)

6, 5al
6abp
hl

9ae
9a
36d
3d
4ad
9ac

7a
7b
7c
7d
7e
7f
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7h
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MUNRO TOWNSHIP

LEGEND

Phanerozoic

Cenozoic

Quaternary

Pleistocene and Recent

Till, reworked till, esker sand and gravel, varved clay, dune sand, alluvium, and peat.

Unconformity

Late Precambrian

Mafic Intrusive Rocks

14 Abitibi (1.14 Ga.) diabase dike

Middle Precambrian

Mafic Intrusive Rocks

13 Preissac (2.14 Ga.) quartz diabase dikes

Intrusive Contact

Early Precambrian (Archean)

Mafic Intrusive Rocks

12 a) Matachewan (2.63 Ga.) diabase dikes

b) Matachewan diabase dikes with saussuritized feldspar phenocrysts

Intrusive Contact

Subalkalic to Alkalic Intrusive Suite

11 undivided

a) feldspar porphyry dikes -felsic matrix composition

b) feldspar porphyry dikes -intermediate matrix composition

c) lamprophyre

d) mafic phenocryst-bearing

e) rodingitized dikes

Intrusive Contact

Calc-alkalic Intrusive Suite

10 a) quartz diorite

Intrusive Contact

Mafic to Intermediate Intrusive Rocks (discordant)

a) gabbro, fine- to medium-grained

b) gabbro, coarse-grained

c) orthopyroxene phenocryst-bearing

d) diorite, fine- to medium-grained, inhomogeneous

e) diorite dike

Intrusive Contact

S

FIGURE 11. North limb stratigraphic columns

Intrusive Contact

- b) feldspar porphyry dikes - intermediate matrix composition
- c) lamprophyre
- d) mafic phenocryst-bearing
- e) rodingitized dikes

Intrusive Contact

Calc-alkalic Intrusive Suite

- 10 a) quartz diorite

Intrusive Contact

Mafic to Intermediate Intrusive Rocks (discordant)

- 9 a) gabbro, fine- to medium-grained
- b) gabbro, coarse-grained
- c) orthopyroxene phenocryst-bearing
- d) diorite, fine- to medium-grained, inhomogenous
- e) diorite dike

Intrusive Contact

Ultramafic Intrusive Rocks (sills)

- 8 unsubdivided
- a) peridotite
- b) dunite/serpentinite

Intrusive Contact? (certain ultramafic sills may immediately pre-date layered sills situated higher in the stratigraphy)

Layered Sills

- 7 a) gabbro layer
- b) clinopyroxenite layer
- c) peridotite layer
- d) dunite/serpentinite
- e) orthopyroxene phenocryst-bearing
- f) leucogabbro

Intrusive Contact

Komatiitic Metavolcanics

Basaltic Komatiite

unsubdivided

- a) aphanitic to fine-grained (<1 mm) massive lava
- b) medium-grained (1-5 mm) massive lava
- c) coarse-grained (>5 mm) massive lava
- d) pillowed lava and lava tubes
- e) pillow breccia
- f) flow-top breccia, hyaloclastite matrix
- g) olivine spinifex
- h) pyroxene spinifex, random and/or 'string-beef' types
- i) layered flow-gabbroic layer
- j) layered flow-pyroxenite layer
- k) layered flow-peridotite layer
- l) polygonal/columnar jointing
- m) variolitic lava
- n) vesicles/amygdules
- o) related dike of komatiitic composition
- p) gabbroic textured massive flow
- q) mafic (biotite) phenocryst-bearing

Peridotitic Komatiite

unsubdivided

- a) aphanitic to fine-grained (<1 mm) massive lava
- b) medium-grained (1-5 mm) massive lava
- c) coarse-grained (>5 mm) massive lava
- d) pillowed lava
- e) pillow breccia
- f) flow-top breccia, hyaloclastite matrix

- f) flow-top breccia, hyaloclastite matrix
- g) thick poudd flow -dunitic base

- g) olivine spinifex
- h) pyroxene spinifex, random and/or 'string-beef' types
- i) layered flow-gabbroic layer
- j) layered flow-pyroxenite layer
- k) layered flow-peridotite layer
- l) polygonal/columnar jointing
- m) variolitic lava
- n) vesicles/amygdules
- o) related dike of komatiitic composition
- p) gabbroic textured massive flow
- q) mafic (biotite) phenocryst-bearing

Peridotitic Komatiite

5 unsubdivided

- a) aphanitic to fine-grained (<1 mm) massive lava
- b) medium-grained (1-5 mm) massive lava
- c) coarse-grained (>5 mm) massive lava
- d) pillowed lava
- e) pillow breccia
- f) flow-top breccia, hyaloclastite matrix
- g) thick poudd flow -dunitic base
- h) olivine spinifex
- j) vesicles/amygdules
- l) polygonal/columnar jointing

Tholeiitic Metavolcanics

Marginal to Mg-rich Tholeiitic basalt

4 unsubdivided

- a) aphanitic to fine-grained (<1 mm) massive lava
- b) medium-grained (1-5 mm) massive lava
- c) coarse-grained (>5 mm) massive lava
- d) pillowed lava and lava tubes
- e) pillow breccia
- f) hyaloclastite
- g) variolitic lava
- h) vesicles/amygdules
- i) related dike of tholeiitic composition
- j) flow-top breccia, flow breccia
- k) gabbroic textured massive flow
- l) mafic phenocryst-bearing
- m) quartz phenocryst-bearing
- n) interflow sediments (graphitic chert and argillite, fine-grained pyrite)
- o) close-packed flow breccia (picritic composition), -fine to medium size, well sorted, sub-angular to rounded fragments

Fe-rich Tholeiitic Basalt

3 unsubdivided

- a) aphanitic to fine-grained (<1 mm) massive lava
- b) medium-grained (1-5 mm) massive lava
- c) coarse-grained (>5 mm) massive lava
- d) pillowed lava and lava tubes
- e) pillow breccia
- f) hyaloclastite
- g) variolitic lava
- h) vesicles/amygdules
- i) related dike of tholeiitic composition
- j) flow-top breccia, flow breccia
- k) gabbroic textured massive flow
- l) mafic phenocryst-bearing
- m) quartz phenocryst-bearing
- n) layered flow-gabbroic layer
- o) layered flow-pyroxenite layer
- p) layered flow-peridotite layer
- q) interflow sediments, (graphitic chert and argillite, pyrite)
- r) fine-grained massive and bedded sandstone
- s) silicified massive lava possibly of intermediate composition

Lady Maude L.

80° 25' 00"

48° 37' 50"

PIPESTONE FAULT ZONE

Maude Lake Gold Mines Ltd.

trenches: 3def cb
shears 75/80°
328780
45790
qcv, py, Au, q - ser alt'n zones
cb

3/4am
3a qcv, s, A
11d
12a
11d
Au

11d
Au

open pit
3dh, ef, ch
py, asp

2bl, sil?
trench

3a 12a 3d
2d, 3aj, ep

14

12d 1a AB 3d

1d 12b

BEATTY TOWNSHIP

LEGEND

Phanerozoic

Cenozoic

Quaternary

Pleistocene and Recent

Till, reworked till, esker sand and gravel, varved clay, alluvium and peat.

Unconformity

Late Precambrian

Mafic Intrusive Rocks

- 14 Abitibi (1.14 Ga.) olivine diabase dike

Middle Precambrian

Mafic Intrusive Rocks

- 13 Preissac (2.14 Ga.) quartz diabase dikes

Intrusive Contact

Early Precambrian (Archean)

Mafic Intrusive Rocks

- 12 a) Matachewan (2.63 Ga.) diabase dikes
b) Matachewan diabase dikes with saussuritized feldspar phenocrysts

Intrusive Contact

Subalkalic to Alkalic Intrusive Suite

- 11 unsubdivided

- a) syenite
b) syenitic feldspar porphyry
c) lamprophyre
d) feldspar porphyry dikes -felsic matrix composition
e) feldspar porphyry dikes -intermediate matrix composition
f) mafic phenocryst-bearing

Intrusive Contact

Calc-alkalic Intrusive Suite

- 10 a) quartz-hornblende-feldspar porphyry dikes
b) quartz-feldspar porphyry dikes

Intrusive Contact

Mafic to Intermediate Intrusive Rocks (discordant)

- 9 a) gabbro, fine- to medium-grained
b) gabbro, coarse-grained
c) leucogabbro
d) diorite dike
e) orthopyroxene phenocryst-bearing

Intrusive Contact

Ultramafic Intrusive Rocks

- 8 unsubdivided
a) peridotite

ABBREVIATIONS

au	-gold
asb	-anastomosis
cb	-carbonate
ce	-cement
cp	-chert
ep	-epidote
gal	-galena
fu	-fluorite
gn	-gneiss
gr	-granite
hem	-hematite
mag	-magnetite
mo	-molybdenite

serp	-serpentine
to	-tuff
cb	-carbonate
car	-carbonate
ep	-epidote
hem	-hematite
ser	-serpentine
sil	-silica
may	-may
str	-stratification
alt	-alteration
FF	-ferrite

indicated by grain gradation;
(returned).

from pillow shapes and

on.

vertical).

- serpentine
- talc
- diabase
- carbonatized zone
- serpentinization
- silicification
- massive fine-grained
- stringers
- alteration
- fracture filling

Calc-alkalic Metavolcanics

unsubdivided

- a) aphanitic to fine-grained (<1 mm) massive lava
- b) medium-grained (1-5 mm) massive lava
- c) coarse-grained (>5 mm) massive lava
- d) pillowed lava and lava tubes
- e) pillow breccia
- f) hyaloclastite
- g) variolitic lava
- h) vesicles/amygdules
- i) related dikes of tholeiitic composition
- j) flow-top breccia, flow breccia
- k) gabbroic textured massive flow
- l) mafic phenocryst-bearing
- m) quartz phenocryst-bearing
- n) layered flow-gabbroic layer
- o) layered flow-pyroxenite layer
- p) layered flow-peridotite cumulate layer
- q) interflow sediments, (graphitic chert and argillite, pyrite)
- r) fine-grained massive and bedded sandstone
- s) silicified massive lava possibly of intermediate composition

Calc-alkalic Metavolcanics

unsubdivided

- a) rhyolite, dacite
- b) andesite, basalt
- c) chert, silicic siltstone, fine-grained tuffaceous sediment
- d) autoclastic breccia
- e) tuff breccia
- f) interflow sediments, tectonic breccia - blocks of cherty tuff in a pyritiferous black chert matrix
- g) flow banding
- h) spherulitic lava
- i) quartz phenocryst-bearing
- j) feldspar phenocryst-bearing
- k) vesicles/quartz amygdules

Unconformity

Porcupine Group Metasediments¹

unsubdivided

- a) arenite
- b) feldspathic greywacke
- c) intraformational conglomerate
- d) argillite
- A) thickly bedded (30-100 cm)
- B) medium bedded (10-30 cm)
- C) thinly bedded (3-10 cm)
- D) very thinly bedded (1-3 cm)

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11d
Au

2b1, sil?
trench

3a 12a 3d
2d, 3aj, ep

14

12d 1a 1a AB
1d

1d 12b

1a
85° 1d

o.v.98
1d

Faulk L.

1
medial to disto

o.v.107 1d

a) peridotite

Calc-alkalic Intrusive Suite

- 10 a) quartz-hornblende-feldspar porphyry dikes
b) quartz-feldspar porphyry dikes

Intrusive Contact

Mafic to Intermediate Intrusive Rocks (discordant)

- 9 a) gabbro, fine- to medium-grained
b) gabbro, coarse-grained
c) leucogabbro
d) diorite dike
e) orthopyroxene phenocryst-bearing

Intrusive Contact

Ultramafic Intrusive Rocks

- 8 unsubdivided
a) peridotite
b) dunite/serpentinite

Intrusive Contact? (certain ultramafic sills may immediately pre-date layered sills situated higher in the stratigraphy)

Layered Sills

- 7 a) gabbro layer
b) clinopyroxenite layer
c) peridotite layer
d) dunite pods
e) orthopyroxene phenocryst-bearing

Intrusive Contact

Komatiitic Metavolcanics

Basaltic Komatiite

- 6 unsubdivided
a) aphanitic to fine-grained (<1 mm) massive lava
b) medium-grained (1-5 mm) massive lava
c) coarse-grained (>5 mm) massive lava
d) pillowed lava and lava tubes
e) pillow breccia
f) flow-top breccia, hyaloclastite matrix
g) olivine spinifex
h) pyroxene spinifex, random and/or 'string-beef' types
i) layered flow-gabbroic layer
j) layered flow-pyroxenite layer
k) layered flow-peridotite layer
l) polygonal/columnar jointing
m) variolitic lava
n) vesicles/amygdules
o) related dike of komatiitic composition
p) gabbroic textured massive flow
q) mafic (biotite) phenocryst-bearing

Peridotitic Komatiite

- 5 unsubdivided
a) aphanitic to fine-grained (<1 mm) massive lava
b) medium-grained (1-5 mm) massive lava
c) coarse-grained (>5 mm) massive lava
d) pillowed lava
e) pillow breccia
f) flow-top breccia, hyaloclastite matrix
g) coarse-grained massive lava
h) olivine spinifex
i) vesicles/amygdules
l) polygonal/columnar jointing

Tholeiitic Metavolcanics

SYMBOLS

	Highway.		Bedding, top (arrow) 1 inclined, vertical, ov
	Secondary road.		Lava flow; top (arrow) packing.
	Track.		Glacial striae direction.
	Trail.		Anticline, with plunge.
	Power line.		Syncline, with plunge.
	Pit.		Cleavage; (inclined, v
	Trench.		Schistosity; (inclined
	Abandoned mine shaft.		Shear; (inclined, vert
	Mine dump.		Jointing; (inclined, v
	Drill hole; vertical, overburden depth shown.		Major fault; dot indica arrow indicate directi
	Drill hole; (projected vertically) overburden depth shown.		Mirror cross-fault; (inc indicate horizontal mov
	Vein; (quartz-carbonate, quartz).		Fault breccia.
	Small bedrock outcrop.		Banding; (inclined, ve
	Area of bedrock outcrop.		Geological boundary; f
	Bedding, top unknown; (inclined, vertical).		Geological boundary of dip indicated.
	Bedding, top indicated by arrow; (inclined, vertical, overturned).

ABBREVIATIONS

Au	-gold
asb	-asbestos
cb	-carbonate
Co	-cobalt
cp	-chalcopyrite
ep	-epidote
fel	-feldspar
fu	-fuscherite
gn	-galena
gf	-graphite
hem	-hematite
mag	-magnetite
mo	-molybdenite
py	-pyrite
po	-pyrrhotite
pent	-pentlandite
pu	-pumpellyite
q	-quartz

ser
tc
ch
car
ep
hem
ser
ser
sil
msv
str
alt
FF

row) indicated by grain gradation;
al, overturned).

arrow) from pillow shapes and

direction.

plunge.

lunge.

ned, vertical).

clined, vertical).

, vertical, dip unknown).

ned, vertical).

indicates down throw side,
direction of oblique slip.

t; (inclined, dip unknown, arrows
tal movement).

ed, vertical, dip unknown).

ary; flow contacts, layering.

ary of intrusive; (defined, assumed,

ABBREVIATIONS

Au -gold
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 hem -hematite
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 mo -molybdenite
 py -pyrite
 po -pyrrhotite
 pent -pentlandite
 pu -pumpellyite
 q -quartz

serp -serp
 tc -talc
 ch -cher
 carb -carb
 ep'n -epit
 hem'n -hem
 serp'n -serp
 ser'n -seri
 sil -sili
 nov fgr -mass
 str -stri
 alt'n -alter
 FF -fractu

alteration

-fracture filling

-serpentine

-talc

-chert

-carbonatized zone

-epitoditization

-hematization

-serpentinization

-sericitization

-silicification

-massive fine-grained

-stringers

-alteration

-fracture filling

-alteration
-fracture filling

rp -serpentine
-talc
-chert
rb -carbonatized zone
in -epitaxialization
m'n -hematization
ep'n -serpentinization
r'n -sericitization
l -silicification
v fgr-massive fine-grained
rs -stringers
t'n -alteration
-fracture filling

- e) tuff breccia
- f) interflow sediments, tectonic breccia - blocks of cherty tuff in a pyritiferous black chert matrix
- g) flow banding
- h) spherulitic lava
- i) quartz phenocryst-bearing
- j) feldspar phenocryst-bearing
- k) vesicles/quartz amygdules

Unconformity

Porcupine Group Metasediments¹

unsubdivided

- a) arenite
- b) feldspathic greywacke
- c) intraformational conglomerate
- d) argillite
- A) thickly bedded (30-100 cm)
- B) medium bedded (10-30 cm)
- C) thinly bedded (3-10 cm)
- D) very thinly bedded (1-3 cm)

1. The Porcupine Group assemblage stratigraphically occupies a position in the lower half of the Stoughton-Roquemaure Group. The rocks belonging to this group only pre-date those volcanic rocks located north and northeast of the metasedimentary belt's northern edge.

100 m 0 0.5 1 km

medial to dista

O.V. 107 1d

DESTOR

PORCUPINE

12b

1dc

2alfe
2aidf
4ab

13a
ep'n
3a, 4e, 5ll
7e, 8a, 11cA
serp'n

1d

3a, 8a

11cA

Mickle

mat'ic
3adg
3agh, 3c

7c o

13

3/4

Au

Salve

unsubdivided

- k) layered flow-peridotite layer
- l) polygonal/columnar jointing
- m) variolitic lava
- n) vesicles/amygdules
- o) related dike of komatiitic composition
- p) gabbroic textured massive flow
- q) mafic (biotite) phenocryst-bearing

Peridotitic Komatiite

5 unsubdivided

- a) aphanitic to fine-grained (<1 mm) massive lava
- b) medium-grained (1-5 mm) massive lava
- c) coarse-grained (>5 mm) massive lava
- d) pillowed lava
- e) pillow breccia
- f) flow-top breccia, hyaloclastite matrix
- g) carbonatized ultramafic lava
- h) olivine spinifex
- i) vesicles/amygdules
- l) polygonal/columnar jointing

Tholeiitic Metavolcanics

Marginal to Mg-rich Tholeiitic basalt

4 unsubdivided

- a) aphanitic to fine-grained (<1 mm) massive lava
- b) medium-grained (1-5 mm) massive lava
- c) coarse-grained (>5 mm) massive lava
- d) pillowed lava and lava tubes
- e) pillow breccia
- f) hyaloclastite
- g) variolitic lava
- h) vesicles/amygdules
- i) related dike of tholeiitic composition
- j) flow-top breccia, flow breccia
- k) gabbroic textured massive flow
- l) mafic phenocryst-bearing
- m) interflow sediments (graphitic chert and argillite, massive fine-grained pyrite)

Fe-rich Tholeiitic Basalt

3 unsubdivided

- a) aphanitic to fine-grained (<1 mm) massive lava
- b) medium-grained (1-5 mm) massive lava
- c) coarse-grained (>5 mm) massive lava
- d) pillowed lava and lava tubes
- e) pillow breccia
- f) hyaloclastite
- g) variolitic lava
- h) vesicles/amygdules
- i) related dike of tholeiitic composition
- j) flow-top breccia, flow breccia
- k) gabbroic textured massive flow
- l) mafic phenocryst-bearing
- m) interflow sediments, (graphitic chert and argillite, massive fine-grained pyrite)
- n) layered flow-gabbroic layer
- o) layered flow-pyroxenite layer
- p) layered flow-peridotite layer

Calc-alkalic Metavolcanics

2 unsubdivided

- a) rhyolite, dacite
- b) andesite, basalt
- c) ash tuff, fine tuffaceous sediment
- d) autoclastic breccia
- e) tuff breccia
- f) lapilli tuff
- g) ~~interflow sediments, graphitic chert and argillite, massive fine-grained pyrite~~

SYMBOLS

	Highway.		Bedding, top (arrow inclined, vertical)
	Secondary road.		Lava flow; top (arrow packing).
	Track.		Glacial striae direction
	Trail.		Anticline, with plunging
	Power line.		Syncline, with plunging
	Pit.		Cleavage; (inclined)
	Trench.		Schistosity; (inclined)
	Abandoned mine shaft.		Shear; (inclined)
	Mine dump.		Jointing; (inclined)
	Drill hole; vertical, overburden depth shown.		Major fault; dot indicates arrow indicate direction
	Drill hole; (projected vertically) overburden depth shown.		Minor cross-fault; indicate horizontal
	Vein; (quartz-carbonate, quartz).		Fault breccia.
	Small bedrock outcrop.		Banding; (inclined)
	Area of bedrock outcrop.		Geological boundary
	Bedding, top unknown; (inclined, vertical).		Geological boundary dip indicated.
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p (arrow) indicated by grain gradation;
vertical, overturned).

top (arrow) from pillow shapes and

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QV. 80'
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BEATTY TWP.
ODM 6387

zone
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2

- g) interflow sediments, chert/argillite matrix
- h) spherulitic lava
- i) quartz phenocryst-bearing

- m) interflow sediments, (graphitic chert and argillite, massive fine-grained pyrite)
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 - e) tuff breccia
 - f) lapilli tuff
 - g) interflow sediments, rhyolite breccia, black chert/argillite matrix
 - h) spherulitic lava
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100 m 0 0.5 1 km

END

20.08.88

FIN