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STRATIGRAPHY, PHYSICAL VOLCANOLOGY
AND GEOCHEMISTRY
OF THE
BELMONT LAKE METAVOLCANIC COMPLEX,
SOUTHEASTERN ONTARIO

by

© James Rodney Bartlett, B.Sc.

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

Department of Geology
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June, 1983

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ABSTRACT

The Helikian Belmont Lake Metavolcanic Complex, located in the Hastings region of the southwestern Grenville Province, is a metavolcanic-metasedimentary succession with an apparent thickness of 12 km. Metamorphic grade in the study area (Belmont Township) increases northwesterly from upper greenschist to middle amphibolite facies. Essentially homoclinal and east-facing, the succession comprises rocks grouping naturally into four mafic-to-felsic volcanic cycles.

Each cycle comprises variable amounts of basalt, andesite and rhyolite. The lowermost cycle (I) is predominantly rhyolite pyroclastics; Cycle II consists of a base of basalt and andesite flows and pyroclastics, overlain by rhyolite volcanoclastics; Cycles III and IV are composed mainly of basalt flows. Clastic and chemical sediments, including carbonates, are associated with each cycle, generally concentrated at or near the top. A major gabbro body truncates Cycle IV. The lower part of Cycle I has been removed by emplacement of a granite body.

Eruption and deposition of volcanics of Cycles I and II occurred in subaerial to shallow subaqueous environments dominated by composite volcanoes in the north part of the area. Cycle III volcanism was mainly shallow subaqueous, with composite volcanoes, probably in part subaerial, in the north and south. Cycle IV represents the growth of an emergent to subaerial shield volcano.

Basalts of all cycles are tholeiitic, as are all analyzed andesites and dacites; rhyolites are calc-alkaline. Trace element geochemistry reveals that most Belmont basalts grossly resemble modern rise and arc tholeiites, although some are similar to modern calc-alkaline varieties. On the basis of this and field evidence, the complex is interpreted to have formed in a shallow back-arc environment.

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I wish to thank Dr. Calvin Pride of the University of Ottawa for assisting me with the acquisition and manipulation of geochemical, especially rare earth element, data.

The OGS provided logistical support throughout the summers of 1980 and 1981, and provided many thin sections and most geochemical analyses. Discussions with OGS geologists, John Wood and, in particular, Marika S. Bourque, contributed to my understanding of the sedimentary parts of the complex.

The faithful and uplifting field assistance of N. J. Hulme, P. E. Pilon and J. A. Strutt in 1980, and E. DeKemp and S. V. Thompson in 1981 is greatly appreciated. Parts of the study area were mapped by M. J. Murray in 1980.

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All members of my family showed interest in my work, and constantly lent much appreciated material support and moral encouragement. I am particularly grateful to my mother, who, with a love known only between mothers and sons, cheerfully performed the gruelling task of colouring five copies of my detailed geological map.

I dedicate this thesis, and all the work that went into it, to the loving memory of Pepper and Jenny, my dearest friends.

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CHAPTER 1

INTRODUCTION

1.1 Purpose of Study

This thesis is an account of the stratigraphic, volcanologic, and geochemical aspects of a Proterozoic metavolcanic-metasedimentary succession displaying previously unreported volcanic cyclicity. The succession is treated in terms of:

- 1) lithology, stratigraphy, and metamorphism;
- 2) physical volcanology;
- 3) geochemical characteristics and trends in metavolcanic rocks.

1.2 Location and Access

The study area is Belmont Township, located approximately 150 km northeast of Toronto, Ontario (Figure 1). The towns of Havelock and Cordova Mines are situated in the southwest and northeast parts, respectively, of the township. Highway 7 traverses the southern part of Belmont Township. Numerous county, township, concession, fire access, farm and private cottage roads provide excellent access to most of the area, as do Round, Lost, Cordova, Belmont, and Crowe Lakes. Rivers connecting Round and Belmont, Cordova and Belmont, and

Figure 1 General geology of part of eastern Ontario, showing location of Belmont Township. Modified from Freeman (1978).

Belmont and Crowe Lakes are partially navigable.

1.3 Previous and Current Work

Table 1 summarizes previous and current studies of Precambrian rocks in Belmont Township and the surrounding region.

The evolution of thought concerning the regional stratigraphy has been summarized by Moore and Thompson (1980). The metavolcanic rocks, termed "Keewatin" by early workers, are now assigned, along with most of the metasedimentary units, to the Grenville Supergroup. The conglomerates cropping out mainly on the islands and shores of Belmont Lake have provoked considerable controversy, having been assigned by some geologists to the "Hastings Series" (believed by Miller and Knight (1914) to postdate most of the stratified rocks in the area), and to the Grenville "Series" (now Supergroup) by others. Moore and Thompson (1980) suggested correlation of these conglomerates with the Flinton Group, which unconformably overlies Grenville Supergroup rocks to the east of Belmont Township.

1.4 Field and Laboratory Work

The majority of the field mapping was carried out in the summer and fall of 1980; rock samples were collected during the course of the mapping, and in the winter, summer, and fall of 1981. Mineralogy and textures were observed in more than 200 thin sections and many hand specimens. Plagioclase composition was determined by the Michel-

Table 1

Previous and Current Studies of Precambrian Rocks in
Belmont Township and the Surrounding Region

Reference	Nature of study
Dawson (1865)	Investigation of occurrences of <u>Eozoön canadense</u> (stromatolites) in Hastings region.
Logan (1866)	Reconnaissance survey of parts of Hastings region, including Belmont Township.
Venner (1870)	Compilation map and report on part of Hastings region (includes map, by Alexander Murray, of part of Belmont Township).
Miller and Knight (1914)	Maps of several areas in Hastings region; includes 1:15840 map of central Belmont Township.
Wilson (1940)	1:63360 map of northern Belmont and neighbouring townships (1920-1925).
Hewitt and Satterly (1957)	1:126720 compilation map of Haliburton-Bancroft area (includes part of Belmont Township).
Heidecker (1963)	Structural geology of northern Belmont Township.
Lumbers (1964)	Compilation illustrating distribution of mineral occurrences in relation to metamorphic grade; includes part of Belmont Township.
Beavon (1967)	Structural geology related to distribution of stratiform base metal sulphide deposits in northeast Belmont and Marmora Townships.
Bartlett et al. (1980, 1982)	1:15840 mapping of Belmont and southern Methuen Townships; subsequent preliminary map and report.

Table 1 (cont'd)

Reference	Nature of study
Carter (1980)	Evaluation of economic mineral potential of parts of Hastings region.
Dunlop <i>et al.</i> (1980)	Paleomagnetic studies of several intrusive bodies (including the Cordova gabbro) in the Haliburton and Hastings regions.
Pilon (1981)	Geology of coarse clastic metasedimentary rocks of Belmont Lake.
Bartlett and Moore (1981, 1983)	1:15840 mapping of Marmora and parts of Belmont Townships; preliminary map of Marmora Township.
Bourque (1981, 1982, in prep.)	Stratigraphy and sedimentology of carbonate and associated metasedimentary rocks in Belmont and neighbouring townships.
Thomas (in prep.)	Petrology, structure and geochemistry of gold-bearing shear zones in the Cordova metagabbro (M.Sc. thesis, University of Ottawa).
Thomas and Cherry (1981)	Geology of the Cordova metagabbro.
Hulme (1982)	Petrography and volcanology of metabasalts east of Belmont Lake.
Murray (1982)	Stratigraphy, structure and metamorphism of rocks of Belmont and southern Methuen Townships.
Bartlett and Moore (in prep.)	Final report, for Ontario Geological Survey, on Belmont, southern Methuen and Marmora Townships.

Lévy method. Samples were chemically analyzed by X-ray Assay Labs for the Geoscience Laboratories of Ontario Geological Survey, and by the author, C. R. Pride and J. R. Hartree at the University of Ottawa.

Details of analytical techniques are described in Appendix D.

CHAPTER 2

REGIONAL GEOLOGY

The study area lies near the southwestern edge of the Central Metasedimentary Belt of the Grenville Province (Wynne-Edwards, 1972). The general region, termed the "Hastings Basin"¹ by Hewitt (1956) has been considered by Wynne-Edwards (1972) to contain the thickest succession of supracrustal rocks in the Grenville Province. The stratified rocks of the Central Metasedimentary Belt, collectively referred to as the Grenville Supergroup (Moore and Thompson, 1972; Wynne-Edwards, 1972), are mainly marbles, clastic metasediments (schists and/or gneisses in areas of higher grade metamorphism), and metavolcanics (typically amphibolites). These rocks are intruded by plutons of varied composition. The Grenville Supergroup is overlain unconformably by the Flinton Group, comprising clastic and carbonate metasediments (Moore and Thompson, 1980). Figure 1 illustrates the distribution of major rock types in the vicinity of the study area.

Lumbers (1967) divided layered rocks of the Hastings region into two conformable groups, the predominantly metasedimentary Mayo

1. The geographic term "Hastings Basin" is used here for its historic value. Lumbers (1964) pointed out that the only feature of the region suggestive of a basin is the distribution of the metamorphic zones; that the Hastings Basin is not of basin shape with respect to structure, stratigraphy or topography. It is suggested here that the geographic term "Hastings Basin" be discontinued; "Hastings region" is preferred.

group and the underlying, predominantly metavolcanic Hermon group. The Hermon group was considered by Lumbers (1967) to be concentrated in the eastern part of the Hastings region, around the Weslemkoon and Elzevir plutons. Work carried out by the present author in Belmont and Marmora Townships, however, leads him to believe that metavolcanic rocks of those townships are probably correlative with the Tudor formation of the Hermon group, thus extending the group considerably westward. Lumbers (1967) estimated the combined thickness of the Hermon and Mayo groups to be about 8200 m. If the present author's premise regarding correlation is correct, then that estimate could be at least doubled.

Silver and Lumbers (1966) dated metarhyolite from the lowest (Tudor) formation in the Hermon group at 1286 ± 15 Ma.² They interpret this as the age of extrusion.

The Hastings Metamorphic "Low", centred around Millbridge (about 35 km northwest of Havelock; see Carmichael *et al.*, 1978, Figure 1), contains rocks of the lowest metamorphic grade in the Grenville Province. Metamorphic grade increases northwesterly from garnet-muscovite-chlorite zone (middle greenschist facies) to biotite-sillimanite-K-feldspar zone (upper amphibolite facies) southwest of Bancroft, and southeasterly to cordierite-hypersthene-K-feldspar zone (upper granulite facies) near Ganonoque. Carmichael *et al.* (1978)

2. Silver and Lumbers' date, is recalculated using revised decay constants of Jaffey *et al.* (1971) (Davidson *et al.*, 1980).

suggest that most of Belmont Township is within greenschist facies and that grade increases to middle amphibolite facies. A detailed treatment of the metamorphism of the rocks of Belmont Township is presented in Chapter 4.

Two major orogenies affected the rocks of the Grenville Supergroup: the Elzevirian (ca. 1300-1100 Ma) and the Ottawan (ca. 1050-1000 Ma); the former pre-dates deposition of Flinton Group rocks (Moore and Thompson, 1980).

The southwestern boundary of the Grenville Province is marked by the contact with Middle Ordovician sedimentary rocks, mainly limestone. These rocks cover much of the southwest half of Belmont Township and occur as outliers throughout the remainder of the study area.

CHAPTER 3

GEOLOGY OF BELMONT TOWNSHIP

3.1 Introduction

Metamorphosed Precambrian rocks occupy most of the northeast half of Belmont Township; several outliers of Ordovician sedimentary rocks are areally insignificant. The Precambrian stratified rocks constitute the Belmont Lake Metavolcanic Complex; these are mainly volcanic flows and fragmental deposits, ranging in composition from basalt to rhyolite. About twenty percent of the outcrop area comprises rocks unquestionably of sedimentary origin; these are mainly marble, with less abundant units of metamorphosed conglomerate, sandstone, mudstone and chemical precipitates. Some major quartzofeldspathic rock units are undoubtedly composed both of pyroclastic and epiclastic deposits, with rapid facies transitions. In some parts of the area, particularly the northwest, it is difficult to distinguish these rock types given the limited exposure, scale of mapping and metamorphic recrystallization. However, in the northwest part of the township, the abundance of high viscosity felsic flows and the coarse nature of some units of unequivocally pyroclastic origin (based on textural analysis of fragments and matrix, and vertical variations in primary structures) suggest that depositional environment is relatively proximal; in younger volcanic terranes the proximal environment is

characterized by a predominance of volcanic rocks relative to sedimentary rocks (cf. Smedes and Prostka, 1972). Therefore when dealing, in this study, with fragmental rocks of dubious origin the author has consciously chosen a pyroclastic origin for some units that other workers might consider to be epiclastic.

The supracrustal rocks have been intruded by the Cordova metagabbro and a number of smaller intermediate and mafic intrusions, and by a major granitic body in the northwest corner of the township.

Because all Precambrian rocks of the study area are metamorphosed, primary lithologic terms are used henceforth where they are reasonably well established and more concise than metamorphic names. The exception is the retention of the term "marble" to emphasize the distinction between metamorphosed Precambrian marbles and unmetamorphosed Ordovician limestone.

The general distribution of rock units in Belmont Township is illustrated in Figures 2 and 3. Figure 4 (in back pocket) illustrates the distribution of rock units and sub-units in Belmont and southern Methuen Townships. The legend for Figure 4 is based mainly on protolith (refer to Appendix A for criteria used to classify rocks). Some stratigraphic interpretation was employed in the distinction between Units 5 and 6 and Unit 9. Although these units share many lithologic similarities, Unit 9 was considered, at the time of mapping, to be separated from underlying rocks by a major unconformity, in contrast to the intraformational nature of Units 5 and 6.

3.2 Structural Geology

The following summary of structural geology draws, in part, from Bartlett *et al.* (1982) and Murray (1982). Detailed structural observations are documented in Murray (1982).

Although Murray (1982) divided Belmont and southern Methuen Townships into seven structural domains, the present author has generalized the structural geology of Belmont Township and considers the area to consist of three domains (Figure 2). In the region north of, and between, Round and Belmont Lakes the rocks constitute an upright, moderately dipping, east-facing homocline. The north-trending regional planar fabric (S_1), expressed by orientation of micas and amphiboles, is subparallel to bedding, volcanic flow and lithological contacts (S_0). S_1 is weak or absent in metavolcanic rocks east of Belmont Lake, however north-trending S_0 fabric suggests that these rocks belong to the domain described above.

A western domain is characterized by open to close macroscopic folds with near-vertical, east- to northeast-trending axial planes. In places a weak schistosity (S_2) is evident. The amplitude of map-scale D_2 folds increases westerly and northerly, paralleling an increase in metamorphic grade. D_2 folds generally plunge east-northeasterly; the only major reversal occurs outside the present study area, at Oak Lake.

The third structural domain includes mainly sedimentary rocks north and east of Belmont Lake. Here S_0 and S_1 have been refolded by

D_2 ; a locally strong S_2 fabric resulted, expressed most clearly in marbles as elongate calcite grains and fracture cleavage, axial planar to D_2 folds. Southeast of Cordova Lake, S_2 fabric either developed almost everywhere nearly parallel to the margin of the Cordova gabbro, or was subsequently wrapped around the pluton.

A prominent east-northeast-trending, moderately to steeply plunging lineation (L_1) is extant in all domains; it is defined by S_0/S_1 intersection, stretching of primary features, and mineral/mineral aggregate elongation. Perturbations in plunge direction are local. A weak, northeast-trending, steeply plunging lineation (L_2) results from the crenulation of S_1 schistosity.

Indirect evidence (cf. Chapters 3.4.5 and 3.4.6) suggests that map-scale faulting accounts for the contact between mafic volcanics and marble, siliciclastics and volcanics from south of Belmont Lake to Cordova Lake. The timing of fault motion relative to other deformational events is presently not known with certainty.

Numerous outcrop-scale and smaller faults are present throughout the study area. Post- D_1 cataclasis is evident locally in the quartzofeldspathic unit north of Round Lake.

The structural geometry of Precambrian rocks of Belmont Township can thus be explained, for the most part, in terms of three phases of deformation. The first phase (D_1) resulted in transposition of primary planar features, and development of pervasive schistosity, subparallel to the north-striking, east-dipping axial plane of a tight to isoclinal fold having a wavelength of at least 50 km. During the

second phase of deformation (D_2), these structures were refolded, with large variations in amplitude, about east- to northeast-trending axial planes. D_1 and D_2 structures are warped by open D_3 folds with northwest-trending axial surfaces. This phase could be a late stage of D_2 , representing the time when northwest-southeast compression, which formed the D_2 structures, bent the folds around the Cordova gabbro.

3.3 Stratigraphy

The homoclininal arrangement of the volcanic-sedimentary succession simplifies stratigraphic interpretation; only in the area north and east of Cordova Lake, where D_2 and D_3 (?) folds complicate the map pattern, is the stratigraphic order uncertain.

About twenty-five localities throughout the map area yielded reliable information on stratigraphic top direction; facing direction at some localities was substantiated by thin section analysis. Dubious top indications were recorded at a few localities. Way-up criteria include pillow orientation, amygdule and flow breccia distribution in lavas, and grain gradation, cross-bedding, scour-and-fill and load structures in clastic rocks. At some localities several mutually corroborative primary facing indications are present. Except in areas where complex D_2 folding has produced local reversals in stratigraphy, all reliable primary facing criteria indicate that the succession is east-facing. Data from carbonate metasediments in the vicinity of Belmont Lake support this conclusion (M. S. Bourque, personal communication, 1982).

The stratigraphic scheme proposed by Lumbers (1967) for rocks of the Bancroft-Madoc area is generally inapplicable to rocks of the present study area. Instead of employing a type section based on primary facing data he constructed an hypothetical section based solely on major lithologic characteristics. Difficulties arise in trying to equate observed stratigraphy with this hypothetical section (Table 2). Thus a more practical stratigraphic scheme is required. The present writer recommends that Lumbers' (1967) group and formation names be retained on grounds of precedent, but that they be re-defined to correspond to observed stratigraphy.

In this study, formation names are assigned to the rock units of Belmont Township (Figure 3) to facilitate greater ease in describing the lithology; the stratigraphic nomenclature proposed here may serve as a basis for correlating rocks of this area with those of neighbouring map areas. Table 2 outlines the major rock types associated with each formation and member therein. The succeeding lithologic descriptions of these units follow the stratigraphic order of Table 2 - the oldest (Oak Lake) formation is considered first and the youngest (Crowe River) formation last. Plutonic rocks are described after the stratified rocks.

Figure 3. General geology of Belmont Township, showing distribution of formations and volcanic cycles. Formations are separated by bold lines. Cycles are separated by dotted lines. Formation abbreviations: O.L.= Oak Lake, L.W.L.= Little Whitney Lake, W.C.= Whitney Creek, C.L.= Cordova Lake, V.= Vansickle, M.= Marmora, B.L.= Belmont Lake, C.R.= Crowe River. C.G.= Cordova Gabbro.

Table 2

Formations of the Belmont Lake Metavolcanic Complex,
compared with Lumbers' (1967) inferred stratigraphy

Formation	Member	Major Rock Types	Formation Designation in Lumbers' (1967) Stratigraphic Scheme
Crowe River	B	calcitic marble; skarn	?
	A	basalt	Tudor (?)
Belmont Lake		lithic clastic sediments	Vansickle
Marmora		calcitic and dolo- mitic marble	Dungannon
Vansickle	D	andesite	Tudor
	C	basalt	Tudor
	B	siliciclastics	Vansickle
	A	marble	Vansickle
Cordova Lake	B	andesite; dacite	Tudor
	A	basalt; andesite	Tudor
Whitney Creek	D	rhyolite; silici- clastics	?
	C	marble	?
	B	exhalative sediments	?
	A	basalt; andesite	Tudor
Little Whitney Lake		marble	Dungannon
Oak Lake	C	rhyolite	Oak Lake
	B	andesite	Tudor
	A	basalt	Tudor

3.4 Lithologic Descriptions

3.4.1 Oak Lake formation

Hewitt (1960) defined the Oak Lake formation in Methuen Township; named for the excellent exposures around the shores of Oak Lake, the formation within that township consists of about 1500 m of "pink arkose, pink and grey quartzite and some interbeds of amphibolite schist and greenstone schist". The present study shows that the Oak Lake formation, as defined by Hewitt (1960) extends into Belmont Township, where its maximum exposed thickness is greater than 2000 m. Although Hewitt (1960) referred to the Oak Lake formation as sedimentary, the provenance was probably wholly volcanic, with deposition controlled by volcanic, sedimentary and transitional processes.

Within Belmont Township the Oak Lake formation comprises three members - mafic, intermediate and felsic volcanics. The heterogeneous felsic volcanic member encloses both of the other members; the mafic member occurs low in the succession exposed in the study area; the intermediate member occurs as lenses throughout.

The lower contact of the Oak Lake formation lies outside of the map area, between the shoreline and marble-bearing islands of Oak Lake (Hewitt, 1960). The upper contact is, in the north, at least in part transitional, over 5-10 m, with the Little Whitney Lake formation. Further south, the upper contact with the Whitney Creek formation is nowhere clearly exposed; however in places the change from felsic to mafic rocks can be delineated to within 10 m.

The Oak Lake formation is, to the south (Figure 3), obscured by Ordovician limestone cover; to the north it is continuous through Methuen to Lake Township, and may correlate with volcanics in Wollaston and Limerick Townships (Hewitt, 1960).

The mafic volcanics are largely confined to two stratigraphically distinct lentils, concentrated in the nose of the major syncline west of Little Whitney Lake. The lower lentil comprises black, dark grey-weathering, fine-grained, massive to schistose and lineated amphibolites; colour index (CI) is 45-50. Plagioclase and hornblende are the major constituents, with minor magnetite.³ Plagioclase-phyric varieties are common; phenocrysts average 3 mm, range to 15%, and are almost totally recrystallized. Rare relict twinning at one locality (UTM26751/493852)⁴ yielded a plagioclase phenocryst composition of An₂₉. Quartz amygdules, averaging 1 cm long, are present locally to 10%.

The upper lentil consists of fine-grained, moderately schistose, lineated amphibolites, dark grey to green-grey on fresh and weathered surfaces. These rocks are typically quartz amygdaloidal and blastoporphyritic, with plagioclase phenocrysts up to 12 mm long composing 5-40% of the rock (Plate 1a). Minor epidote is present in some rocks. Titanite typically occurs as an alteration product with

3. Detailed petrographic descriptions and sample locations are documented in Appendix B.

4. All universal transverse Mercator (UTM) coordinates refer to zone 18; reference grid is given in Appendix B, Figure B1.

PLATE I

- a) Plagioclase-phyric mafic flow of Cycle I. Phenocrysts are recrystallized to a fine mosaic of plagioclase. Matrix is amphibolite. UTM 27012/493937.
- b) Felsic volcanic flow of Cycle I, displaying relict flow banding (vertical laminations). UTM 26878/493838.
- c) Deformed felsic lapilli tuff of Cycle I. Fragments (including large lithics) have been flattened in the plane of schistosity. Five cent piece (2.15 cm) for scale. UTM 27191/493169.
- d) Photomicrograph (plane polarized light) of probable ash flow tuff of south part of Cycle I. Minute magnetite grains concentrated in some fragments (probably recrystallized pumice) accentuate the wispy appearance of the fragments, thus defining the eutaxitic foliation. UTM 26904/493232.

PLATE I

magnetite. Colour index varies from 35 to 45. Primary mesoscopic features are generally well-preserved in these rocks; flow thickness varies from 2 to 10 m, or more. Elliptical rimmed structures, 15-100 cm long, probably represent pillows; these are plagioclase-phyric and amygdaloidal. Moderately deformed quartz amygdules within the pillow-like structures are up to 10 mm long and occupy 10-15% of the rock. Locally, hyaloclastites are present, containing varietal prograde chlorite and biotite.

Elsewhere, mafic volcanics occur only sporadically in the Oak Lake formation. One outcrop, 2 km northwest of Round Lake, comprises amygdaloidal mafic flows. Two kilometres north of Round Lake mafic flows grade into gabbro, demonstrating the subvolcanic nature of the gabbro. A fine- to medium-grained, centimetre-layered (hornblende-rich versus plagioclase-rich) rock, in which plagioclase is highly altered to sericite, lies directly beneath the Little Whitney Lake formation on the north limb of the major syncline (UTM 27026/493971). The scale and uniformity of layering, fineness of grain and the mineral composition suggests that this rock represents airfall tuff (cf. Williams and McBirney, 1979).

Intermediate volcanics occur mainly at two stratigraphic levels in the Oak Lake formation; in southern Methuen Township units are more continuous and widespread than in Belmont Township (Figure 4). The areal extent of intermediate volcanics in the region 3-4 km north of Round Lake is exaggerated on Figure 4; in this region rocks having a CI of 10, or slightly less, have been labelled "2d" to emphasize the

contrast between them and associated rocks, labelled "3d", that have a CI of 0-5. Two small, lenticular units occur at, or close to, the lower contact of the upper lentil of mafic volcanics, one on each limb of the major syncline. Nearer the top of the formation a relatively thick, continuous unit occupies the major syncline and smaller anticline to the south. In the core of the syncline intermediate volcanics comprise massive flows, and tuff and pyroclastic breccias, layered on the scale of metres to tens of metres, containing angular to subrounded fragments. The unit pinches out on the north limb of the syncline; south of the syncline fragment size decreases to ash- and lapillus-size; here the rocks are mainly tuff and lapilli tuff layered on the scale of centimetres to decimetres.

Thin septa of intermediate volcanics occur in both lentils of mafic volcanics. The intermediate volcanics cropping out further south generally occur in thin lenticular units, or, as is the case toward the top of the formation, as centimetre-scale layers within felsic volcanics.

Intermediate volcanics are generally medium grey, brown-grey-weathering, fine-grained, granoblastic quartz-biotite-plagioclase fels to semi-schists. Hornblende is a common varietal mineral; occurring in amounts up to 15% in some rocks; magnetite is ubiquitous (1-4%), commonly with mantles of titanite. Colour index ranges from 10 to 25. Schistosity, where present, is typically weak, defined by biotite orientation. Rare hornblende (or biotite after hornblende) lineation is weak. Some rocks are typically massive on an outcrop scale and

are thus considered to be flow rocks. Calcite-quartz lenticles in some rocks (eg. UTM 26878/493776) may represent amygdules.

Locally, fine- to medium-grained intermediate volcanics exhibit decimetre-scale layering, defined by variations in grain size and colour index. The scale and uniformity of layering, mineralogy, grain size, shape and gradation within layers and alternating grain size from layer to layer suggest that these rocks represent airfall tuffs (cf. Heiken, 1972; Sheridan, 1971; Sigurdsson, 1982a; Williams and McBirney, 1979).

The felsic volcanic member consists of pyroclastic deposits with subordinate flow rocks and volcanically derived epiclastic rocks. The member is of relatively uniform thickness. Deformation and recrystallization have rendered determination of the origin of some rocks tenuous, however in many recrystallization has been incomplete, leaving original textures partially preserved.

The greatest diversity of rock types of this member occurs in the vicinity of the major syncline west of Little Whitney Lake. In this region strain is typically high, but unidirectional. The lowest-exposed sections are dominated by fine-grained, pink-grey, pink-white-weathering, granoblastic quartz-alkali feldspar fels. For the most part the rocks appear to be megascopically uniform; millimetre- or weak centimetre-scale compositional layering is local.

Near the base of the lower mafic volcanic lentil felsic rocks are distinctly fragmental and are of two main types, distinguished by different matrix characteristics, and particularly by the great

disparity in the amount of strain they have taken up. The two rock types are interlayered on the scale of metres to tens of metres; layer-to-layer contacts are commonly indistinct and possibly transitional. Poor exposure does not allow a reliable assessment of the relative proportions of these rock types. The relatively unstrained type is characterized by ash- to block-sized, angular to sub-angular, commonly delicate fragments composing 40-60% of the rock; the fragments are generally of one type, with minor variations in colour. The rock is commonly matrix-supported. Comprising mainly fine ash, the matrix has a darker hue than the pale brown-grey fragments; in thin section distinction between fragments and matrix is commonly complicated by similar composition and texture. The coarse layering, poor sorting, felsic composition, uniformity of fragment type, and uniformity of texture of fragments (non-vesicular) and matrix suggests that this lapilli tuff represents either a pyroclastic flow deposit, possibly a Pelean-type block and ash flow (cf. Fisher, 1982a; Williams and McBirney, 1979), or a near-vent airfall deposit.

The other, more highly strained, rock type consists of up to four felsic fragment types, all quartzofeldspathic, that are variable only in the relative proportions of quartz and feldspars, and colour of the weathered surface. Length:width ratios of the fragments vary within each fragment family, and from type to type; ratios average 40:1. Fragment lengths average 30-40 cm; their terminations are typically round. Fragments predominate over the fine-grained matrix, and form the framework. In thin section the distinction between matrix

and fragments is mainly one of texture - fragments are more complex-interlocking than the granoblastic matrix. The pronounced deformation of this rock precludes precise determination of its original character; fragments in this rock are obviously more susceptible to strain than fragments in neighbouring block and ash flows. Collapse of vesicles can lead to marked flattening of pumice fragments (Fiske, 1969); this may, in part, explain the highly deformed nature of the fragments described above.

Lapilli tuff predominates in the area between the mafic volcanic lentils. Essential fragments, composing up to 60% of the rock are of two types - white- and dark grey-weathering. In addition, discontinuous quartzose septa probably represent flattened, silicified pumice fragments (cf. Thurston, 1980b; Fiske, 1969). The matrix consists of fine to coarse ash-sized grains and is similar to rocks in the area that do not have lapillus-sized or coarser fragments.

Throughout the felsic volcanic member north of UTM Northing 4937 are intercalations, metres to tens of metres thick, of coarse fragmental rocks with felsic ($CI < 5$) fragments in an intermediate ($CI > 15$), biotite-rich, strongly schistose matrix. Although the fragments, which include a minor intermediate type, are less strained than the matrix, precise determination of original size and shape is not possible; they are now mainly lenticular, average 10-30 cm, and occupy more than 50% of the rock. Stratification within these units was not observed. Strain renders definition of the original deposit tenuous; however, if the biotitic matrix represents original clay, the presence

and abundance of this size fraction, along with the considerable thickness and lack of internal stratification of the units suggest a laharic origin (cf. Fisher, 1982b).

Overlying the upper mafic volcanic lentil, and concentrated in the nose and on the southern limb of the major syncline, one of the main rock types is a pink-grey-weathering, fine-grained rock, uniform on the scale of metres to tens of metres, with or without pervasive, dark grey quartz laminations, 0.5 mm thick, spaced 2-3 mm apart (Plate Ib). The laminations are laterally continuous over metres to tens of metres; microscopic study reveals that these features consist of equant (recrystallized) quartz grains, 0.5 mm in diameter, and are locally accentuated by magnetite along the borders. By analogy with younger volcanic rocks (cf. Christiansen and Lipman, 1966; Wachendorf, 1973), these are interpreted to be felsic flow rocks, the laminations representing relict flow banding. Similar rocks in the Mazinaw Lake area (70 km to the northeast) have been interpreted by Ayer (1979) to be felsic flow rocks.

In the study area felsic flows can be traced laterally for 2 km. In the fold nose local close folding of laminations about D_2 axes indicates that the rocks in the nose have been tectonically thickened, probably accompanied by thinning along limbs.

Associated with felsic flows at some localities is the rock, described above, for which a laharic origin was suggested. In addition, centimetre-layered, locally graded felsic rocks composed of ash and lapilli crop out in the area of the felsic flows; the composition,

grain size and gradation, and scale and uniformity of layering suggest that these are airfall tuffs and lapilli tuffs (cf. Heiken, 1972; Sheridan, 1971; Sigurdsson, 1982a; Williams and McBirney, 1979). These rocks give way, on the north limb of the syncline, to fine-grained quartzofeldspathic semi-schists bearing varietal microcline, muscovite and biotite; 8% kyanite occurs at one locality (UTM 27026/493971) as lineated poikiloblasts. The aluminous and quartz-rich nature of some of these rocks suggest an epiclastic origin (cf. Ayres, 1982b).

On the south limb of the major syncline the middle to upper part of the felsic volcanic member contains layers, several metres thick, of granule to cobble volcanic conglomerate. Although bedding orientation in most units is uncertain, clast size variation within each unit is commonly gradational. In areas of low strain clasts are equidimensional to elongate, and are generally less than 35 cm in diameter. In the coarser rocks clasts occupy up to 70% of the rock - 30% in finer rocks. Clast and matrix characteristics are highly variable from area to area. One rock (UTM 27041/493758) contains nine rounded clast types - one is composed entirely of quartz, the others variations about a felsic lithic theme; the matrix is intermediate, and is composed of sand-sized grains; up to 7% magnetite is common in the matrix. Other conglomerates (eg. UTM 27044/493680) contain two varieties of siliceous carbonate clasts, one massive, the other with sub-millimetre-scale planar quartzose segregations (algal laminations?). The rock is matrix-supported and bears clasts up to 15 cm long; clast outlines are commonly irregular. The sand-sized matrix is composed mainly of

quartz and alkali feldspar, highly epidotized, with only minor carbonate. The heterolithic, in part non-volcanic, nature of the clasts, and size, texture and composition of clasts and matrix suggest that the conglomerates are epiclastic deposits.

South of UTM Northing 4937 the abundance of conglomerates and coarse pyroclastic rocks diminishes. The lower, middle and some of the upper parts of the member comprise mainly pink-grey, pink-grey- to white-weathering rocks containing fine ash- to lapillus-sized particles. Bedding, evident in many rocks, is defined, on the scale of millimetres to decimetres, by interlayering with intermediate (CI = 10-15) beds; variation in the abundance of quartz, feldspar, biotite, muscovite and locally calcite within each bed; and grain size variation within beds. Rocks at several localities exhibit normal size grading of ash- and (or) lapillus-sized fractions. A distinct lack of bedding is apparent in ash-sized rocks at several localities; massive sections range from metres to tens of metres thick. Lapillus-sized fragments, common in rocks north of Round Lake (Plate 1c), rarely occupy more than 30% of the rock. Some rocks contain more than one type of lapillus-sized fragment; quartz and (or) plagioclase crystal fragments generally do not exceed 3 mm; quartzofeldspathic lithic fragments up to 10 cm long have length:width ratios of 5-10:1; wispy quartz-rich fragments 10-15 cm long probably represent silicified pumice (cf. Thurston, 1980b; Fiske, 1969). At one locality (UTM 26923/493377) both latter fragment types occur in the same rock; compositional grading on the scale of several metres is defined by a vertical increase of pumice

fragments relative to lithic fragments. Another outcrop (UTM 26904/493232) contains elongate lithic or pumiceous lapilli up to 9 mm long deformed around crystal fragments. Plate Id illustrates that the texture of the rock resembles eutaxitic foliation.

The scale and gross uniformity of layering, grain size and composition, and grain size gradation in the well-bedded rocks described above suggest that these rocks represent airfall tuff (cf. Heiken, 1972; Sheridan, 1971; Sigurdsson, 1982a; Williams and McBirney, 1979). The lack of distinct bedding on the scale of metres to tens of metres, texture and composition of constituent grains, and compositional grading involving lithic and pumice fragments indicate that the non-bedded rocks were deposited by pyroclastic flows (cf. Fisher, 1982a; Sparks *et al.*, 1973).

Rocks forming the uppermost part of the felsic volcanic member between UTM Northings 4938 and 4936 include mappable units of rusty-weathering, highly-cleaved, fine-grained siliceous rocks interpreted, on the basis of weathering characteristics and high quartz : feldspar ratios, to be epiclastic. Grey-weathering, commonly size-graded, rocks containing ash-sized particles are layered on the scale of centimetres to decimetres north of UTM Northing 4935; scale of layering decreases southerly to millimetre- to centimetre-scale. The scale, uniformity and inferred continuity, of layering, grain size and composition, and grain gradation suggest that these are airfall tuffs (cf. Heiken, 1972; Sheridan, 1971; Sigurdsson, 1982b; Williams and McBirney, 1979).

Chert is locally abundant as thin lenses and as millimetre-scale tops of tuff beds south of UTM Northing 4933. Near Round Lake the top of the felsic member is marked by a 5 m thickness of massive chert, containing a 2 m thick lens of massive pyrite. The coincidence of chert and massive pyrite in this lenticular unit suggests that this deposit may represent hydrothermal exhalation at a localized vent; the deposit may be loosely termed "sulphide facies iron formation" (cf. Fryer and Hutchinson, 1976).

3.4.2 Little Whitney Lake formation

Rocks of the Little Whitney Lake formation are concentrated in the nose of the major syncline in the area around Little Whitney Lake. Complex fold patterns indicate that the unit has been considerably thickened tectonically in the nose, accompanied by attenuation along the north limb in Methuen Township.

The lower contact of the formation is exposed in one area (UTM 27085/493800) where layered felsic tuffs of the Oak Lake formation grade upward, over 5-10 m, into dolomitic marble. Elsewhere the lower contact is traceable to within metres to tens of metres. The upper contact with mafic and intermediate volcanics of the Whitney Creek formation is less well-defined.

Calcitic and dolomitic marbles are the predominant rock types of this formation. Calcitic marbles are white or pale grey, fine- and medium-grained and granoblastic; centimetre-scale interlayers of calc-silicate rocks containing epidote, white mica and magnetite are common.

Rare, centimetre-scale massive pyrite interlayers probably represent precipitation arising from fumarolic activity in the waning stages of volcanism (cf. Fryer and Hutchinson, 1976).

Dolomitic marbles are white, buff-weathering, medium-grained and saccharoidal. Tremolite is locally abundant in these rocks, forming sheaves up to 10 cm long. Centimetre-scale siliceous layers and lenses are local; laminated varieties are interpreted to be algal structures (M. S. Bourque, personal communication, 1982).

Biotitic, carbonate-bearing siliceous rocks are locally abundant, particularly west of Little Whitney Lake. These rocks include both massive and centimetre-layered varieties.

3.4.3 Whitney Creek formation

The Whitney Creek formation comprises four members - composite mafic and intermediate volcanics, rusty-weathering siliceous semi-schist, marble and felsic volcanoclastics. The formation thickens to the north, from about 500 m east of Round Lake to about 1500 m at the north boundary of the township; thence it thins to about 500 m in southern Methuen Township.

The composite mafic and intermediate volcanic member is areally the dominant member of the Whitney Creek formation. Throughout the unit mafic flows and pyroclastics are intercalated with intermediate pyroclastics and rare flows; mafic rocks are generally more abundant, though in some areas (Figures 2, 3) the reverse is true. Laterally discontinuous intercalations are common on the scale of tens to

hundreds of metres; mafic layers are generally thicker. Minor, thin felsic tuff layers are also present.

Mafic flow rocks are commonly fine- to medium-grained, uniform, dark grey, brown-grey-weathering, lineated and foliated; they are composed essentially of hornblende and plagioclase. Colour index varies from 35-60, averaging 45-50. In areas where flow contacts can be observed, the thickness of flows is about 10 m; some are 1 m thick. Most flows observed are massive; pillowed flows and hyaloclastites are only prevalent 3-4 km north of Round Lake. Amygdaloidal flows are not common; where present, amygdules occupy 10-20% of the rock.

Mafic fragmental rocks occur mainly south of UTM Northing 4934 in the lower and middle parts of the member. The coarsest rock contains rounded and sub-rounded fragments, up to 15 cm long; the rock is typically fragment-supported with less than 20% fine-grained matrix. Some rocks contain scoriaceous (amygdaloidal) fragments up to 8 cm long with 30-40% matrix. Lack of sorting and stratification, degree of rounding, composition and monolithologic character of fragments suggest that these rocks are agglomerates (cf. Williams and McBirney, 1979).

Fine-grained mafic fragmental rocks also occur as centimetre-scale layers that alternate with quartzofeldspathic layers of similar thickness; this rock type is common in the area immediately north of Round Lake. Fineness of grain and scale and uniformity of layering suggests an airfall origin for these rocks (cf. Williams and McBirney, 1979).

Intermediate fragmental rocks are mainly fine- to medium-grained and bedded on a scale of centimetres to decimetres; bedding is defined by variations in CI and abundance of lapillus-sized fragments, generally more felsic than the matrix. These rocks are quartz-biotite-hornblende-plagioclase schists to semi-schists with CI = 10-25. An airfall origin is suggested, based on the scale and uniformity of bedding, composition, and grain texture and size (cf. Heiken, 1972; Sigurdsson, 1982a; Williams and McBirney, 1979).

Occupying the middle of the south half of the Whitney Creek formation is a 3.5 km long lens of rusty-weathering siliceous schists and semi-schists; thickness of this member is 50-100 m. Compositional layering, occurring on a scale of metres to several metres, is distinct, defined mainly by the size and abundance of porphyroblastic garnet and cummingtonite, and, less commonly, by magnetite and pyrite. Some layers are gradational (UTM 27218/493392), with garnet-rich bases yielding upward to garnet + cummingtonite and thence to a cummingtonite-rich top. Most rocks of this member are porphyroblastic; 1-10 mm garnets occupy up to 80% of some layers; cummingtonite commonly occurs as radiating crystals up to 3 cm in diameter, and occupies more than 50% of some layers. Porphyroblasts typically overgrow and, in the case of garnet, incorporate D_1 schistosity as quartz inclusion trains. Quartz with or without plagioclase is the only other major constituent of the porphyroblastic rocks; minor biotite was observed in the field. Non-porphyroblastic rocks commonly contain, in addition to quartz and feldspar, 15-20% muscovite, up to 15% graphite, as much as 10% pyrite,

and minor biotite. In some rocks magnetite porphyroblasts averaging 5 mm are present to 15%.

Minor layered magnetite chert is intercalated with the rocks in the north part of this unit.

Rocks of this member are interpreted, on the basis of analogy with similar rocks 40 km to the north (Hall, 1980), to be mainly chemical sediments derived from volcanic-exhalative processes; they may be loosely termed "silicate facies iron formation" (cf. Klein, 1973). Although Figure 4 depicts the rocks of this unit as siliceous clastic metasediments, the epiclastic component is probably subordinate.

A thin unit of mafic and intermediate volcanics separates, in most places, the rusty-weathering schists from the overlying calcitic and dolomitic marble member. The lower contact of this member is exposed on the shores of Round Lake; here rusty-weathering, garnetiferous, amphibole-rich intermediate tuffs yield conformably to a 5 m thickness of well-bedded, muscovitic, calcitic marble. The member is exposed along strike for about 5 km; its average thickness is about 100 m, and thickens to 150 m in the south.

The dolomitic component is dominant in the northern part of the member, with white, buff-weathering, medium-grained marble commonly containing uniform or faintly laminated, centimetre- to decimetre-scale layers and lenses of fine white quartz. Some of these segregations are relict algal structures. A calcitic component is more evident to the south, occurring as fine- to medium-grained centimetre-scale layers with or without interlayers of dolomitic marble.

In most places an interval of mafic and (or) intermediate volcanics, 30-150 m thick, separates the marbles from the felsic volcanoclastic member. From a thickness of 500-700 m at the northern township boundary, felsic volcanoclastic rocks thin and, in the vicinity of Seright Bay, yield through a major facies change to epiclastic rocks. Epiclastic rocks are areally most extensive in the Seright Bay area, but also occur in a thin, continuous zone overlying and in part interlayered with felsic volcanoclastic rocks.

The majority of the member consists of aphanitic to medium-grained, grey, white- to brown-grey-weathering quartz-albite semischists. Primary clastic texture can be recognized locally. Well-rounded, flattened, lapillus-sized felsic volcanic fragments, locally composing up to 10% of the rock, are generally rare but more prevalent in the central to northern parts of the member. The rocks are increasingly more cherty and graphitic to the south. Bedding, defined by variations in grain size and mica content, is typically millimetre- to centimetre-scale, locally decimetre- to metre-scale; normal and reverse grading are evident at several localities. In the upper parts of the member the rocks are increasingly rusty-weathering and pyritic toward the top; intercalations of layered felsic volcanoclastic and epiclastic rocks and, in some areas, chert gradually yield upward to graphite- and pyrite-bearing plagioclase-biotite (or muscovite)-quartz schists. Relict clastic texture in these rocks indicate that they were originally poorly sorted mudstones. Epiclastic rocks to the south are more pelitic; at one locality (UTM 27322/493176) garnet poikiloblasts

in a chlorite-garnet-biotite-quartz schist are sigmoidal, having rotated during overgrowth of D_1 schistosity.

Post- D_1 , possibly D_4 (see Table 7), cataclastic brecciation locally affected the rocks of this member.

3.4.4 Cordova Lake formation

The Cordova Lake formation comprises two members, the lower composed of mainly mafic volcanic rocks including massive and pillowed flows, and hyaloclastites; intermediate and felsic flows and pyroclastic rocks form the upper member. The formation attains a maximum thickness of about 3000 m south of Cordova Lake; thence it thins drastically to the north, pinching out near the township boundary. It thins gradually to the south where the minimum exposed thickness is less than 1500 m. In most places the lower contact of the formation can be traced to within tens of metres; where mafic volcanics overlie pyritic siltstones of the Whitney Creek formation the transition is abrupt, though rarely exposed. The upper contact is marked in most places by the major fault, mentioned earlier, which separates mafic and intermediate volcanics from marble and siliciclastic rocks of the Vansickle and Marmora formations.

In the north the lower part of the formation consists largely of aphyric, massive and pillowed flows and breccias, and hyaloclastites; lenses of intermediate tuff and siliceous chemical sediments are subordinate. To the south, intermediate and felsic tuffs dominate. Rare mafic tuffs occur near the transition from essentially mafic to

essentially intermediate rocks (Figure 3).

Plagioclase phenocrysts, absent in the lower third of the formation, increase in abundance in mafic flows and dykes to a maximum at about the middle part of the stratigraphic section; locally, phenocrysts up to 3 cm occupy more than 50% of the rock. In terms of lateral variation, rocks in the middle part of the formation are generally more replete with phenocrysts than those in the north and south.

Mafic dykes, also generally absent in the lower part of the formation, increase in abundance through the middle and upper parts; south of Cordova Lake mafic dykes account for about half of the outcrop area. Mafic and, more rarely, intermediate dykes are probably synvolcanic, as, at several localities, the transition from flow rocks to dykes (and in some cases from dykes to gabbro bodies) is gradational.

Flow morphology is best observed in exposures on and south of Cordova Lake, and on Belmont Lake. Flow units commonly include a gradational, upward progression from massive through pillowed flows to hyaloclastites; in many exposures pillow breccias, isolated pillow breccias and broken pillow breccias intervene between pillowed flows and hyaloclastites. This sequence corresponds well with those observed in Archean (Dimroth *et al.*, 1978) and Triassic (Carlisle, 1963) volcanic successions. Flow units are 20-70 m thick.

Pillow lavas typically consist of closely packed, equidimensional to elliptical, unbroken pillows, generally less than 1 m in length; within any particular flow they have fairly regular shapes

and sizes. Selvages are commonly 1-3 cm thick. The gradation from pillowed flow to isolated pillow breccia is rapid. The unstratified, unsorted isolated pillow breccias (Plate IIa) are composed of unbroken pillows varying greatly in size and shape, but generally becoming smaller upward until most are only several centimetres long. The unbroken pillows are generally not in mutual contact; rather they are separated by an hyaloclastic matrix. The isolated pillow breccias, and in places the pillow lavas themselves, pass upward into broken pillow breccias (Plate IIb), composed mainly of fragments, up to 15 cm long, of pillows in a matrix of hyaloclastite. Pillow fragments are generally angular and elongate, with delicate terminations (Plate IIc); they are dark grey, grey-brown-weathering, aphanitic and felty-textured to weakly schistose. Micro-amygdules and plagioclase microphenocrysts are common. Hornblende is the major constituent (up to 80%) with plagioclase subordinate. Some fragment boundaries are diffuse due to gradational transition from fragment to matrix. Hyaloclastite contrasts sharply with pillows and pillow fragments; it weathers to distinctive yellow- or grey-brown hues. It is fine-grained and moderately schistose; plagioclase is the main constituent, with up to 30% chlorite and varietal hornblende and calcite.

Amygdules are sparse in rocks of the Cordova Lake formation; where present they are typically small (1-2 mm) and rarely occupy more than 1-2% of the rock. Cherty space fillings are common throughout the formation, particularly in pillowed flows; some cherty lenses are 1 m long.

PLATE II

- a) Isolated pillow breccia of Cycle III, Cordova Lake area. Unbroken pillows (smooth surfaces) of various sizes and shapes are separated by a matrix of hyaloclastite (rubbly appearance). Scale card is 8.6 cm long. UTM 2753/493838.
- b) Broken pillow breccia of Cycle III, Cordova Lake area. Fragments of broken pillows are dark; light matrix is hyaloclastite. Twenty-five cent piece (2.4 cm) for scale. UTM 27518/493825.
- c) Photomicrograph (plane polarized light) of broken pillow breccia of Cycle III, Belmont Lake area. Pillow fragments are dark, hornblende-rich and commonly have delicate terminations. Hyaloclastite matrix is composed mainly of plagioclase and chlorite. UTM 27444/492994.
- d) Photomicrograph (crossed nicols) of felsic volcanic flow of Cycle III, Belmont Lake area. Partially preserved felty texture and rare elongate plagioclase phenocrysts are evident. UTM 27498/49308.
- e) Part of a felsic pillowed flow, Cycle III, Belmont Lake area. Inner part of pillow is essentially the same lithology as the rock in Plate II d. Scale card is 8.6 cm long. UTM 27498/493080.
- f) Columnar stromatolite from the lower part of the Marmora formation, north of Belmont Lake. UTM 2761/49355.

PLATE II

Massive mafic flow rocks, including pillow interiors are typically dark grey, medium brown-grey-weathering, fine- to medium-grained, uniform and massive to weakly foliated. Colour index varies from 45 to 85, averaging 60-70. Plagioclase and hornblende are the essential constituents; simple- to complex-interlocking plagioclase is generally interstitial to commonly coarser, more abundant hornblende. Up to 10% prograde chlorite occurs in some mafic flows, particularly in the southeastern part of the formation, and imparts a moderate schistosity to the rock. Plagioclase ubiquitously includes up to 10% epidote.

Mafic dyke rocks are similar to the flow rocks, save for their medium grain and general lack of foliation.

Fine-grained mafic rocks displaying millimetre- to centimetre-scale layering defined by hornblende-rich versus plagioclase-rich beds are locally abundant in the lower part of the formation. The scale and uniformity of layering, and grain size and composition suggest that these rocks are tuffs, erupted subaerially or subaqueously, but probably deposited in a subaqueous environment (cf. Williams and Mc-Birney, 1979).

Rocks in which chlorite, with or without biotite, is the predominant mafic mineral occur near the top of the mafic volcanic member of the Cordova Lake formation. Essential quartz in these rocks suggests that they are not primary mafic deposits. Although stratification in these rocks is commonly cryptic, they are tentatively interpreted to be deposits formed from reworked ash and (or) decomposed flow tops (soil).

Rocks similar to the rusty-weathering siliceous schists of the Whitney Creek formation crop out in small lenses in the lower and upper parts of the Cordova Lake formation; they contain up to 30% chlorite, in contrast to the chlorite-poor rocks to the west.

Fine-grained, centimetre-layered intermediate volcanics occur with similar felsic rocks in small lenses throughout the formation. The fragmental nature of some of the rocks is borne out by the presence of fine lapillus-sized crystal fragments. Layering is typically uniform on the scale of several metres. The scale and uniformity of layering, and grain size, texture and composition suggest that these are airfall tuffs (cf. Heiken, 1972; Sheridan, 1971; Sigurdsson, 1982a; Williams and McBirney, 1979).

A lenticular unit in the Lost Lake area contains intermediate (CI = 30) tuff and lapilli tuff, and flow rocks, including hyaloclastites and flow breccias.

Magnetite-bearing cherts occur near the top of the formation, cropping out intermittently over a strike length of 3.5 km between Belmont and Cordova Lakes. They are fine- to medium-grained, centimetre-layered granular rocks consisting mainly of quartz, with about 10% magnetite overall. The maximum thickness of the interval containing magnetite-bearing chert is 30 m. Enclosing rocks are commonly chlorite schists, with garnet in places.

The upper member of the Cordova Lake formation is a composite unit comprising intermediate and felsic volcanics, occurring on the west shore of Belmont Lake; its maximum thickness is 200 m. Fine-

grained, centimetre-layered biotite- or chlorite-bearing quartz-hornblende-plagioclase schists with $CI = 20$ are probably airfall tuffs, based on scale and uniformity of layering, and grain size and mineralogy (cf. Heiken, 1972; Sheridan, 1971; Sigurdsson, 1982a; Williams and McBirney, 1979). Associated, layered intermediate rocks containing more than 20% quartz probably represent locally derived reworked tuff. Biotite- and (or) chlorite-bearing quartz-plagioclase fels and semi-schist with $CI < 10$ are commonly uniform on the scale of several metres and contain 1-2% amygdules. Partially preserved felty (Plate IIId) and intersertal to felty textures confirm a flow origin for these rocks; some (UTM 27498/493080) contain pillows exceeding 1 m in length (Plate IIe). Rocks of this unit have been slightly to intensely epidotized.

3.4.5 Vansickle formation

Hewitt (1960) defined the Vansickle formation within Methuen Township; overlying the Oak Lake formation, it comprised schist, marble and some conglomerate. Its base was marked by a discontinuous conglomerate unit 60-90 m below the base of the marble unit that, in this study, is known to be the northerly extension of the Little Whitney Lake formation.

The Vansickle formation⁴ is re-defined in this study to exclude the conglomerate base, the "Lower marble" and the "Lower schist" units (Hewitt, 1960) which correspond to the Oak Lake, Little Whitney Lake and Whitney Creek formations of Belmont Township. Retained are the remainder of Hewitt's (1960) units; additions include siliciclastic rocks,

pure and impure marbles, mafic and intermediate volcanics and rusty-weathering siliceous schists east of Cordova Lake.

The nature of the contact between the Cordova Lake formation and the Vansickle formation is uncertain in the western Cordova Lake area due to limited mapping and poor exposure. The rapid thinning of the Cordova Lake formation west of Cordova Lake suggests that the contact is not simply a primary facies transition; tectonic control is likely. A major fault is inferred to govern contacts along, and south of, the east shore of Cordova Lake. The main evidence for this fault is the apparent truncation of rock units in the Vansickle formation against the Cordova Lake formation to the west.

Stratigraphic analysis of the Vansickle formation is hampered by the lack of primary facing information and by complex D_2 folds. The mafic volcanic unit east of Cordova Lake consists of mafic hyaloclastites and chlorite (with or without amphibole) schists similar to and contiguous with the rocks of the Cordova Lake formation, with which it may be genetically related. Carbonate rocks are mainly centimetre-layered calcitic marble; dolomitic marble, commonly with thin siliceous segregations, is subordinate. Interlayered calcitic marble and fine siliciclastic or siliceous carbonate rocks are locally abundant. Metaclastic rocks, mainly derived from wackes and siltstones, are disposed in several units northwest and east of Cordova Lake. The southeasternmost unit contains aphanitic to fine-grained quartzofeldspathic fels and semi-schists with minor or varietal calcite and accessory biotite, opaques, epidote and (or) garnet; quartz ranges from 70-85%.

Millimetre- to centimetre-scale compositional layering, some graded, is common. Coarser clastic rocks are locally abundant in this unit. Some rocks contain fragments of aphanitic biotite-quartz-plagioclase semi-schist, derived from an intermediate volcanic source, in an aphanitic calcite-quartz-plagioclase semi-schist matrix; subhedral and euhedral plagioclase grains in the matrix indicate little reworking. Other rocks have muscovite-quartz-plagioclase, and minor calcite-rich sub-rounded fragments up to 8 cm long.

Intercalated with the fine siliciclastic rocks described above are rusty-weathering siliceous schists similar to those of the Whitney Creek and Cordova Lake formations. Most display millimetre- to decimetre-scale compositional layering and contain poikiloblastic garnet and cummingtonite; some rocks also have actinolite poikiloblasts. These rocks are interpreted, on the basis of their mineralogy and layering characteristics, to have originated as exhalative sediments (silicate facies iron formation).

Uniform and, more commonly, centimetre-layered intermediate rocks form the most southerly unit of the Vansickle formation; these rocks are interpreted on the basis of their mafic mineral content to be volcanically derived. Structural relations along the upper contact, with marble of the Marmora formation, are uncertain.

3.4.6 Marmora formation

The Marmora formation consists mainly of pure and impure dolomitic and calcitic marbles, with subordinate siliciclastic rocks. The contact between these rocks and volcanic rocks of the Cordova Lake formation is inferred to be fault-controlled; the most northerly part of the contact may involve structural truncation of the Marmora formation. Along much of the contact structures across it are discordant, save in the central Belmont Lake area. Evidence in favour of a fault-controlled contact along the west side of Belmont Lake includes progressively stronger cleavage/schistosity in the marbles toward the contact, and the strongly contrasting deformation styles on either side of the contact. The width of the zone of apparently fault-related planar fabric is 150-200 m. Tectonic brecciation of cherty layers in marble is evident 150 m from the contact and may be ascribed to brittle movement along it..

Calcitic and dolomitic marbles are intercalated on a scale of decimetres to hundreds of metres throughout the formation. Calcitic marbles are commonly fine-grained, light grey or blue-grey and layered on a centimetre scale. Dolomitic marbles are fine- to medium-grained, white, buff-weathering and generally occur in beds 1 m or more thick. Both varieties contain thin, black, grey or white cherty segregations; dolomitic marble hosts centimetre-scale layers and lenses of laminated cherty material interpreted to be algal mats (Bourque, 1981). These features are abundant in the Belmont Lake area, and are well-exposed on the shores and islands. Columnar stromatolites (Plate IIf) are also

present, but less common (Bourque, 1981).

Several lenses of siliciclastic rocks occur throughout the Marmora formation; these comprise mainly mudstones, with subordinate sandstones. Millimetre- to centimetre-scale layering is typical. Those rocks bearing metamorphic micas and (or) chlorite are commonly schistose. Primary structures, including slump folding and ripple marks, are locally well-preserved.

Thinly laminated to medium-bedded, fine-grained sedimentary rocks occur, in some cases, at the interface between dominantly siliceous and dominantly carbonate units, representing facies transitions. The rhythmic alternation between laminated, silica-rich, and uniform, calcite-rich rocks (Plate IIIa) may be controlled by chemical or biochemical processes. These rocks also occur in lenses not spatially related to dominantly siliceous units.

Intercalated with marbles northeast of Belmont Lake is a unit of clastic sedimentary rocks ranging from fine-grained to conglomeratic. Matrix-supported conglomerates are the most common rock type; clasts are dominantly felsic volcanic.

Locally along the contact between the Marmora formation and the Cordova gabbro, marble has been converted to diopside-garnet-epidote-carbonate skarn.

PLATE III

- a) Thinly laminated metasedimentary rock of the upper part of the Marmora formation, Belmont Lake area. Rhythmic alternation is of positively weathered siliceous material versus negatively weathered carbonate material. Folds are D_2 structures. Scale card is 8.6 cm long. UTM 27645/493377.
- b) Photomicrograph (crossed nicols) of felty-textured intermediate volcanic flow clast (left side of photograph) in a fine-grained quartz-carbonate matrix. From conglomerate of the Belmont Lake formation. UTM 275/4929.
- c) Discontinuous, laminated fossil algal mats in dolomitic marble of the Belmont Lake formation. Lens cap is approximately 50 mm in diameter. UTM 27575/493015.
- d) Intermediate agglomerate of Cycle IV. Note variations in vesicularity of fragments. UTM 27746/492885.

PLATE III

3.4.7 Belmont Lake formation

Named for its areal restriction to the shores and islands of Belmont Lake, this formation comprises polymictic granule to cobble (rarely boulder) conglomerate with subordinate sandstone, mudstone and dolomitic marble. Rocks of the Belmont Lake formation were nowhere observed to overlie directly volcanic rocks of the Cordova Lake formation nor marbles of the Marmora formation. Previous belief (Bartlett *et al.*, 1980, 1982) held that a major structural unconformity separated the Belmont Lake formation from underlying rocks. Further field work, however, has not confirmed the existence of a major unconformity; one or more intraformational erosional unconformities, instead, best explains the present configuration of rock units. Chert and felsic volcanic clasts of the Belmont Lake formation strongly resemble rocks of the Cordova Lake formation, the probable major provenance. Clasts were probably derived from the Marmora formation as well; some marble clasts contain stylofibrous cement, a feature observed in place only in the Marmora formation (Bourque, 1982).

Restricted exposure and mesoscopic, open to close folding of some parts of the Belmont Lake formation render thickness determination of the formation tenuous in places. However, a section across Big Island (Figure 4) to the east shore of Belmont Lake traverses consistently east-facing strata, indicating a thickness in excess of 700 m.

Although the predominant clast type varies locally, the conglomerates share several characteristics; they are mainly polymictic and poorly to moderately sorted with sub- to well-rounded clasts

having generally low to moderate sphericity. Graded bedding and scour-and-fill structures are present locally. Thickness of conglomerate units, defined by alternation with units containing different particle size, is typically on the order of several metres.

Most conglomerates are clast-supported. Principal clast types include felsic and intermediate volcanic, chert and marble, mainly dolomitic; subordinate types are quartzose and feldspathic sandstone, quartz-feldspar porphyry and mafic volcanic (Pilon, 1981). Felsic and intermediate volcanic clasts are mainly fine-grained, felty-textured lavas (Plate IIIb). Some felsic clasts contain former pumice fragments and evidence of welding. Quartz-feldspar porphyry clasts are probably the eroded subvolcanic equivalent of the lavas. Massive and layered chert clasts are grey, red and (or) black; some bearing magnetite strongly resemble rocks west of the north end of Belmont Lake (cf. Pilon, 1981). Marble clasts are abundant at two, possibly three, stratigraphic levels in the formation; typically they occur immediately overlying intervals of marble interstratified with siliceous clastic rocks (M. S. Bourque, personal communication, 1983). Whereas many marble clasts are massive, some contain algal structures; Miller and Knight (1914) recognized such "Eozoon" structure in clasts of the conglomerate on Crowe River Point of Belmont Lake (Figure 4). Sandstone clasts generally resemble layers interbedded with the conglomerates. Mafic volcanic clasts are typically highly amygdaloidal.

The matrix of the conglomerate varies from mudstone to quartz and (or) calcareous sandstone. Granule-size lithic fragments, generally

felsic volcanic and subvolcanic, occupy up to 15% of the matrix. Magnetite and hematite are commonly abundant in the matrix.

Thin to thick bedded mudstone and sandstone units interstratified with conglomerates are grossly similar to the conglomerate matrix, although the lithic fragment component is generally minor or lacking. Primary sedimentary structures such as cross-bedding, scour channels and load features are locally abundant.

Cropping out at two distinct stratigraphic levels on Big Island, and on the east shore of Birch Island (Figure 4) are dolomitic marble units interlayered with mudstones and conglomerates. Characteristically massive in their lower parts, these units contain domal and laminar algal structures (Plate IIIc).

Near the top of the Belmont Lake formation, on the west shore of Belmont Lake, a 20 m thick unit of fine-grained felsic fragmental rock is exposed for a strike length of about 300 m. Directly overlying cross-bedded sandstone, the unit is massive. The upper half of the unit is generally poorly exposed; the succeeding description draws mainly from observations on the lower half. The pink-grey, beige-weathering rock contains up to 15% each of plagioclase and blue and colourless quartz crystal fragments; some are euhedral and up to 5 mm across. Lithic fragments, some accidental, occupy up to 5% of the rock; these include carbonate-rich (sedimentary?), plagioclase-rich (subvolcanic) and scoriaceous intermediate lava fragments; lithic fragments are generally less than 5 mm long. A common alignment of elongated fragments is parallel to the base and strike of the unit. Some

lenticular fragments several millimetres in length are here interpreted to be pumice; these are more easily seen in thin section. The matrix is roughly equigranular, and has been recrystallized to quartz and alkali feldspar; in thin section the originally vitric (now devitrified) nature of the matrix is revealed by the irregular, wavy distribution of minute magnetite grains that, in part, mimic original shards. Discrete shards are generally not recognizable, but have been flattened and partly transposed, probably due to moderate welding. The resultant eutaxitic foliation, parallel to fragment alignment, is also defined by pumice fragments, now flattened to wispy lenticles composed of quartz, alkali feldspar and up to 30% magnetite dust; these *fiamme* are commonly draped over crystal fragments.

Poor sorting, lack of stratification, composition of matrix and major fragment types, eutaxitic foliation and moderate welding in the lower parts of the unit indicate that this rock is an ash flow tuff (cf. Ross and Smith, 1961).

This unit is overlain by cross-bedded sandstone, pebble conglomerate and thinly bedded mudstone which are, in turn, overlain conformably by rocks of the Crowe River formation.

3.4.8 Crowe River formation

A sharp, basal contact of the Crowe River formation is exposed in one area only - north of Wilson Bay of Belmont Lake (Figure 4); the contact with the rocks of the Marmora formation is traceable only to within several tens of metres, and may, in part, be fault-controlled.

To the north and east the Crowe River formation is truncated by the Cordova gabbro; to the south it is obscured by Ordovician limestone. The maximum thickness of the formation is about 4500 m.

The Crowe River formation comprises two members. The lower, dominant member consists mainly of massive and amygdaloidal mafic lavas; plagioclase-phyric lavas are locally abundant. Subordinate rock types include intermediate lavas and pyroclastics, and felsic tuffs. On the south side of Crowe Lake this unit is succeeded by a relatively thin member consisting of marble and derived skarn.

The lower part of the Crowe River formation consists mainly of aphanitic to fine-grained, dark green-grey, red-brown-grey-weathering mafic flows, typically amygdaloidal and locally plagioclase-phyric. The rocks are generally uniform, although Miller and Knight (1914) reported the presence of coarse fragmental rocks, probably flow breccias or agglomerates. Primary flow textures are partially preserved in the southernmost rocks of the lower section, however rocks of the central and northern parts are more recrystallized, with simple- to complex-interlocking plagioclase subgrains interstitial to hornblende blades or aggregates. The principal mineralogy is hornblende and plagioclase, with chlorite present only in the southernmost rocks. Where present, chlorite imparts a moderate schistosity to the rock. Colour index varies from 45 to 80. Amygdules show little deformation and consist mainly of quartz and (or) epidote and calcite.

Rocks of the middle part of the formation crop out mainly in a 7 km-long peninsular exposure indenting the Ordovician limestone

(Figures 3, 4). These rocks differ significantly from those of the lower part in that intermediate volcanics are more abundant, as are flow breccias and pyroclastic rocks; primary textures are generally well-preserved and hornblende is uncommon; amygdule size and abundance is generally greater than in rocks of the lower part; plagioclase phenocrysts are more common, particularly in the northeastern rocks of the middle part.

Mafic flow rocks of the middle part of the formation are grossly similar to those of the lower part; they are aphanitic, medium green-grey, light beige- to dark brown-grey-weathering, uniform, massive to amygdaloidal with a CI of 35-75. Actinolite is the sole amphibole, occurring as prisms and blades; plagioclase is generally recrystallized to simple- to complex-interlocking subgrains interstitial to actinolite. Chlorite is a common varietal mineral, in some cases imparting, with actinolite, magnetite and titanite, a weak schistosity to the rock. Some rocks contain up to 50% chlorite, randomly oriented. Prograde epidote is present in some rocks, in varietal amounts.

Mafic rocks also occur in fragmental deposits several metres thick; mafic felty-textured fragments up to 40 cm long, averaging 10 cm, are commonly elongate or irregular in shape and amygdaloidal; some have mutually conformable boundaries, with or without delicate outlines contacting a matrix composed of epidotized, aphanitic, possibly size-graded, plagioclase. The fragment : matrix ratio is commonly 2:1. The non-sorted nature of these rocks, lack of overall stratification, and composition, size and texture of fragments and matrix suggest that

these rocks are agglomerates; further, those rocks containing fragments with mutually conformable boundaries are interpreted to be agglutinates (cf. Parsons, 1969; Macdonald, 1972). Grossly similar rocks consisting of intermediate volcanic fragments in a mafic matrix are also common and are also interpreted to be agglomerates; fragments are typically fine-grained, pilotaxitic to trachytic, amygdaloidal to cellular and consist essentially of epidotized plagioclase with up to 10% magnetite. The aphanitic matrix is composed of epidotized plagioclase and 25% actinolite, with 10% biotite defining a weak schistosity.

The middle part of the Crowe River formation contains intermediate volcanics as flows, including flow breccias, and as agglomerate and rare lapilli tuff and lapillistone. Flows are commonly fine-grained, medium green-grey, light green-brown-grey-weathering, uniform, massive to highly amygdaloidal and have a CI of 15-30. Flows are typically 5-10 m thick, and commonly exhibit amygdule gradation; flow bases are non-vesicular, but amygdules increase in size and abundance toward the top. Amygdules consisting of quartz, epidote, calcite and (or) actinolite range to 10 cm or more. Amygdule size, shape, abundance and distribution in many flows of the study area strongly resemble amygdule characteristics in the massive parts of typical aa flows (cf. Macdonald, 1972). These rocks are generally pilotaxitic or felty-textured; some contain minor plagioclase phenocrysts. Groundmass plagioclase (An_8) occupies 40-70% of the rock; actinolite varies to 25%. Chlorite and actinolite were not observed to be compatible in the same rock; while most rocks are actinolitic, some contain up to

20% chlorite. Ten to twenty percent epidote is disseminated throughout the rock, in part included in plagioclase grains. Up to 5% magnetite is typical, partly altered to titanite.

Flow top breccia units, where measurable, are 1-3 m thick (Hulme, 1982).

Coarse intermediate fragmental rocks consist of rounded to sub-rounded, medium grey, light green-grey-weathering fragments, averaging 10-12 cm, in a fine-grained matrix, medium brown-grey on fresh and weathered surfaces (Plate IIIId). Fragments are felty-textured to pilotaxitic and amygdaloidal (Plate IVa, b); they are of identical composition to the lavas described above; fragment type is variable mainly with respect to amygdule content. In contrast, the matrix consists of granular plagioclase, essential hornblende and epidote, and minor magnetite and chlorite. The CI of both fragments and matrix is generally about 30. On the basis of the general lack of stratification, poor sorting, and fragment and matrix size and texture, these rocks are interpreted to be agglomerates (cf. Parsons, 1969; Williams and McBirney, 1979).

In mafic and intermediate rocks the content of magnetite and, in particular, hematite generally increases east of UTM 277/4929. This may, in part, reflect the oxidation potential of the environment of deposition of these rocks; that is, the relatively sudden appearance of hematite may signify the change from predominantly subaqueous to predominantly subaerial deposition. Because the formation is generally poorly exposed in its lower to middle parts this hypothesis would be

PLATE IV

- a) Photomicrograph (plane polarized light) of intermediate agglutinate of Cycle IV. Note amygdaloidal, felty to pilotaxitic texture and elongation of fragments. Welding of fragment boundaries is not well-represented in this photograph. UTM 27673/492784.
- b) Photomicrograph (plane polarized light) of intermediate agglomerate of Cycle IV. Fragments are typically well-rounded and contain abundant quartz and (or) epidote amygdules. Matrix consists mainly of granular plagioclase, hornblende and epidote. UTM 27673/492784.
- c) Granule to boulder felsic volcanic conglomerate of Cycle IV. Note degree of rounding and low sphericity of clasts, and overall poor sorting of deposit. UTM 27590/492470.
- d) Intermediate lapillistone unit with layers deformed around epidotized pod of unknown origin. Twenty-five cent piece (2.4 cm) for scale. UTM 27673/492784.
- e) Coarse intrusive breccia common to western margin of the Cordova gabbro. Fine- to coarse-grained gabbro has been fractured and injected by dioritic and tonalitic material, probably late differentiates of the gabbro. UTM 27822/493277.
- f) Compositional layering in gabbro near north boundary of the Cordova gabbro. Amphibole-rich parts of layers grade upward into plagioclase-rich sections. UTM 27892/493575.

PLATE IV

difficult to test by further mapping. Alternatively, the lack of pillow structure and the presence, albeit local, of agglomerate may suggest subaerial deposition of rocks of the lower part of the formation.

Felsic volcanics and derived rocks are rare in the Crowe River formation. At UTM 27762/492922 a 2-3 m thick unit of millimetre- to centimetre-layered, aphanitic, highly epidotized quartzofeldspathic rock exhibits normal size grading. These characteristics suggest that this rock represents a waterlaid airfall tuff (cf. Williams and McBirney, 1979). The laterally discontinuous nature of this deposit, coupled with the close spatial relationship to agglomerates, suggests that this rock may have formed in a pond on the flank of the volcano.

At UTM 27590/492470 a granule to boulder volcanic conglomerate unit (Plate IVc), 1.5 m thick, contains sub- to well-rounded clasts, up to 30 cm long, of white and pink, aphanitic felsic rocks, and epidotized, amygdaloidal material in a medium brown-weathering matrix. On the basis of heterogeneity of clast types and degree of rounding of felsic clasts, the deposit is interpreted to be epiclastic. Low sphericity, poor sorting, relatively large clast size and lack of internal stratification suggest that this is a proximal deposit (cf. Blatt *et al.*, 1980); the rounding does not preclude this conclusion (cf. Pearce, 1971).

Limited exposure of, and access to, the upper part of the Crowe River formation renders it poorly understood relative to lower parts. Rocks grossly similar to those of the middle part were observed. Some mafic flows display ophitic and sub-ophitic textures.

An enigmatic, though common, feature of volcanic rocks of the Crowe River formation is the presence of epidotized, podiform bodies varying from several centimetres to more than 1 m in length, hosted by flows and fragmental rocks. Though epidote has extensively replaced much of the original rock, some primary structures are preserved; vesicles and fragment outlines within the pods indicate that replacement by epidote occurred without regard for differences in rock type or matrix-fragment transition. This suggests that the replacement process was not related solely to porosity and permeability of the host rock. The replacement appears to have been complete before D_1 deformation; a unit of lapillistone (Hulme, 1982) (UTM 27673/492784) shows the D_1 deflection of primary structures around one epidote-rich pod (Plate IVd).

Near Blairton (Figure 4), a 70 m thick interval of calcitic marble and skarn separates the volcanic member of the Crowe River formation from gabbro. This unit, cropping out on the south shore of Crowe Lake, hosts the Blairton Iron Mine which yielded an estimated 300,000 tons of magnetite ore between 1820 and 1875 (Bartlett *et al.*, 1982). Although now largely converted to skarn, marble occurs as vestiges; fine-grained, granoblastic calcite is the dominant constituent of the marbles; tremolite is a common essential mineral, occurring as euhedral prisms generally elongate parallel to a minor chlorite sheaf foliation. Skarns are fine-grained rocks composed mainly of garnet, amphibole, epidote, magnetite, pyrite, pyrrhotite and carbonate. A discontinuity between the north-northeast-trending aeromagnetic

anomaly at Blairton and the concentric magnetic pattern of the Cordova gabbro suggests that the skarns are related to a tabular gabbroic intrusion roughly concordant with volcanics of the Crowe River formation. This intrusive body is largely obscured by Ordovician limestone.

3.4.9 Intrusive rocks

Felsic intrusive rocks are mainly confined to the northwest corner of the township. Deformed felsic volcanic rocks of the Oak Lake formation are cut by fine- to coarse-grained biotite leucogranite, porphyritic granite, quartz monzonite and granodiorite. Microcline, sodic oligoclase and quartz are the essential constituents; orthoclase is rare. The rocks are typically hypidiomorphic- to allotriomorphic-granular and seriate, with simple- to complex-interlocking grains. Marginal granulation of coarse feldspar, and a weak mica fabric indicate a degree of strain considerably lower than that of the enclosing rocks, suggesting late tectonic emplacement of the intrusive rocks.

Mafic rocks intrude all formations (Figure 4). The Cordova gabbro is the largest intrusive body in Belmont Township; smaller mafic bodies intrude the Oak Lake and Cordova Lake formations; mafic dykes are common only in the middle and upper sections of the Cordova Lake formation, and in parts of the Vansickle and Marmora formations.

Apart from the Cordova gabbro, nearly all mafic intrusive rocks are amphibolites composed of hornblende and plagioclase; the only exceptions are biotite and (or) chlorite lamprophyre dykes intruding rocks of the Belmont Lake and Crowe River formations. Several gabbro

bodies of various size occupy the area north of Round Lake (Figure 3); the northern gabbros are typically coarse- to very coarse-grained, with cumulate and (or) oikocrystic textures common. Further south, gabbros are generally fine- to medium-grained and contain up to 40% plagioclase phenocrysts, commonly heavily saussuritized and, locally, normally zoned. Colour index varies from 40 to 60. Some elongate map-scale gabbro bodies (Figure 4) are oriented parallel to sinuous D_1 structures, suggesting that intrusion took place before D_1 deformation; it is thus possible that these gabbros were synvolcanic. This relationship is demonstrated by gradational transition from mafic flows to gabbro north of Round Lake.

Mafic dyke rocks, best represented south of Cordova Lake, are typically medium-grained; in all other aspects they are identical to nearby extrusive rocks. In some places, particularly between Lost and Cordova Lakes, a gradational transition from fine-grained extrusive rocks through medium-grained to coarse gabbroic rocks indicates that the latter types are the hypabyssal and deeper equivalents of surficial flows. Dykes similar to those associated with volcanic rocks of the Cordova Lake formation cut marbles in the Belmont Lake and Cordova Lake areas. One 4 m wide dyke on the west shore of Belmont Lake (UTM 27540/493168) metamorphosed the host marbles within 30-40 cm of the contact. Because all dykes observed have been metamorphosed, it is possible that their intrusion was a synvolcanic event. Indirect evidence supporting this includes the close spatial relationship, despite the proposed major fault, between intermediate volcanics and dykes of

the Cordova Lake formation (Figures 3, 4), and intermediate dykes cutting the marbles of the Marmora formation.

The Cordova gabbro differs from other intrusive bodies in the map area in that the predominant amphibole is actinolite rather than hornblende, and layering, absent in all other plutonic rocks, is locally distinct. Rocks of the pluton are fine- to very coarse-grained gabbro and leucogabbro, with minor anorthosite; oikocrysts up to 15 cm across are present in some parts of the body. Generally uniform, these rocks are massive to moderately foliated; foliation is typically most pronounced within a zone 500-1000 m from the contact of the pluton, and is commonly parallel to it (Thomas and Cherry, 1981). Recrystallization mainly affected the mafic constituents of the gabbro, converting pyroxene to actinolite, and, locally, hornblende and chlorite; in some rocks former pyroxene grains have actinolite cores and hornblende rims. Original shape and size of plagioclase grains has been generally retained; despite partial alteration to chlorite, sericite, calcite and epidote in the northern rocks, and clinozoisite in the southern rocks, the composition of plagioclase is andesine (An_{32} to An_{44}). Magnetite, ilmenite, apatite and titanite are commonly present in minor amounts.

Compositional layering on a scale of centimetres to decimetres is evident locally near the north and west margins of the Cordova gabbro. Amphibole-rich parts of layers grade into plagioclase-rich sections (Plate IVf). These features are interpreted to represent primary gravity settling structures within the magma chamber.

Within the gabbro body shear zones up to tens of metres in width host auriferous quartz-carbonate veins that have been exploited in the past. Highly sheared rocks consist primarily of chlorite and biotite (Thomas and Cherry, 1981).

Associated with parts of the western margin of the Cordova gabbro are coarse intrusive breccias (Plate IVe), that have resulted from fracturing of fine- and coarse-grained gabbro and injection of fine-grained dioritic and tonalitic material. The felsic intrusive rocks are probably late differentiates of the gabbroic magma.

CHAPTER 4

METAMORPHISM

4.1 Metamorphic Zonation

On the basis of the mineralogy of mafic and intermediate rocks, the area has been divided into three zones, in order of increasing grade : actinolite, chlorite-hornblende and hornblende. The actinolite zone corresponds to the greenschist facies and the hornblende zone to the amphibolite facies of regional metamorphism; the chlorite-hornblende zone represents the transition from greenschist to amphibolite facies. The zones are illustrated in Figure 5, and their stable mineral assemblages are tabulated in Table 3.

The actinolite zone occupies the southeasternmost part of the area, encompassing most of the Crowe River formation. Actinolite⁵ is the predominant amphibole; hornblende⁵ is less common and is not compatible with actinolite. Chlorite occurs throughout the actinolite zone, commonly with actinolite or hornblende. The "actinolite-out" isograd is diffuse; it defines the upper boundary of the actinolite zone.

5. Although there is probably a continuous range of compositions between the tremolite-ferroactinolite and the hornblende series, for the purposes of this study a qualitative distinction between actinolite and hornblende has been made on the basis of stronger pleochroism and birefringence of hornblende relative to actinolite.

Figure 5. Distribution of metamorphic zones and isograds based on stable mineral assemblages in mafic and intermediate volcanic rocks of Belmont Township. Refer to Fig. 3 for geological units, and to Table 3 for abbreviations.

Table 3. Mineral assemblages of mafic and intermediate volcanic rocks of Belmont Township. Minerals in parentheses may be present in some rocks. Minerals present in trace amounts not included.

Zone	Mineral assemblage
Actinolite	ab-ac-ep-mt pc-ac-ep-mt-ch (ti) pc-ac-ep-mt-bi ab-ep-mt-ch-hb (bi, cz) pc-hb-mt pc-hb-ep-ch
Chlorite-hornblende	ab-qz-hb-ch-mt-ep (ac) ab-qz-hb-bi-mt-ep ab-qz-hb-bi-ch-mt-ep ab or og-hb-bi-mt-ep-qz og-hb-ch-ep-mt (cc, ti, qz, bi, ap) pc-hb-ep-mt (cc) pc-hb-ep (mt, ti, qz, gt, cz) pc-ac-ch-ox
Hornblende	pc-hb-qz-ch ¹ -mt-ep-ap pc-hb-ch ¹ -bi-ap-hm pc-hb-ep-qz (ti) pc-hb-ep-qz-bi-mt (ti, ap) pc-hb-ep-qz-mt (ti, ap) pc-hb-ap-ox pc-qz-bi-mt-ep-ti-ap (cc, gt, mu) og-qz-hb-bi-mt-ap (ti, ep, cc)

1. Chlorite present in hornblende zone due to locally high CO₂ activity.

Note: Abbreviations

ab: albite	hm: hematite
ac: actinolite	hb: hornblende
ap: apatite	mt: magnetite
bi: biotite	mu: muscovite
cc: calcite	og: oligoclase
ch: chlorite	ox: Fe/Ti oxide
cz: clinozoisite	pc: plagioclase of unknown composition
ep: epidote	qz: quartz
gt: garnet	ti: titanite

Hornblende, occurring locally in the actinolite zone and throughout the chlorite-hornblende zone may have, in part, arisen from the reaction:

(Winkler, 1979). This reaction can occur over a range of P-T conditions, possibly explaining the stable occurrence of actinolite and hornblende in this zone.

The predominant mafic mineral in the chlorite-hornblende zone is hornblende, which occurs with or without chlorite in mafic volcanics. Chlorite occurs without hornblende in intermediate volcanics and mafic fragmental rocks. In general, epidote is less abundant and plagioclase is more calcic toward the west (higher grade).

The hornblende zone is marked by the disappearance of chlorite in most mafic and intermediate volcanics; the presence of prograde chlorite in mafic hyaloclastites and pyroclastics at three localities (Figure 5) is ascribed to higher attendant CO_2 activity. It is possible that chlorite is consumed by reaction with epidote to produce hornblende and more calcic plagioclase:

(Sethuraman and Moore, 1973).

Table 4 summarizes the distribution of minerals in mafic and intermediate volcanic rocks, quartzofeldspathic rocks (mainly felsic volcanics) and pelites, and siliceous carbonate rocks as a function

Table 4. Mineral distribution and textural preservation in metamorphic zones of Belmont Township. Not all minerals occur in a given rock type. Quartz, apatite, magnetite, hematite, graphite, and pyrite may occur as accessories. Dashed line indicates that the mineral concerned is rare.

Metamorphic facies		Greenschist facies	Greenschist/Amphibolite Transition	Amphibolite facies
Mineral zoning		Actinolite	Chlorite-hornblende	Hornblende
Mafic and intermediate rocks	Plagioclase	Albite	Albite-sodic oligoclase	Calcic oligoclase
	Epidote	_____	_____	_____
	Clinozoisite	-----	-----	-----
	Hornblende	-----	-----	-----
	Actinolite	_____	-----	_____
	Biotite	_____	_____	_____
	Chlorite	_____	_____	-----
Quartzofeldspathic and pelitic rocks	Retrograde chlorite	-----	-----	-----
	Chlorite	_____	_____	_____
	Muscovite	_____	_____	_____
	Biotite	_____	_____	_____
	Almandine	_____	_____	-----
	Cummingtonite	_____	_____	-----
	Kyanite	_____	_____	-----
Carbonate rocks	Sodic plagioclase	_____	_____	_____
	K-feldspar	_____	_____	_____
	Tremolite	_____	_____	_____
Textural preservation	Dolomite	_____	_____	_____
	Quartz	_____	_____	_____
	Primary volcanic flow textures	-----	-----	-----
	Pillows/hyaloclastites	_____	_____	-----
	Phenocrysts/amygdules	_____	_____	_____
	Fragment outlines	_____	_____	_____
	Algal structures	_____	_____	-----

of metamorphic grade. Some isograds in the latter three rock types are illustrated in Figure 6, together with the distribution of relevant stable mineral assemblages. Table 4 and Figures 5 and 6 illustrate several salient features:

- (i) minerals common to all metamorphic zones include biotite and epidote in mafic and intermediate rocks; biotite, muscovite and sodic plagioclase in quartzofeldspathic and pelitic rocks, and quartz and dolomite in carbonate rocks;
- (ii) anorthite content of plagioclase in mafic and intermediate rocks increases from about 8 mol % in the actinolite zone to about 29 mol % in the highest-grade part of the hornblende zone;
- (iii) the stability fields of chlorite-hornblende and actinolite overlap; thus the lower boundary of the chlorite-hornblende zone is not marked by the first appearance of chlorite-hornblende;
- (iv) the "chlorite-out" isograds for mafic and intermediate, and quartzofeldspathic and pelitic rocks are coincident;
- (v) inappropriate bulk compositions inhibit the precise location of some isograds (eg. "kyanite-in"). The reaction-isograd "dolomite + quartz = tremolite + calcite" was located only to within 1-2 km;
- (vi) although dolomite and quartz persist in carbonate rocks on the high grade side of the abovementioned reaction-isograd, they do not occur together;
- (vii) low pressure indicators such as cordierite and andalusite, and high temperature minerals such as sillimanite do not occur in rocks of appropriate bulk composition.

Figure 6. Distribution of isograds and selected stable mineral assemblages in quartzofeldspathic, pelitic and siliceous carbonate rocks in Belmont Township. Refer to Fig. 3 for geological units. Abbreviations: cm = cummingtonite, dm = dolomite, Kf = K-feldspar, ky = kyanite, tr = tremolite; see also Table 3.

Assemblages in mafic rocks of the lower grade (southeast) part of the actinolite zone are roughly consistent with the common assemblage for greenschist facies metamorphism (Moody *et al.*, 1983). Definition of the beginning of the greenschist-amphibolite transition zone is tenuous in the study area; this zone may overlap with the actinolite zone.

The chlorite-hornblende zone of the study area probably represents the greenschist-amphibolite transition. The width of the model transition zone is strongly dependent on oxygen fugacity; in more reducing environments the isobaric temperature range may be as much as 150° C, whereas in more oxidizing environments the temperature range may be less than 50° C. The presence of epidote in the stable mineral assemblage of rocks of the chlorite-hornblende zone suggests that oxygen fugacities were, in general, relatively high, and that the temperature range across the zone was thus relatively low (Moody *et al.*, 1983).

The coincidence of the two "chlorite-out" isograds in the study area (Figures 5, 6) marks the beginning of amphibolite facies. This is in accord with the findings of Moody *et al.* (1983), who defined the end of the greenschist-amphibolite transition zone by the disappearance of chlorite in mafic rocks. Winkler (1979), however, stated that Mg-rich chlorite may persist into amphibolite facies in mafic rocks.

The disappearance of chlorite alone from pelitic rocks does not necessarily mark the beginning of amphibolite facies (Winkler, 1979). However, the onset of amphibolite facies conditions is marked

by the appearance of staurolite or cordierite in rocks of appropriate bulk composition. In the study area some quartzofeldspathic rocks close to, and on the low grade side of the "chlorite-out" isograd (Figure 6) have bulk compositions plotting on an AFM diagram mainly in areas where staurolite could form; the absence of staurolite in these rocks suggests that staurolite is not stable in the chlorite-hornblende zone. The absence of staurolite and (or) cordierite on the high grade side of the "chlorite-out" isograd is attributed to inappropriate bulk composition of the rocks.

The relative prevalence of the assemblage muscovite + K-feldspar (typically microcline) in rocks of the Oak Lake formation is due mainly to higher K content; other quartzofeldspathic rocks in the area have very low K contents and bear virtually no modal K-feldspar.

4.2 Textural Changes

Table 4 summarizes the state of textural preservation of rocks of all zones. Generally, most textures are well-preserved, except in the highest grade areas. Felty, pilotaxitic and trachytic flow textures are best preserved in rocks of the actinolite zone. Welding features in ash flow tuffs are recognized with certainty at one locality only, near the "actinolite-out" isograd; in the hornblende zone such features are cryptic. In rocks having a strong mineral or aggregate lineation, primary features are commonly well displayed in sections perpendicular to the direction of principal extension. With

increasing grade grains become larger, more uniform in size and habit and more equant, particularly in the hornblende zone.

4.3 Metamorphic Conditions

The change from actinolite to hornblende probably takes place at about 500 °C, rising only slightly with increasing pressure (Winkler, 1979); this temperature must have prevailed throughout most of the actinolite zone. Assuming that garnets in quartzofeldspathic and pelitic rocks of the study area are almandine-rich, minimum pressures can be proposed for rocks of the chlorite-hornblende zone; Winkler (1979) stated that a pressure of 4 kb at 500 °C must be exceeded to stabilize almandine-rich garnet with a very low content of spessartine component. Other estimates, based on petrographic observations, of P-T conditions in the higher-grade zones are more speculative.

Comparison of the sequence of mineral assemblages in the study area (Table 4) with sequences of the Abukuma Plateau and the southeastern Highlands of Scotland (Tables 5 and 6) reveals several mineralogic similarities and contrasts. These regions are considered to typify, respectively, relatively low and intermediate pressures of regional metamorphism (respectively, "Abukuma" and "Barrovian" facies series of Winkler (1965)) (after Ernst (1968), as reproduced in Sethuraman and Moore, 1973).

The sequence of mineral assemblages and their stability fields suggests recrystallization under a P-T regime similar to that of the Barrovian facies series. The metamorphic zones in the mafic and

TABLE 5. Mineral assemblages in the metamorphic zones of the central Abukuma Plateau, Japan (Ernst 1968)

Metamorphic facies		Greenschist facies	Amphibolite facies		Granulite facies
Mineral zoning		A	B	C	D
Mafic rocks	Sodic plagioclase	_____			
	Intermediate and calcic plagioclase		_____		
	Epidote	_____	_____		
	Actinolite	_____			
	Hornblende		_____		
			Blue-green	Green	Brown
Pelitic rocks	Cummingtonite			_____	
	Chlorite	_____			
	Clinopyroxene		_____		
	Orthopyroxene				_____
	Chlorite	_____			
	White mica	_____			
	Biotite	MnO > 18%		MnO < 10%	
	Pyralspite	_____			
	Andalusite		_____		
	Sillimanite			_____	
	Cordierite		_____		
	Plagioclase	_____			
	K-feldspar		_____		

TABLE 6. Mineral assemblages in the metamorphic rocks of the Scottish Highlands (Ernst 1968)

Metamorphic facies		Greenschist facies	Epidote-amphibolite facies	Amphibolite facies	
Mineral zoning		Chlorite and biotite zones	Almandine zone	Staurolite and kyanite zones	Sillimanite zone
Mafic rocks	Sodic plagioclase	_____			
	Intermediate and calcic plagioclase				
	Epidote	_____			
	Amphibole	Actinolite	Blue-green hornblende	Green hornblende	Green or brown hornblende
	Chlorite	_____			
Pelitic rocks	Almandine		_____		
	Chlorite	_____			
	White mica	_____			
	Biotite	_____			
	Almandine		_____		
	Staurolite			_____	
	Kyanite			_____	
	Sillimanite				_____
	Sodic plagioclase	_____			

intermediate rocks correspond, in pelitic rocks, to the interval between biotite zone and staurolite and kyanite zones.

4.4 Metamorphism of Major Intrusive Bodies

Primary igneous textures of felsic intrusive rocks in the northwest corner of the map area have been partly modified by recrystallization; feldspars exhibit mortar texture, and a weak planar or linear biotite fabric is present locally. Ribbon texture in quartz grains indicate that the rocks underwent at least moderate strain. Timing of emplacement of the granitic pluton is uncertain; Ordovician limestone cover masks much of the contact between the intrusive body and rocks of the Oak Lake formation. It is thus unknown if the pluton cuts D_2 structures.

The mafic mineralogy of the Cordova gabbro is consistent with upper greenschist facies metamorphism. Pronounced disparity between plagioclase compositions in the Cordova gabbro (An_{32-44}) and the adjacent basalts of the Crowe River formation (An_8) suggests that the intrusive rocks are less recrystallized. This may be due to the greater resistance to recrystallization of coarse-grained plutonic rocks relative to fine-grained rocks. It is also possible that the recrystallization history of the gabbro was different from that of the neighbouring basalts; the gabbro may have been emplaced after peak- M_1 conditions, resulting in incomplete metamorphic re-equilibration relative to the basalts. Emplacement was demonstrably post- D_1 , as the gabbro truncates D_1 structures in the basalts. The general absence of obvious D_1 fabric

within the gabbro is also evidence supporting post- D_1 emplacement. Skarns produced from marble at the western edge of the Cordova gabbro contain diopside that did not re-equilibrate to M_1 metamorphic conditions, and thus probably formed after peak metamorphism. However, as the skarns are typically medium- to coarse-grained, and thus more resistant to recrystallization, precise timing of formation of these rocks relative to metamorphic events is not possible. That the gabbro pre-dates D_2 deformation is demonstrable; D_2 fabric in marbles of the Marmora formation "wraps around" the pluton.

4.5 Contact Metamorphism

Intrusion of the Cordova gabbro resulted in the contact metamorphism and metasomatism of some surrounding rocks. An aureole 1.5 km wide surrounds the east side of the pluton, in Marmora Township; tremolite occurs to the outer edge of the aureole, phlogopite occurs locally, and, at one locality, wollastonite was observed. Contact metamorphism is less well-documented on the west side.

The tremolite-bearing marbles of the upper member of the Crowe River formation were produced by the thermal metamorphic effect of the gabbro body cropping out south of the Cordova pluton.

4.6 Metamorphism and Deformation History

Table 7 summarizes the relation between metamorphic and deformational events in Belmont Township. The salient aspects include:

2

- (i) the development of a homoclinal succession by isoclinal folding (D_1) about north-striking, east-dipping axial surfaces;
- (ii) a major regional metamorphic event (M_1) beginning in D_1 and persisting well into D_2 ;
- (iii) the emplacement of gabbroic plutons in Belmont and southern Methuen Townships between D_1 and D_2 ;
- (iv) NW-SE compression (D_2 and D_3) to produce close to gentle folding.

Table 7. Correlation of metamorphic and deformational events in Belmont Township.

Deformation	Metamorphism	Planar Fabric	
		S ₀	Original sedimentary and volcanic fabric.
D ₁	M ₁	S ₁	Major isoclinal folding, resulting in homoclinal arrangement of strata. Recrystallization and development of planar fabric : chlorite and mica plates, amphibole porphyroblasts, and inclusion trails incorporated in later porphyroblasts. Metamorphism outlasted deformation to produce main regional zonation: growth of chlorite, garnet, cummingtonite and kyanite porphyroblasts. Major faulting (?). Regional emplacement of gabbro plutons. Contact metamorphism.
D ₂			Map-scale open to close folding in western part of Belmont Township; outcrop-scale folding local in east. Continuation of M ₁ metamorphic event. Rotation of late-M ₁ porphyroblasts. Local crenulation of cleavage in M ₁ minerals.
	M ₂	S ₂	Recrystallization and development of localized planar fabric : mica plates and elongate calcite grains.
D ₃			NW-SE regional compression (continuation of D ₂ event (?)). S ₂ fabric deformed around Cordova gabbro.
	M ₃		Overprinting of S ₁ (and S ₂ ?) by muscovite porphyroblasts.
D ₄			Local faulting and brecciation.

CHAPTER 5

PHYSICAL VOLCANOLOGY

5.1 Cyclical Volcanism

5.1.1 General statement

In the context of this study cyclical volcanism refers to the repetition of generalized mafic to felsic volcanic sequences, with or without accompanying sedimentary units. This accords with the nomenclature used to describe the classic mafic to felsic volcanic sequences observed in Archean greenstone belts (Goodwin, 1967, 1977).

Anhaeusser (1971) examined cyclicity in Archean volcanic and sedimentary rocks and described its occurrence on four scales:

- 1) mini-cycles: measured in centimetres, or parts thereof (eg. greywacke-argillite couplets); most evident in sedimentary rocks;
- 2) minor-cycles: measured in metres, tens of metres, or hundreds of metres; particularly prominent in volcanic sequences;
- 3) major-cycles: a few hundred metres to many thousands of metres; generally manifested in mafic to felsic volcanic sequences;
- 4) super-cycles: embraces the whole volcanic and sedimentary pile and may change from ultramafic to tholeiitic to calc-alkaline to alkaline; generally on the order of tens of thousands of metres thick.

The literature abounds with examples of Archean volcanic cycles on all scales; major- and minor-cycles are almost invariably represented.

Thurston (1980a) compiled many examples of volcanic cyclicity in the Archean shield areas of Africa and Australia, and the Superior Province of the Canadian Shield, and discussed the significance of super-cycles in an Archean context. Lambert (1977) described one singular and two superposed mafic to felsic volcanic cycles in the Slave Province of the Canadian Shield.

Although workers in volcanic terranes of post-Archean age generally do not refer to volcanic cyclicity *per se*, they describe one or more mafic to felsic volcanic sequences on the scale of Anhaeusser's (1971) major-cycle. Proterozoic successions of the Canadian Shield yield several examples of mafic to felsic volcanic cyclicity. Moore's (1977) summary of Proterozoic orogenic volcanism in Canada contains descriptions of one single and two superposed volcanic major-cycles in the Churchill Province; he also referred to "Hadrynian basalt-andesite-rhyolite suites" of the Northern Appalachians. Hoffman and McGlynn (1977) reported a basal basalt-rhyolite sequence succeeded by "cyclic sequences" of andesite-dacite-rhyolite in the Bear Province; thin basalt units toward the top of the succession alternate with rhyolite and constitute three minor-cycles. The Southern Province bears mafic to felsic volcanic sequences on the minor-cycle scale in the Sudbury district (Moore, 1977), and, in the Lake Superior district, on the major-cycle scale (Green, 1977). Moore (1977) and Sethuraman and Moore (1973) described one basalt-andesite-rhyodacite cycle and Ayer (1979) one basalt-andesite-rhyolite cycle in the Bishops Corners-Donaldson and Mazinaw Lake areas, respectively, of the Hastings region

of the Grenville Province.

Phanerozoic examples of mafic to felsic cyclical volcanism are abundant; some Canadian examples include Paleozoic basalt-rhyolite suites in Newfoundland (Strong, 1977) and New Brunswick (Pajari *et al.*, 1977). Clarke (1977) described a mafic to felsic sequence in the Tertiary volcanics of the Baffin Bay region. Lambert (1974) reported two superposed rhyolite-dacite-andesite (and minor basalt) suites in the Yukon; these reverse cycles were suggested by Lambert to represent the tapping of a vertically zoned magma chamber.

5.1.2 Cyclicity in the Belmont Lake Metavolcanic Complex

The rocks of Belmont Township group naturally into four distinct volcanic cycles on the scale of Anhaeusser's (1971) major-cycle. Although the cycles are generally defined by a progression from a mafic base to a felsic top, one end-member in each of two cycles is not well-represented. A mafic base to Cycle I, the lowermost cycle, is not exposed in the study area. Cycle IV, the uppermost cycle, does not have an exposed felsic top. Sedimentary units are generally concentrated toward or at the top of each cycle, and are considered to be part of the cycle they overlie or are intercalated with. Each cycle contains one or more formations; correlation between cycles and formations is outlined in Tables 8-11.

Cyclicity on the minor-cycle scale occurs in all cycles of the Belmont Lake Metavolcanic Complex, most commonly as the progression from mafic to intermediate and (or) felsic rocks; metres to hundreds

of metres thick, these sequences occur throughout the major-cycles.

Figure 4 illustrates many minor-cycles, the coarsest of which involve two mafic- (locally) intermediate-felsic suites in the lower to middle parts of the Oak Lake formation; each has a thickness of about 500 m.

Cyclicity on the mini-cycle scale of Anhaeusser (1971) was observed in millimetre- to centimetre-scale beds of felsic tuff with cherty tops, particularly in the felsic volcanoclastic member of the Whitney Creek formation. The Belmont Lake formation contains numerous examples of greywacke-argillite-type couplets on the mini-cycle scale.

This study concerns mainly major-cycles; thus further mention of minor- and mini-cycles will be limited to specific examples as they apply to major-cycles.

5.2 Facies Analysis and Paleovolcanic Reconstruction

5.2.1 General statement

Stratigraphic units have been defined on the basis of composition; facies variations are defined by textures, primary structures and structure sequences. Facies analysis is more meaningful in pyroclastic and epiclastic units than in units consisting only of flows because there are more measurable variables such as: nature of bedding, grain size, degree of sorting, angularity of clasts, composition, heterogeneity of clasts and matrix, and primary structures (Parsons, 1969; Buller and McManus, 1973; Heiken, 1972; all as quoted by Ayres, 1977). For flows the critical features to be observed are thickness

and extent, primary structures including flow top (and bottom) characteristics, primary textures and alteration (Ayres, 1977). Facies analysis thus yields important information on the type of eruption, distance from and direction to source, method of transport, degree of reworking and depositional environment. Identification of depositional environment can be aided by the presence of indicators such as pillows and (or) hyaloclastites, amygdules (Moore, 1970; Jones, 1969), volcanic pyroclastic rocks (McBirney, 1971), welded ash flow tuff (Rankin, 1960), and accretionary lapilli (Moore and Peck, 1962), among others (in part quoted by Ayres, 1977).

Facies in volcanic terranes are commonly cited as central, proximal and distal (cf. Williams and McBirney, 1979), relative to the vent that supplied the volcanic material. In the study area, as in many deformed, ancient volcanic terranes it is commonly difficult or impossible to precisely delimit source areas due to several factors:

- 1) because most volcanic vents are small relative to the overall dimensions of the volcano, the present erosion surface is more likely to expose a flank section;
- 2) in most deformed shield areas vertical relief of the erosion surface is minimal, thereby allowing an observer only a two-dimensional view. Ayres (1977), however, pointed out that complex folding and faulting may allow extrapolation to a third dimension;

- 3) erosion may have completely removed the source area, thus "orphaning" the rocks being studied;
- 4) the source area may have been removed, in whole or in part, by subsequent intrusions, or unconformably overlain by rocks and (or) unconsolidated deposits.

Volcanic rocks emplaced close to vents are commonly easy to recognize in the field. The distinction between proximal and distal facies, however, is made on relative terms and is hence somewhat arbitrary.

Volcanic eruptions have been classified on several bases, but no classification so far devised is wholly satisfactory (Macdonald, 1972). Williams and McBirney (1979) discussed the advantages and disadvantages of attempts to rigidly classify eruptions, and concluded that old, firmly entrenched terms should be defined more clearly, and new terms introduced only where necessary.

Williams and McBirney (1979) described and illustrated, with case histories of examples, the following principal types of central eruptions: Hawaiian, Strombolian, Vulcanian, Pelean, Plinian (Krakatoan), phreatomagmatic (Surtseyan), and phreatic. They also described fissure eruptions. The classification used by Williams and McBirney (1979) is generally consistent with that of Macdonald (1972), and is used as the standard for this study. More recent studies by other workers (eg. Self, 1982) have defined further some types of eruption, particularly Plinian.

Eruption types of ancient volcanoes are, by necessity, deduced from the nature of associated volcanic deposits. In metamorphosed and deformed terranes it is commonly difficult to recognize deposits that have resulted from individual eruptions; hence, in this study, conclusions made concerning kinds of eruptions are, in general, approximate.

5.2.2 Cycle I

Cycle I comprises the Oak Lake and Little Whitney Lake formations. Figure 7 illustrates the distribution and general geology of Cycle I; Figure 8 consists of three stratigraphic sections through Cycle I and illustrates general facies relationships within the cycle. Table 8 summarizes the stratigraphy and evolution of Cycle I, based on facies analysis, and deduced types of eruption and depositional environment.

5.2.2.1 Facies analysis

Deposition of central facies volcanic rocks is recorded in the nose of the major syncline west of Little Whitney Lake. Here thick, flow banded felsic flows have a lateral extent of 2 km; this is in accord with typical felsic flows, which rarely travel more than 1-2 km from source (Williams and McBirney, 1979). Intermediate lavas, also present in and near the nose of the syncline, are nowhere longer than 800 m; they constrain the positioning of the volcanic centre, as andesite flows commonly come to rest close to the vent area (Dimroth

Figure 8. Stratigraphic sections of Cycle I, illustrating facies relationships. Sections are located in Fig. 7. Legend as in Fig. 7. Section A-A' probably thickened tectonically.

Figure 7. Distribution and general geology of Cycle I. Stratigraphic sections are illustrated in Fig. 8. Refer to Fig. 3 for formation boundaries.

Table 8

Summary of the Stratigraphy and Evolution of Cycle I

Formation	Member	Thickness (metres)	Dominant rock type(s)	Minor rock type(s)	Facies analysis and depositional environment	Environmental indicators
Little Whitney Lake		0-1000	Calcareous dolomitic marble	Siliceous clastic rocks	A quiescent interval following volcanism; shallow water deposition in restricted basin (caldera?); minor component of carbonate (and sulphide) from fumarolic deposition.	Algal structures; massive pyrite interlayered with carbonate.
Oak Lake	C (felsic volcanics) north part	1500-2000	Heterogeneous - felsic flows, tuff, lapilli tuff, tuff breccia, volcanic conglomerate		Near-vent deposition in area of major syncline west of Little Whitney Lake - evidence: abundant felsic flows with lateral extent of 2 km, and coarse and massive to thickly bedded nature of most fragmental deposits; volcanic conglomerates mainly deposited on south flank of volcano; heterolithic nature and abundance of these deposits indicates active erosion, suggestive of subaerial or shallow water provenance and (?) deposition; forms part of major composite cone.	Thick bedding; heterogeneous lithic volcanic conglomerate.
	C south part	1500-2000	Felsic tuff, ash flow tuff	Felsic lapilli tuff, intermediate tuff, chert, sulphide facies iron formation, siltation, siliciclastics	Proximal to distal facies deposition indicated by fining of bedding and grain size of airfall pyroclastics to south; moderately to strongly welded ash flow tuffs, commonly tens of metres thick, indicate subaerial deposition; chert and sulphide facies iron formation probably deposited by fumarolic activity.	Thin to very thin bedding; graded bedding; moderate to strong welding in ash flow tuff.

Table 8 (cont'd)

Formation	Member	Thickness (metres)	Dominant rock type(s)	Minor rock type(s)	Facies analysis and depositional environment	Environmental indicators
	B	0-400	Intermediate tuff, lapilli tuff, breccia, flows		Near-vent deposition indicated by presence of intermediate flows, and coarse nature of pyroclastics; amygdules in flows, and presence of pyroclastics indicates subaerial or shallow water deposition; away from near-vent area bedding and grain size are finer, and resorted deposits more abundant; occur as one thick unit and as smaller, lenticular units.	Amygdules; coarse grain size; medium to thickly bedded pyroclastics.
	B south part	0-100	Intermediate tuff	Intermediate lapilli tuff	Relatively distal, subaqueous deposition indicated by thin bedding and fine grain size; occur as small lenses throughout.	Thin bedding, fine grain size.
	A	0-300	Mafic flows	Mafic tuff	Near-vent deposition suggested by proximity to felsic flows; in part deposited in shallow water environment; local mafic airfall tuff represents last phase of mafic volcanism before deposition of Little Whitney Lake formation; mainly confined to nose and limbs of syncline.	Pillows, hyaloclastites, amygdules, thin to very thin bedding in tuff.
	A south part	0-20	Mafic flows		Amygdules indicate shallow water or subaerial deposition; may represent isolated flank eruptions, as associated gabbro swarm is probably subvolcanic to a poorly exposed mafic sequence.	Amygdules

1. Measured thickness without allowance for tectonic thickening or thinning.

and Rocheleau, 1979; Williams and McBirney, 1979). The occurrence of non-reworked pyroclastic and tuff breccia of intermediate and felsic composition also indicates central facies deposition (cf. Williams and McBirney, 1979) in the area of the syncline. The lower part of a section through the syncline (Figure 8, section A-A') contains rocks (tuff breccias, lapilli tuffs) that cannot demonstrably be assigned to central facies deposition, yet are at least proximal (cf. Williams and McBirney, 1979). The significance of this observation cannot be evaluated without more data, however it may reflect the correlation of increasing distance from the conduit with decreasing height of the volcano that would be brought about if the erosional surface exposed the volcano's western flank. Such a section through the volcano could also explain the minimal exposure of intrusive rocks in the central facies area.

North and south of the central facies area tuff and lapilli tuff are more abundant; bedding is commonly extremely thick (> 3m) to the north boundary of the township. Relatively distinct facies transitions occur directly south of the major syncline; lahars, and volcanic conglomerate and wacke form mappable units up to 3 km south of the structure. Proximal facies tuff, lapilli tuff and ash flow tuff deposits are evident to the contact with Ordovician limestone south of Round Lake. A southerly increase in distance from the vent is indicated by the gradual fining of scale of bedding and grain size of airfall pyroclastic rocks.

Minor vent areas, possibly sites of eruptions on the flanks of the main volcano, occur north of Round Lake, in the middle and upper parts of the Oak Lake formation. A swarm of gabbro bodies (including sills ?) occupies the area 4 km north-northwest of Round Lake (Figure 4); local gradation between gabbro and mafic flows indicates that the intrusive bodies represent feeders to mafic effusions that are presently minimally exposed. It is uncertain whether or not the mafic flows were deposited concurrently with associated felsic rocks. The close spatial relationship between the swarm of gabbro bodies and rocks of higher CI (~ 10) than most felsic rocks in the area suggests that minor intermediate to felsic volcanism may have been associated with this satellitic vent area, although there is no other evidence to support central facies deposition.

The lenticular unit comprising chert and sulphide facies iron formation 2 km north of Round Lake marks the site of fumarolic activity which may or may not have been related genetically to the gabbro bodies north of Round Lake. Deposition resulting from this activity was apparently local.

5.2.2.2 Eruption types

The interstratified nature of mafic, intermediate and felsic flows and pyroclastics indicates the presence of a composite volcano occupying the area of central facies deposition. Varied deposit types in the area reflect different styles of eruption. The thin flows of the mafic volcanic lentils are certainly the products of mild effusive

activity, probably Hawaiian-type; this type of eruption is, however, most commonly associated with shield volcanoes (cf. Williams and McBirney, 1979). Vulcanian and (or) Pelean eruptions were probably the most common types in the lower part of the exposed cycle, leading to the deposition of coarsely stratified airfall tuff to tuff breccia, possibly pyroclastic (including block and ash) flows, and felsic lavas. Sheet-forming pyroclastic flow and Plinian eruptions (Self, 1982) respectively accounted for most of the ash flow tuff, and airfall tuff and lapilli tuff deposits of the middle and upper parts of the cycle in the vent area, and most of the deposits in more distal areas.

5.2.2.3 Depositional environment

The presence of pyroclastic rocks throughout the central facies area suggests that subaerial or shallow water, (less than 500 m depth) conditions prevailed (cf. McBirney, 1963) while the volcano was active. The local occurrence of pillows and hyaloclastites demonstrate that there was at least minor subaqueous deposition; 10-15% large amygdules in pillows suggest depths considerably less than 500 m (Jones, 1969). Proximal facies volcanic conglomerates occur mainly in the middle part of the exposed stratigraphy; the abundance and heterolithic nature of these deposits indicates active erosion, suggestive of subaerial provenance and subaerial or shallow water deposition (cf. Ayres, 1977, 1982a).

Further from, and, particularly, south of the main vent ash flow tuff dominates the lower and middle part of the cycle; features suggestive of moderate to strong welding constrain the environment of deposition. Although welding has been documented in subaqueous ash flow tuffs (Francis and Howells, 1973), the intensity of welding, shown by extreme flattening and silica replacement of pumice, indicates subaerial deposition (cf. Thurston, 1980a, b).

Tuffs forming the upper part of the cycle in proximal to distal areas display thin to very thin bedding and graded bedding, probably indicative of subaqueous deposition (cf. Ayres, 1977). Chert and sulphide facies iron formation at the top of the cycle are also suggestive of subaqueous deposition in a more distal area.

Marble of the Little Whitney Lake formation is restricted mainly to the area of central facies deposition of the volcanics. Lying above the volcanics it illustrates that subaqueous conditions prevailed in that area upon cessation of volcanism; although tectonically thickened in the major syncline, two major facies can be recognized. Calcitic marble predominates in the lower part of the formation whereas dolomitic marble bearing algal structures is most abundant in the upper part. Presumably, this change reflects a transition in depositional environment from relatively deep to shallow water (cf. Blatt *et al.*, 1980) with increasing stratigraphic height. The probable maximum depth for formation of Precambrian stromatolites was estimated by Playford *et al.* (1976) to be 100 m. Bourque (1982, unpublished data) concluded, on the basis of silt content and distribution in the

carbonate rocks, that the carbonates occupying the syncline were deposited in a restricted basin.

5.2.2.4 Large scale reconstruction

The most prominent feature of Cycle I is the composite volcano, here interpreted to have supplied most or all of the volcanic material of Cycle I, within Belmont Township. The exact coincidence of the vent area and the axial surface trace of the fold having the largest amplitude in the township is puzzling, however the restriction of central facies rocks, particularly felsic lavas, to the fold nose must reflect either a close primary spatial relationship among them, or capricious tectonism. The author prefers the former, however allows that minor tectonic re-distribution of rock units in the central facies area may have occurred; structural data argue against mass migration of non-carbonate rocks to the fold nose; S_1 and S_2 planar fabric is, in general, not complexly folded in the nose. Certainly marble of the Little Whitney Lake formation has been thickened in the nose of the syncline.

The restricted lateral extent of mafic flows, the abrupt transition south of the syncline from vent-type to flank-type (volcanic conglomerate) deposition, and the apparent restricted basin deposition of the marble suggests that at least the south side of the vent was a major factor in controlling depositional regimes, and may thus have been a wall of a major volcanic or volcano-tectonic subsidence feature (caldera). Such features are commonly formed by collapse following

Plinian eruptions (Williams and McBirney, 1979). Subsidence in the vent area is demonstrable; from the lower mafic volcanic lens, deposited at depths no greater than several hundred metres, to the base of the evidently subaqueous marble unit, about 1000-1500 m of stratigraphy are represented. Subsidence in more distal areas is also apparent; the lower and middle parts of the cycle are interpreted to have been deposited in a subaerial environment, in contrast to subaqueously deposited rocks at the top of the cycle.

The shape of the main volcano can be inferred, in part, from the distribution of ash flow tuffs assumed to have issued from it. Bond and Sparks (1976) studied ash flow deposits associated with the Santorin caldera in Greece and found that ignimbrites generally do not come to rest on slopes greater than 5° ; they also noted that 10° is the maximum gradient of repose on Tenerife. That ash flow tuffs are apparently predominant only in more distal parts of Cycle I in the study area suggests that only there did the slope of the flank decrease to about 10° or less.

5.2.3 Cycle II

Cycle II comprises the Whitney Creek formation. Figure 9 illustrates the distribution and general geology of Cycle II; Figure 10 consists of three stratigraphic sections through Cycle II and illustrates general facies relationships within the cycle. Table 9 summarizes the stratigraphy and evolution of Cycle II, based on facies analysis and deduced types of eruption and depositional environment.

Figure 9. Distribution and general geology of Cycle II. Black unit is silicate facies iron formation. Stratigraphic sections are illustrated in Fig. 10.

Figure 10. Stratigraphic sections of Cycle II, illustrating facies relationships. Sections are located in Fig. 9. Legend as in Fig. 9. Black unit is silicate facies iron formation.

Table 9

Summary of the Stratigraphy and Evolution of Cycle I

Formation	Member	Thickness (metres)	Dominant rock type(s)	Minor rock type(s)	Facies analysis and depositional environment	Environmental indicators
Whitney Creek	D	150-700	Felsic volcanoclastics, mudstone	Chert	Felsic volcanoclastics thickest in north, suggesting proximal facies; bedding and grain size fine to south, indicating more distal facies; a major facies transition occurs east of north side of Round Lake: the volcanoclastics pinch out in a southward thickening pile of mudstone, representing distal facies deposition in deepening marine basin; chert is more abundant to south and as thin layers in uppermost part of member, possibly indicating deposition in deeper water; graphite content increases to south, suggesting environment was more euxinic; thin pyritic unit at top of most of member may have formed from fumarolic activity after and in the late stages of deposition of volcanoclastics.	Very thin to medium bedding, graded bedding, chert, graphite.
	C	0-150	Marble		Deposited during hiatus in late stage of mafic volcanic activity; dolomitic marble, bearing algal structures, is most common in north part of member, indicating shallow water deposition; member thickens gradually to south; calcitic component increases to south through zone of interbedded calcitic and dolomitic marble to dolomite-poor, non-stromatolitic part of unit - this may indicate deepening marine basin to south.	Algal structures; relative abundance of calcite vs. dolomite.

Table 9 (cont'd)

Formation	Member	Thickness (metres)	Dominant rock type(s)	Minor rock type(s)	Facies analysis and depositional environment	Environmental indicators
	B	0-100	Silicate facies iron formation	Chert, mudstone	Deposited by exhalative activity during hiatus in volcanism; distribution of silicate, oxide and sulphide minerals indicates vertically and laterally fluctuating chemical conditions.	
	A	250-800	Mafic flows, mafic agglomerates, tuff, intermediate tuff, lapilli tuff	Intermediate flows, felsic tuff, chert	Interstratified flows and pyroclastics in the north form east flank of composite volcano, the apex of which has been eroded away; smaller, sub-serial volcano probable 2 km north of Round Lake where agglomerates are abundant; area between north and south parts of member may represent restricted subaqueous basin where pillows and hyaloclastites formed, and where chemical precipitation of Member B occurred; mafic rocks lying between Members C and D may represent detritus derived from flows and pyroclastics.	Agglomerates, pillows, hyaloclastites, amygdulites.

1. Measured thickness without allowance for tectonic thickening or thinning.

5.2.3.1 Facies analysis

Central facies rocks associated with a major vent are not present in Cycle II. A minor vent is postulated for the area 2 km north of Round Lake where agglomerates are most abundant. Agglomerate is generally considered to be a near-vent deposit (Parsons, 1969; Williams and McBirney, 1979). This minor vent may have contributed all or most of the mafic and intermediate volcanic material in the south part of the exposed cycle.

The cycle gradually thickens northward to a maximum near the township boundary, whence it thins considerably and may pinch out in Methuen or Lake Township. This suggests that, at least in relative terms, proximal facies rocks occupy the north part of the cycle. Structural data indicate, however, that some of the thickening is tectonic. The presence of intermediate lavas, and their interstratification with pyroclastic rocks, suggests deposition on the proximal flanks of a composite volcano. A more distal environment in the south part of the cycle is indicated by the southward thickening of the marble of member C and the gradual fining of fragment size and bed thickness in rocks of member D; in addition, the relatively abrupt lateral transition from volcanoclastic to predominantly epiclastic rocks coincides with the thickening of the marble unit, and indicates a distal, predominantly sedimentary environment.

5.2.3.2 Eruption types

The presence of fluid mafic lavas, such as occur throughout member A of Cycle II, is characteristic of Hawaiian eruptions (Williams and McBirney, 1979). The interstratified nature of mafic lavas with intermediate tuff and lapilli tuff may signify constantly alternating styles of eruption from one vent; it may however, be due to mixing of material from separate vents.

The distribution of silicate facies iron formation was probably controlled by a fissure system that may or may not have been associated genetically with the composite volcano.

The agglomerates of the south part of the cycle were probably erupted during Strombolian activity (cf. Williams and McBirney, 1979). The relatively widespread occurrence of mafic tuff and lapilli tuff, in part well-stratified, throughout the south part of member A may signify a change in eruptive style from Strombolian to phreatomagmatic (Surtseyan) (cf. Williams and McBirney, 1979).

Data are presently insufficient to estimate with accuracy the eruptive mechanism that led to the deposition of the felsic volcaniclastic member.

5.2.3.3 Depositional environment

Subaqueous deposition of mafic rocks can be demonstrated only in the lower to middle parts of member A in the central part of the cycle; pillows and hyaloclastites are restricted to this part of the cycle. The lack of pillows and hyaloclastites in other rocks does

not necessarily indicate subaerial deposition, however the abundance of intermediate pyroclastics throughout member A constrains the maximum water depth to 500 m (cf. McBirney, 1963). The general paucity of amygdules thus does not necessarily represent deposition in deep water; instead it may indicate that the lava was largely de-gassed before coming to rest, or it may reflect a chemical peculiarity such as low K_2O content (Bryan and Moore, 1977). Where present, amygdules occur within thin flows.

Strombolian eruptions are generally considered to be subaerial phenomena (Williams and McBirney, 1979); deposition, however, may be subaqueous. Subsequent probable phreatomagmatic eruptions (see previous section) suggest an increasing accessibility of water to the vent.

The silicate facies iron formation was deposited subaqueously by exhalative activity (cf. Klein, 1973). The subordinate amount of associated clastic deposits suggests that it was deposited in a basin restricted from major clastic sedimentation.

Algal structures in dolomitic marble limit the maximum depositional depth of the north part of member C to 100 m (cf. Playford *et al.*, 1976); alternatively these rocks may have been deposited at intertidal to supratidal levels (cf. Hoffman, 1976). The southward decrease in dolomitic marble, with or without algal structures, relative to non-stromatolitic calcitic marble probably indicates a deepening marine basin to the south.

Thick bedding in the north part of the felsic volcanoclastic member may indicate subaerial or near-vent subaqueous deposition; small lenses of marble in this part of the unit, however, reflect subaqueous deposition. Very thin bedding and chert in the more southerly rocks are indicative of a subaqueous environment. The gradual increase in the amount of chert, pyrite and graphite in rocks toward the top of the member, and to the south is interpreted to reflect a change in depositional environment from one in which active clastic deposition predominated to one in which conditions were more euxinic. The pyrite-rich rocks capping much of member D may have been formed by fumarolic activity.

5.2.3.4 Large scale reconstruction

Strata in the north part of the cycle are generally more steeply dipping than those in the south, possibly suggesting that the northern rocks constitute the east flank of the composite volcano. If this is the case the apex and central conduit have been eroded away, leaving few intrusive rocks exposed.

A restricted subaqueous basin separated the volcano from one or more cinder cones that controlled much of the deposition of mafic and intermediate rocks in the southern part of the cycle. A southward deepening sea dominated the distal area, where carbonates were succeeded vertically by mudstones, the distal analogue to the felsic volcanoclastics that lie at the top of much of the cycle.

Subsidence, probably manifested throughout the cycle, is most evident in the south where subaerial and shallow water deposits gradually yield upward through several hundred metres of stratigraphy to relatively deep subaqueous deposits.

A close spatial, if not genetic relationship exists between the mafic volcanics of the south part of Cycle II and the fumarolic vent(s) at the top of Cycle I: near-vent agglomerates directly overlie the exhalative deposit suggesting the possibility that the fumarolic vent area(s) was (were) re-activated to allow passage of magma to form the cinder cone(s) of Cycle II. The possibility, raised earlier, that the fumarolic activity was genetically related to the nearby gabbro bodies permits the conjecture that the intrusive rocks represent the feeders to the southern mafic volcanics of Cycle II.

5.2.4 Cycle III

Cycle III comprises the Cordova Lake, Vansickle, Marmora and Belmont formations. Figure 11 illustrates the distribution and general geology of Cycle III; Figure 12 consists of three stratigraphic sections through Cycle III and illustrates general facies relationships within the cycle. Table 10 summarizes the stratigraphy and evolution of Cycle III, based on facies analysis and deduced types of eruption and depositional environment.

Most of the volcanic rocks of Cycle III are in the Cordova Lake formation; therefore treatment here of facies analysis and eruption types will centre on this unit. The predominantly sedimentary

Figure 12. Stratigraphic sections of Cycle III, illustrating facies relationships. Sections are located in Fig. 11. Legend as in Fig. 11.

Figure 11. Distribution and general geology of Cycle III. Stratigraphic sections are illustrated in Fig. 12. Refer to Fig. 3 for formation boundaries.

Table 10

Summary of the Stratigraphy and Evolution of Cycle III

Formation	Member	Thickness (metres)	Dominant rock type(s)	Minor rock type(s)	Facies analysis and depositional environment	Environmental indicators
Belmont Lake		0-700	Conglomerate	Sandstone, mudstone, marble, fel- sic tuff	Polymictic conglomerate; most volcanic and chert clasts strongly resemble rocks of the Cordova Lake formation, the proposed provenance; marble clasts are in part derived from the lower part of the Marmora formation and in part from immediately underlying marble units within the formation; the Belmont Lake formation is time-equivalent to part of the Marmora formation, the distinction being a facies change; cobble- and locally boulder-size clasts, poor sorting and low to moderate sphericity suggest relatively proximal facies relative to source area(s); fluvial transport of detritus evi- denced by filled scour channels cut into earlier conglomerates; alluvial and lahatic processes may also have contributed to the transport and deposition of rocks of this formation; mudcracks in fine clastic sediments attest to periodic subaerial exposure; dolostone with algal mats and columnar stromatolites; some dolostones caked and reworked by wave and (or) current action to form minor conglomerate; felsic ash flow tuff near top of formation may signify the return to a predominantly volcanic regime; welding in this rock indicates subaerial or shallow subaqueous	Coarse clast size, poor sorting, scour channels, mudcracks, algal struc- tures, welding in ash flow tuff.

Table 10 (cont'd)

Formation	Member	Thickness (metres)	Dominant rock type(s)	Minor rock type(s)	Facies analysis and depositional environment	Environmental indicators
Belmont Lake (cont'd)					deposition; it is tentatively assigned to Cycle III volcanism, however it may, alternatively, be associated with a volcano outside the map area, or not presently exposed.	
Marmora		0-2000	Calclitic and dolomitic marble, interlaminated carbonate and siliceous clastic sediments	Mudstone, conglomerate	Divisible into two regimes: one, predominantly dolomitic, occupies the lower part of the formation; the abundance of algal structures, mainly mats, indicates that deposition took place in very shallow water; one or more erosional unconformities yielded material deposited in the Belmont Lake formation; upper part of Marmora formation is predominantly non-stromatolitic calcitic marble, with or without interlaminae of siliceous clastic material, suggesting a deeper water environment of deposition.	Domal and laminar algal structures, relative abundance of calcite vs. dolomite.
Vansickle	D	0-1000	Intermediate volcanics	Mudstone	Probably mostly reworked intermediate volcanics; relatively distal facies.	Thin bedding, fine grain size.
	C	0-300	Mafic flows	Mafic schist of uncertain derivation	Subaqueous deposition; similar and probably related to Member A of Cordova Lake formation.	Hyaloclastites

Table 10 (cont'd)

Formation	Member	Thickness (metres) ¹	Dominant rock type(s)	Minor rock type(s)	Facies analysis and depositional environment	Environmental indicators
B		4 distinct units:	Sandstone, mudstone	Felsic tuff, volcanic conglomerate	Subaqueous deposition; involved reworking of felsic and intermediate volcanics; relatively distal facies.	Thin beddings; fine grain size.
		0-300 0-150 0-500 0-650				
A		2 units:	Calclitic marble	Dolomitic marble, cal- careous wacke	Subaqueous deposition; predominating non-stro- matolitic calcitic component vs. minor dolomitic component may indicate shallow to moderate water depth; calcareous wacke represents facies change from carbonate to siliceous clastic deposition.	Thin bedding.
		0-1200 0-400				
Cordova Lake	B	0-200	Felsic and intermediate flows and tuff	Volcanic wacke	Near-vent deposition indicated by felsic and in- termediate flows with lateral extent of 2 km, and by locally intense alteration; pillows and thin bedding of tuffs indicate subaqueous deposition; restricted to Belmont Lake area; major source of detritus for deposition of Belmont Lake formation.	Pillows, thin bed- ding, alteration.

Table 10 (cont'd)

Formation	Member	Thickness, (metres)	Dominant rock type(s)	Minor rock type(s)	Facies analysis and depositional environment	Environmental indicators
	A	100-3500	Mafic flows	Intermediate and felsic tuff, oxide and silicate facies iron formation, chert, mud- stone	Abrupt attenuation of member to north probably in part due to tectonic thinning; intercalations of intermediate and felsic tuff with mafic lavas suggestive of composite volcano; relationship to Member B suggests proximal facies in Belmont Lake area; abundance of small gabbro and diorite bodies, and presence of intermediate flows may indicate a vent area in the Lost Lake area; numerous dykes in upper half of member may indicate that fissure eruptions were important; small lenses of chemical sediments indicate periodic, probably local, cessations in volcanism, and deposition in restricted basin; most, if not all of member deposited subaqueously, as evidenced by the ubiquitous hyaloclastites.	Pillows, hyaloclastites.

1. Measured thickness without allowance for tectonic thickening or thinning.

formations, however, provide valuable insights with respect to the prevailing depositional environments and paleogeography during and subsequent to major volcanism.

The fault separating the Cordova Lake formation from the rest of Cycle III restricts the certainty of the paleoenvironmental interpretations. This is especially true north of Belmont Lake, where correlation across the fault is largely conjectural. In the Belmont Lake area, however, the fault separates rocks that differ mainly in their respective modes of deposition, thus allowing at least qualitative correlation.

5.2.4.1 Facies analysis

Rocks undoubtedly deposited close to a major vent are present on the west side of Belmont Lake, where locally intensely altered intermediate and felsic flows have a lateral extent of 2 km; the vent area is not exposed. This was probably the source area for much of the volcanics in the southern part of the Cordova Lake formation. However, the thickest part of the formation is 5 km to the north and thus may have derived from local fissures and (or) one or more major vents not exposed.

A minor (?) vent area is postulated in the area on and east of Lost Lake (Figure 4); the abundant small gabbro and diorite bodies in this area represent feeders to mafic and intermediate volcanics. Intermediate flows, flow breccias and hyaloclastites support the interpretation that this is a near-vent area (cf. Dimroth and Rocheleau, 1979).

As stated in Chapter 3, the extreme, sudden continuation of the Cordova Lake formation northwest of Cordova Lake is probably related to folding and (or) faulting rather than a primary facies change.

Detailed facies analysis of the predominantly sedimentary Vansickle, Marmora and Belmont formations is not attempted in this study. Bourque (in prep.), however, describes and interprets, in detail, Marmora and Belmont formations.

General facies transitions in the Marmora formation include a change from a predominantly dolomite-rich lower half to a predominantly calcite-rich upper half. In addition, the transition from marble to siliciclastic rocks at several places within the formation is marked by gradation through siliceous carbonate rocks. Erosion of the lower to middle parts of the Marmora formation yielded clasts constituting some conglomerates of the Belmont Lake formation; this implies that on a gross scale these formations are, in part, time-equivalent. The distinction between them is interpreted to represent a facies change from, in general, low energy chemical/clastic deposition of the Marmora formation to moderate to high energy clastic deposition of the Belmont Lake formation.

5.2.4.2 Eruption types

The thick accumulation of massive and pillowed mafic lavas forming much of the Cordova Lake formation is consistent with eruptions of basaltic flood- and (or) Hawaiian-type (cf. Macdonald, 1972). The abundance of mafic dykes in the upper part of the formation may

indicate that fissure eruptions were common during the latter period of mafic volcanism.

Deposition of finely bedded mafic tuff at the base of the central part of the formation may have followed phreatic, magmatic, or phreatomagmatic eruptions associated with structures such as fissures or ash cones (cf. Williams and McBirney, 1979) that are not presently exposed.

The presence of pillows in some felsic lavas on the west side of Belmonte indicates that relatively mild, effusive activity led to their formation.

5.2.4.3 Depositional environment

The presence of pillows and hyaloclastites throughout the Cordova Lake formation indicates subaqueous deposition. Mafic, intermediate and felsic tuffs occur in abundance in the lower part, and, more rarely, in the middle and upper parts of the formation, indicating that the maximum depth of eruption was 500 m (cf. McBirney, 1963). Subaerially deposited rocks are not evident in this formation:

The paucity of amygdules, large or small, does not necessarily indicate excessive depth of emplacement; as noted for the mafic flows of Cycle II, the rocks may have been essentially de-gassed before coming to rest and (or) they may have had low initial K_2O values (Bryan and Moore, 1977).

Oxide and silicate facies iron formation occur at various levels throughout the Cordova Lake formation; their presence, together

with the general lack of clastic sediments suggests that deposition occurred in a marine basin restricted from major clastic input. They were deposited during periodic, probably local, cessations in volcanism.

Deposition in the Vansickle formation was predominantly subaqueous, based on the abundance of marble, thinly bedded siliciclastic rocks, and hyaloclastites. Thinly laminated pyritic mudstones, commonly graphitic, and oxide and silicate facies iron formation indicate that much of the southeasternmost (uppermost?) siliciclastic unit was deposited under euxinic conditions.

The lower part of the Marmora formation was deposited, for the most part, in shallow water as evidenced by the ubiquitous occurrence of algal mats and columnar stromatolites in dolomitic marble. By analogy with modern algal structures in Shark Bay, western Australia (cf. Hoffman, 1976), algal mats of the Marmora formation morphologically resemble stratiform cryptalgal sheets that form throughout the intertidal zone of protected embayments and in protected parts of the upper intertidal zone in bights; here, where wave or current action is too weak or impersistent to prevent mats from colonizing loose sand, mats form continuous undifferentiated sheets that grow without forming structures of significant relief. Discrete columnar structures, however, are common in the lower intertidal zone in places where wave and tidal scour are strong.

The upper part of the Marmora formation consists mainly of calcitic marble with or without interlaminae of siliceous clastic

material, suggesting a deeper water environment of deposition and (or) greater openness to a sea.

Most clasts in conglomerates of the Belmont Lake formation were derived from erosion and reworking of rocks of the Cordova Lake formation, with a minor component from the Marmora formation. Deposition occurred in a fluctuating subaerial to subaqueous environment, as indicated by the presence of ripple marks, soft sediment deformation structures, and mudcracks in fine-grained clastic rocks, and algal mats in dolomitic marble; these features, together with cross-bedding, and scour-and-fill structures several metres deep indicate that energy conditions were highly variable.

Moderate welding in the ash flow tuff near the top of the Belmont Lake formation suggests deposition in a subaerial (cf. Ross and Smith, 1961), possibly shallow ~~subaerial~~ subaqueous (cf. Francis and Howells, 1973) environment.

5.2.4.4 Large scale reconstruction

The interstratified nature of tuff units with flows, particularly in the lower half of the Cordova Lake formation, suggests that major edifices were associated with one or more composite volcanoes, possibly centred around the area east of Lost Lake. The thick accumulation of intermediate tuff at the base of the formation, west of Belmont Lake, may represent an ash cone (cf. Williams and McBirney, 1979). Lavas forming the upper part of the formation between Belmont and Cordova Lakes issued from fissures rather than one or more well-

defined central vents. The general lack of intercalated pyroclastic rocks associated with these lavas may, in part, be due to extrusion at depths exceeding 500 m; oxide facies iron formation lying mainly above the fissure-erupted flows suggests that deposition occurred in a restricted basin.

The major vent area on the west side of Belmont Lake resembles a composite volcano in that felsic and intermediate pyroclastics are interdigitated with flows; the felsic and intermediate unit lies above mafic flows and mafic rocks of uncertain derivation which may or may not constitute part of a shield volcano.

The Belmont Lake formation is more coherently related to the Cordova Lake formation than are the Marmora or Vansickle formations. The close spatial and inferred parent-derivative relationship between the Belmont Lake formation and Member B of the Cordova Lake formation (Figure 3) allows qualitative assessment of fault motion in the Belmont Lake area: minor, if any, strike-slip movement, and relatively minor dip-slip movement.

Deposition of a subaerial to shallow subaqueous unit as thick as the Belmont Lake formation requires erosion of a largely subaerial unit considerably thicker than Member B of the Cordova Lake formation. On this basis it is here proposed that Member B was more voluminous, before erosion and faulting, than present exposure suggests. Some clast types allow inferences to be made regarding volcanic and sub-volcanic rocks not presently exposed in outcrop; minor quartz-feldspar porphyry clasts were probably derived from rocks formed beneath the

vent and subsequently brought to or close to the surface in the form of domes or spines, or as fragments ejected with or without juvenile magma; alternatively erosion and (or) explosive processes may have exposed the roots of the volcano. Clasts containing extremely flattened pumice probably were derived from subaerial ash flow tuffs no longer exposed in the Cordova Lake formation.

The relative contributions of erosion versus reworking subsequent to volcanic fragmentation (eg. explosions and destruction of spines and domes) is difficult to establish, however may be largely academic. Certainly erosional fragmentation yielded chert and iron formation clasts, probably derived from Member A of the Cordova Lake formation; this requires uplift of the source area to subaerial or shallow subaqueous conditions, possibly accomplished by regional tectonism and (or) syn- or post-volcanic faulting. Some, if not most of the material re-deposited to form the Belmont Lake formation may have originated as large accumulations of debris in the area of the vent; talus deposits formed by the crumbling of spines and domes, for example, are commonly voluminous (cf. Williams and McBirney, 1979).

The erosional unconformity that separates the Cordova Lake formation from the Belmont Lake formation does not require the passage of appreciable geological time. By analogy with erosion rates determined for the active volcano Fuego in Guatemala (cf. Davies *et al.*, 1978), the probably exaggerated volume estimate of 15 km^3 for the Belmont Lake formation (derived from a strike length of 2 km, an average thickness of 0.5 km and a generously estimated deposit length, in

profile, of 15 km) could have been eroded/reworked from the Cordova Lake formation in about 7000 years. This estimate does not take into account the fact that erosion in Precambrian times was more pronounced due to a lack of vegetation. Quiet sedimentation of limestone and fine clastic sediments, however, suggest that erosion was not continuously tumultuous, and thus probably occurred over a greater period of time.

The presence of abundant hematite in fine clastic sediments and in the matrix of some conglomerates could be construed by some to have been derived from the diagenetic alteration of brown colloidal iron released from minerals in warm, moist upland soils (Van Houten, 1973, quoted by Blatt *et al.*, 1980). This would require a protracted time period from the initial (subaqueous) deposition of the parent rock to the final deposition as a sediment, during which occurred uplift to expose the rock to weathering, soil formation and erosion. Walker (1967, 1974, quoted by Blatt *et al.*, 1980), however, believed that most, if not all, ferric oxide pigment in sedimentary rocks is formed by diagenetic alteration of sand- and silt-size mineral grains, not brown colloidal iron, after deposition; this process does not require uplift and laterization, and carries no paleoclimatic connotations.

The author's data are presently insufficient to determine the exact nature of sedimentary processes responsible for the deposition of most of the Belmont Lake formation. Fluvial processes were important, as evidenced by cross-bedding and scour channels, however lahars may have contributed significantly, as may have alluvial processes. Whatever the mechanism, the spatial distribution of the Belmont Lake

formation relative to the Cordova Lake formation suggests that material was primarily transported down the east flank of the source volcano.

Spatial relations suggest that deposition of dolomitic limestone of the Marmora formation occurred before deposition of the Belmont Lake formation, and synchronous with it mainly in marginal and less proximal areas.

Active subsidence accompanied deposition in both the Belmont Lake and Marmora formations. Throughout both formations more than 700 m of stratigraphy were deposited at, or within several tens of metres of wave base. Calcitic marble in the upper half of the Marmora formation may have formed in a deeper basin and (or) may have been part of a relatively open sea.

5.2.5 Cycle IV

Cycle IV comprises the Crowe River formation. Figure 13 illustrates the distribution and general geology of Cycle IV; Figure 14 consists of two stratigraphic sections through Cycle IV and illustrates general facies relationships within the cycle. Table 11 summarizes the stratigraphy and evolution of Cycle IV, based on facies analysis, and deduced types of eruption and depositional environment.

5.2.5.1 Facies analysis

The original lateral extent of the Crowe River formation is unknown; the Cordova gabbro truncates the northern part, and Ordovician limestone covers the unit in the south.

Figure 13. Distribution and general geology of Cycle IV. Stratigraphic sections are illustrated in Fig. 14.

Figure 14. Stratigraphic sections of Cycle IV, illustrating facies relationships. Sections are located in Fig. 13.

Table II

Summary of the Stratigraphy and Evolution of Cycle IV

Formation	Member	Thickness (metres) ¹	Dominant rock type(s)	Minor rock type(s)	Facies analysis and depositional environment	Environmental indicators
Crowe River	B	70	Skarn	Calclitic marble	Deposited during quiescent interval at or near end of volcanism; subsequently converted to skarn by intrusion of gabbro body.	
	A	0-4500	Mafic and intermediate flows and pyroclastics	Felsic tuff, volcanic conglomeration	<p>Upper part: continuation of growth of maturing shield volcano.</p> <p>Middle part: abundance of pyroclastic rocks marks major change in eruption type - agglomerates indicate central facies, agglutinates indicate sub-aerial deposition; a marked increase in magnetite and hematite in rocks of the middle part may reflect the transition from predominantly subaqueous to predominantly subaerial depositional environments - coincidental with this transition is the relatively sudden increase in amygdule size and abundance; thin laminations and normal grading in felsic tuff suggest local subaqueous deposition; degree of reworking of felsic volcanic conglomerate suggests subaerial source; consistent with growth of maturing shield volcano.</p> <p>Lower part: flows deposited with conformity on shallow water or subaerial, fluvial clastic rocks of the Belmont Lake formation; relatively large amygdules indicate shallow water or subaqueous deposition; shield-building stage.</p>	<p>Middle part: amygdules, iron oxides; thin, graded bedding in felsic tuff.</p> <p>Lower part: amygdules</p>

1. Measured thickness without allowance for tectonic thickening or thinning.

Deposition in central facies is evident throughout the middle part of the formation, and to an unknown extent in the upper part. Near-vent deposits such as agglomerates and agglutinates (cf. Parsons, 1969; Williams and McBirney, 1979), and intermediate lavas (cf. Dimroth and Rocheleau, 1979) attest to eruption from two or more vents in the middle part of the formation; in addition, epidotization in these areas is locally intense. Mafic flows of the lower part of the formation are, by virtue of their close spatial association to the near vent deposits, assumed to be relatively proximal.

The felsic volcanic conglomerate interpreted earlier (Chapter 3.4.8) as a relatively proximal deposit cannot be traced to a source given present exposure.

5.2.5.2 Eruption types

The lower part of the formation comprises a thick accumulation of relatively monotonous mafic lava flows, the product of Hawaiian-type eruptions; this is consistent with the shield-building stage of a volcano (Macdonald, 1972). The principal eruption type changed to agglomerate-producing, predominantly Strombolian or combined Strombolian-Hawaiian by the middle part of the formation, and probably continued in that style until volcanic activity ceased. Agglomerate and agglutinate may have formed spatter cones, probably built on a linear fissure system that supplied much of the mafic and intermediate lavas. The upward change in eruptive style and deposits represents a typical evolution to a mature shield volcano (cf. Macdonald, 1972).

5.2.5.3 Depositional environment

The conformable contact between mafic flows of the Crowe River formation and subaerial or shallow subaqueous deposits of the Belmont Lake formation, and the presence of large amygdules in the basal lavas of the Crowe River formation, indicate that deposition occurred in a subaerial or shallow water environment. In general, this conclusion applies for most, if not all, of Member A of the Crowe River formation. The complete absence of pillows throughout the member argues in favour of subaerial deposition; however, as steep slopes are generally considered to be a prerequisite for the formation of pillows (Williams and McBirney, 1979), the flows may have been deposited subaqueously on shallow slopes.

Rocks in the middle part of the formation were essentially deposited in a subaerial environment. Agglomerate, typically erupted subaerially, may be deposited subaqueously; agglutinate, however, is erupted and deposited in the subaerial environment. As suggested in Chapter 3.4.8, the abrupt increase in the oxide mineral, particularly hematite, content of the rocks, and in the content and size of amygdules in the middle part of the formation may mark the transition from essentially subaqueous to essentially subaerial deposition. Local subaqueous deposition, probably in ponds, is documented by the presence of finely laminated, normally graded felsic airfall tuff. The felsic volcanic conglomerate was probably deposited by fluvial processes; the degree of reworking shown by the clasts is an indication that the source area was subaerial.

The deposition of marble (Member B) was subaqueous; that it occurs atop at least 2500 m of subaerial deposits suggests that either subsidence led to submergence of the entire formation, or, more likely, the marble formed in a lake on the volcano (possibly in a crater).

5.2.5.4 Large scale reconstruction

The Crowe River formation documents the growth of a shield volcano. Predominantly, if not entirely, founded on land, it evolved from a monotonous lower part composed of fluid mafic lavas, to middle and upper parts where mafic and intermediate aa flows, and minor block and pahoehoe (?) lavas issued, probably from fissure systems; spatter cones developed along the fissure systems. Minor pyroclastic activity deposited intermediate and felsic tuff, lapilli tuff and lapillistone. Erosion of unexposed felsic upland areas yielded material that was fluviially deposited as conglomerate on the volcano. Limestone formed at the top of the volcanic succession, either as a consequence of extreme subsidence of the volcano to near sea level conditions, or in a crater lake, possibly at the summit of the volcano.

CHAPTER 6

GEOCHEMISTRY

6.1 Introduction

Fifty-five volcanic and hypabyssal rocks and two gabbroic rocks from Belmont Township were chemically analyzed to determine major and trace element abundances; two granitic rocks from southern Methuen Township were also analyzed. The two gabbroic rocks are from bodies that intrude Cycle I rocks; field relations (discussed in Chapter 3) suggest that the gabbros were the plutonic equivalents of some Cycle I basalts; thus on chemical plots that distinguish individual cycles (Figures 16, 17), the gabbro samples appear with Cycle I rocks. Although the raw chemical data for the two granitic rocks are included in Appendix C, the rocks have not been included in chemical plots because of their post-volcanic nature.

An attempt was made to obtain representative samples from each cycle; although the wide scatter of sample locations allows relatively precise characterization of rock units, only general trends within units can be delineated.

Results of chemical analyses are compiled in Appendix C, Table C1. Analytical methods, precision and accuracy are detailed in Appendix D.

6.2 Role of Alteration

An assumption that chemical analyses reflect primary rock composition is an over-simplification unless consideration is given to alteration processes. To minimize secondary effects in interpreting data from the Belmont Lake Metavolcanic Complex, the author has adopted a series of criteria with which chemically anomalous rocks can be identified, and data pertaining to mobile elements rejected, or at least treated with extreme caution. The salient criteria, as applied to mafic, intermediate and felsic rocks are as follows:

1) Volatile content. A cut-off of 3.8% total H_2O and CO_2 is applied to all data that include determination of volatiles. Rejection based on this criterion and at similar cut-off levels is not new (cf. Gelinas *et al.*, 1977). Of the 33 samples for which volatiles were determined, two (159B1 and 240B1; see Table C1) were rejected.

2) Low analytical totals. Those rocks with analytical totals less than 96.2% (cf. criterion 1) were rejected. This criterion applies only to the University of Ottawa data, as they do not include volatiles. Samples rejected on this basis are 034B3, 159B1, 174B1, 053M1, 478B1, 479B1, 480B1 and 315E1 (cf. Table C1). This criterion for rejection should not however, be used to cast doubt on the validity of rare earth element data.

3) Abnormal normative minerals. The existence of normative (CIPW) corundum, nepheline and wollastonite in subalkaline mafic and intermediate metavolcanics is indicative of alteration; corundum is indicative of peraluminous composition due, for example, to depletion in

CaO, nepheline indicates introduction of Na_2O , and wollastonite is indicative of addition of CaO and (or) the presence of abnormally high Fe contents (Gelinas *et al.*, 1977). Felsic volcanic rocks, however, are commonly corundum-normative (Cox *et al.*, 1979). The following samples are rejected on the basis of abnormal normative mineralogy : corundum : 174B1 and 478B1; nepheline : 067B2, 146B1 and 473B1; wollastonite : 159B1, 398B1 and 491B1 (cf. Table C1).

4) Alkali content. If the metavolcanics plot outside the igneous spectrum of Hughes (1972, as modified by Stauffer *et al.*, 1975) (Figure 15) they are rejected.

Typically more than one criterion will lead to rejection of an altered sample. Some samples plotting within the igneous spectrum were rejected on the basis of other criteria; this condition reflects metasomatism of elements other than alkalis, and (or) the low analytical totals of some of the University of Ottawa data.

On all diagrams used henceforth in this chapter, rejected ("altered") samples will be distinguished from "unaltered" samples; the former are represented by open symbols, the latter by closed symbols.

6.3 Chemical Classification of the Volcanic Rocks

The subalkaline character of all but three samples is established using the Ol'-Ne'-Q' plot of Irvine and Baragar (1971). Two of the anomalous rocks, 067B2 and 146B1, owe their apparently alkaline nature to the high plagioclase phenocryst content (> 25%) of each;

Figure 15. Igneous spectrum diagram of Hughes (1972), as modified by Stauffer et al. (1975). Data points are from the Belmont Lake Metavolcanic Complex : closed circles represent rocks with alkali content not seriously affected by alteration and metamorphism; open circles represent relatively altered rocks. Open circles within the igneous spectrum represent rocks having a high volatile content, low original analytical total, or abnormal normative mineralogy. All data are from University of Ottawa analyses, recalculated to 100%, without volatiles. Numbers correspond to those assigned to samples as outlined in Fig. B1 and in Tables B1, B2 and C1.

they are considered to be of subalkaline affinity once the phenocrysts are taken into account. Sample 473B1, however, shows no petrographic evidence for Na metasomatism (e.g. extensive albitization) or abnormally high initial Na values (e.g. abundant plagioclase phenocrysts), yet plots within the alkaline fields of both the Ol'-Ne'-Q' and the $\text{Na}_2\text{O} + \text{K}_2\text{O}$ vs. SiO_2 diagrams of Irvine and Baragar (1971). Consideration of the major elements alone leads to the classification of this rock as an hawaiite, according to the scheme of Irvine and Baragar (1971). Classification according to the trace elements Zr and Ti, generally considered to be immobile during secondary alteration processes (Floyd and Winchester, 1978; Frey, 1979), reveals a subalkaline character. Its subalkaline nature is also borne out by the relatively flat rare earth element (REE) pattern as compared with those of alkali basalts (cf. Gast, 1968). For the purposes of this study, sample 473B1 is thus considered to be subalkaline.

Volcanic and hypabyssal rocks are classified as basalt, andesite, dacite or rhyolite according to SiO_2 values, normalized to a volatile-free basis (these values are tabulated in Appendix C, Table C2); the normative CI vs. normative plagioclase composition diagram (Figure 16) of Irvine and Baragar (1971) was also used to delimit boundaries for the compositional classes. Relatively unaltered samples plotting in the basalt field of Figure 16 exhibit an SiO_2 range of 47.47 to 52.76%; altered samples in the basalt field extend this range to 75.57%, emphasizing the need to either classify only "unaltered" samples according to Figure 16, or more practicably, to use Figure 16

Figure 16. Normative CI vs. normative plagioclase composition diagram (after Irvine and Baragar, 1971) for rocks of Cycles I-IV. Closed circles represent least altered rocks, open circles rocks rejected following application of rejection criteria (see text). Abbreviated sample numbers corresponding to Fig. B1 and Tables B1, B2 and C1 are used here.

Normative plagioclase composition

in conjunction with normalized SiO_2 values and petrographic data (e.g. CI). Only one "unaltered" sample (no. 11, Cycle I) plots within the andesite or tholeiitic andesite field of Figure 16; its normalized SiO_2 content is 60.98%; the range for altered samples is 50.49 to 61.33% SiO_2 (for all but one, SiO_2 ranges from 55.80 to 61.33%). The SiO_2 range of the four altered samples in the dacite field of Figure 16 is 65.19 to 75.57%; the only "unaltered" sample in the dacite field (no. 18, Cycle I) has 70.53% SiO_2 . The one "unaltered" sample in the rhyolite field of Figure 16 (no. 17, Cycle I) has an SiO_2 content of 69.16%; the SiO_2 range of altered samples is 73.15 to 79.03%.

The compositional classes: basalt, andesite, dacite and rhyolite have accordingly been assigned limits, based on the normalized SiO_2 contents of "unaltered" rocks (and, to a lesser extent, altered rocks) as follows:

basalt	47-54%	SiO_2
andesite	54-63%	SiO_2
dacite	63-68%	SiO_2
rhyolite	> 68%	SiO_2

With the exception of the lower limit of SiO_2 for basalts (ie. 47% instead of 48%), this classification is in exact accord with that used by Condie (1976) and Condie and Moore (1977), and provides a means of rapidly comparing volcanic rocks of the Belmont Lake Metavolcanic Complex with rocks of approximately equivalent bulk chemistry from Archean, modern, and other Grenville volcanic terranes (cf. Condie and

Moore (1977)).

An important accompanying feature of this classification is the close correspondence, in all "unaltered" and most altered rocks, between modal CI and composition according to SiO_2 content. With few exceptions basalts have a CI > 35, andesites 10-35, and dacites and rhyolites < 10. This correspondence should thus allow one to classify, in the field, all but the most altered rocks as basalt, andesite, or dacite/rhyolite on the basis of visual estimation of colour index alone.

The volcanic rocks are divided into tholeiitic and calc-alkaline associations on the basis of the AFM diagram (following Irvine and Baragar, 1971). Rocks from each of Cycles I-IV are plotted separately on AFM diagrams in Figure 17.

The iron enrichment trend from the basalts to the most Fe-rich, (albeit altered) andesite (no. 12, Figure 17) confirms the tholeiitic nature of Cycle I basalts (cf. Stauffer *et al.*, 1975). Although all but one sample of andesite and dacite from Cycle I are considered altered, they consistently plot in the tholeiitic field. Comparison with Figure 15 indicates that most of the samples have undergone alkali enrichment, and are thus not likely to have become tholeiitic via alteration of calc-alkaline rocks. Rhyolites of Cycle I plot consistently within the calc-alkaline field and define a strong alkali enrichment trend.

A clear iron enrichment trend characterizes the consistently tholeiitic basalts of Cycle II. The apparent compositional gap between the basalts and rhyolites is probably a reflection of non-representative

Figure 17. AFM diagrams for Cycles I-IV of the Belmont Lake Metavolcanic Complex. The dashed line dividing the tholeiitic field (above) from the calc-alkaline field is after Irvine and Baragar (1971). $A = Na_2O + K_2O$; $F = FeO + 0.8998 Fe_2O_3$; $M = MgO$, all in weight percent. Refer to Fig. 16 caption for meaning of symbols and numbers.

✓
sampling. The rhyolites are calc-alkaline and define an alkali-enrichment trend.

Basalts of Cycle III are disposed in a tight cluster in the tholeiitic field of the AFM diagram, although a case could be made for a slight iron enrichment trend. Rhyolites define a linear trend toward alkali enrichment.

When all data are considered, Cycle IV basalts plot in the tholeiitic field, defining a trend toward iron enrichment. The author believes that careful sampling of the intermediate lavas of Cycle IV would yield important information on the path of differentiation of the cycle; these rocks were not sampled because they are invariably highly amygdaloidal.

Though a difficult proposition to test, it is possible that some rhyolites are, in actuality, silicified dacites. Future research on these rocks, including trace element studies, may elucidate this point.

Basalts are variably olivine- or quartz and hypersthene-normative; the latter type is predominant. Within individual cycles, systematic variations in the spatial occurrence of these types are generally not demonstrable, however in Cycle I both "unaltered" basalts from the major near-vent area (cf. Chapter 5) are quartz and hypersthene-normative; this feature accords with the highly plagioclase-phyric nature of basalts in this area in suggesting derivation from an evolved magma source. The more southerly olivine-normative basalt may be of local derivation, rather than related to the less primitive basalts in

the north.

"Unaltered" basalts of Cycle III are quartz and hypersthene-normative where spatially related to postulated vent areas in the Lost-Cordova and Belmont Lake areas (cf. Chapter 5). Olivine-normative basalts, however, occur in the area between Belmont and Cordova Lakes, characterized by numerous dykes. A possible explanation for this is that the dykes tapped more primitive magma, either from a separate source, or from the same magma chamber (deeper levels ?) that supplied material for the vent areas to the north and south.

The "unaltered" basalts of Cycle IV are quartz and hypersthene-normative, suggesting derivation from a relatively evolved magma.

6.4 Major and Trace Element Abundances

6.4.1 Basalts

Selected major and trace element contents for basalts of each cycle are compiled in Table 12; for comparative purposes only those basalts passing the rejection criteria are used. Average values for each cycle are divided into two groups on the basis of K_2O content; those rocks having $< 0.2\% K_2O$ correspond to low-K tholeiites of Condie and Moore (1977) and depleted Archean tholeiites (DAT) of Condie (1976); rocks with $> 0.2\% K_2O$ correspond to intermediate- and high-K tholeiites of Condie and Moore (1977) and enriched Archean tholeiites (EAT) of Condie (1976).

Table 12. Chemical composition of "unaltered" basalts of the Belmont Lake Metavolcanic Complex; major elements are normalized to a volatile-free basis. For comparative purposes basalts have been grouped according to cycle and K_2O content, 0.2% K_2O being the boundary between low-K and intermediate- and high-K tholeiites. Major elements in weight percent; trace elements in ppm; n = number of samples used to compile average values for each element.

	Cycle I		Cycle II		Cycle III		Cycle IV		Average for Cycles I-IV		Cycles I-IV (average)
	>0.2% K ₂ O	<0.2% K ₂ O	>0.2% K ₂ O	<0.2% K ₂ O	>0.2% K ₂ O	<0.2% K ₂ O	>0.2% K ₂ O	<0.2% K ₂ O	>0.2% K ₂ O	<0.2% K ₂ O	All K ₂ O
SiO ₂	51.2	50.93	49.97	49.23	49.60	50.70	49.57	50.40	50.02	50.40	50.02
TiO ₂	1.92	1.73	1.40	1.68	2.73	2.34	1.69	1.99	1.85	1.99	1.85
Al ₂ O ₃	15.79	14.94	15.55	15.39	14.26	14.99	15.30	15.26	15.28	15.30	15.28
Fe ₂ O ₃	3.44	3.25	2.94	3.22	4.25	3.86	3.23	3.51	3.38	3.23	3.38
FeO	8.99	9.45	9.64	9.93	10.98	10.08	9.83	9.81	9.82	9.83	9.82
MgO	5.51	6.08	5.85	6.96	5.28	5.05	6.78	5.47	6.07	6.78	6.07
CaO	8.90	10.58	9.86	10.80	9.03	9.51	10.76	9.39	10.01	10.76	10.01
Na ₂ O	3.21	2.56	2.40	2.30	2.99	2.55	2.35	2.74	2.56	2.35	2.56
K ₂ O	0.65	0.11	0.81	0.15	0.42	0.49	0.14	0.63	0.41	0.14	0.41
Ba	149	19	125	27	10	59	25	95	63	25	63
Cr	137	188	117	242	67	88	231	106	163	231	163
Zr	170	151	143	134	172	182	137	164	152	137	152
Sr	315	196	260	131	151	228	144	248	201	144	201
Rb	19	9	22	10	15	16	10	19	15	10	15
Y	43	39	31	33	49	51	34	42	38	34	38
Zn	102	91	92	80	92	106	82	98	91	82	91
Ni	46	49	49	55	35	29	54	41	47	54	47
n	3	2	4	8	2	3	10	12	22	10	22
La	14.13	3.23	4.08	4.98	12.30	14.14	4.73	11.00	8.07	4.73	8.07
Ce	36.2	8.8	10.1	13.63	29.5	34.0	12.9	27.2	20.5	12.9	20.5
Sm	4.99	1.93	1.92	2.63	5.27	6.20	2.53	4.50	3.58	2.53	3.58
Eu	1.76	1.22	0.97	1.27	2.58	2.15	1.26	1.76	1.53	1.26	1.53
Tb	0.99	0.72	0.50	0.76	1.36	1.24	0.75	0.97	0.87	0.75	0.87
Yb	4.07	3.04	1.96	3.33	5.61	4.76	3.29	3.88	3.60	3.29	3.60
La/Yb	3.98	1.06	2.30	1.52	2.19	3.00	1.45	2.96	2.26	1.45	2.26
n	2	1	2	6	1	2	7	8	15	7	15

Tholeiites of the Belmont Lake Metavolcanic Complex are similar to Archean tholeiites (cf. Condie, 1976), both in major and trace element composition; they differ from the latter mainly in their higher Fe, K, Rb, Sr, Zr and Y content and their lower Cr, Ba and Ni concentrations. REE abundances illustrate a striking similarity between basalts with $< 0.2\% K_2O$ and DAT, and between basalts with $> 0.2\% K_2O$ and EAT (cf. Condie, 1976) (Figure 18a).

Compared with modern rise and arc tholeiites, and calc-alkaline basalts (cf. Condie, 1976), tholeiites of the study area are higher in TiO_2 , Fe, Rb, Zr and Y. The trace element, especially REE patterns of the basalts containing $< 0.2\% K_2O$ most closely resemble those of modern rise and arc tholeiites (Figure 18b), whereas basalts containing $> 0.2\% K_2O$ have REE patterns sharing features of both modern rise and arc tholeiites and calc-alkaline and oceanic island tholeiites (cf. Condie, 1976) (Figure 18b). Light REE (LREE) are enriched relative to rise and arc tholeiites, however the pattern as a whole is flatter than the field for calc-alkaline basalts and oceanic tholeiites (Figure 18b). This may reflect the generally greater mobility of the LREE relative to the heavy REE (HREE) under certain geologic conditions (e.g. submarine weathering; Ludden and Thompson, 1978), or, more likely, it is a function of the production of more evolved magma (cf. Gast, 1968).

Similarity between basalts in the study area and modern rise and arc tholeiites is apparent from an examination of variations in Ti, Zr, Y and Sr; the former three are high field strength elements considered to be relatively immobile in basalts; Sr is also considered

Figure 18. Envelopes of variation of chondrite-normalized REE patterns for low-K (LK) and intermediate- and high-K (IHK) Belmont tholeiites compared with a) enriched (EAT) and depleted (DAT) Archean tholeiites, and b) modern oceanic rise and arc tholeiites (RISE-ARC) and calc-alkaline and oceanic island tholeiites (CALC-ISL). Modern and Archean fields after Condie (1976).

to be relatively immobile during alteration and low grade metamorphism (Condie and Moore, 1977).

Most Belmont basalts plot in the field of modern ocean floor basalts, or at higher Ti and Zr values on the Ti-Zr diagram (Figure 19; cf. Pearce and Cann, 1973); some back-arc basin (e.g. Scotia Sea) basalts plot at higher Ti-Zr values than the ocean floor basalt field (Saunders and Tarney, 1979). The Ti-Zr-Y diagram (cf. Pearce and Cann, 1973) illustrates that most basalts plot in the field of ocean floor basalts + calc-alkaline basalts + low-K tholeiites. Further discrimination is achieved using the Ti-Zr-Sr diagram (Figure 20), which shows that most basalts plot in the field of ocean floor basalts; as with the REE patterns, a more calc-alkaline affinity is apparent for some basalts.

6.4.2 Andesites

Only one andesite (483B1) is considered to be "unaltered". It differs significantly from modern andesites in terms of major and trace elements (other than REE) (cf. Condie and Moore, 1977). The differences between this rock and Archean andesites (cf. Condie and Moore, 1977) are as striking as the similarities: TiO_2 , K_2O , Sr and Y are higher, and MgO and Cr are lower in the Belmont andesites. The disparity between 483B1 and modern and Archean andesites may, in part, be due to a non-representative nature of the Belmont andesite. REE were not determined for 483B1; REE for two other Cycle I andesites, considered by the author to be relatively "unaltered", define a field

Figure 19. Ti-Zr diagram for basalts of the Belmont Lake-Metavolcanic Complex. Modern ocean-floor basalts plot in fields A and D, low-K tholeiites in Band D, and calc-alkaline basalts in C (after Pearce and Cann, 1973). Closed circles represent relatively unaltered basalts; open circles represent altered basalts (see text).

Figure 20. Compositional variation of Belmont basalts in terms of Ti-Zr-Sr. Fields as in Figure 19 (after Pearce and Cann, 1973). Symbols as in Figure 19.

that conforms to the field (cf. Condie and Moore, 1977) of combined modern calc-alkaline and most Archean andesites (Figure 21). If most weight is given to the typically immobile REE (Condie, 1976), and Zr, the Belmont andesites very closely resemble Archean andesites (cf. Condie and Moore, 1977). Figure 21 illustrates the pronounced disparity between Belmont andesites and modern andesites of the arc tholeiite series.

6.4.3 Dacites and rhyolites

Dacite is an uncommon rock type in the Belmont Lake Metavolcanic Complex; the two samples falling in this category were rejected as being too altered for interpretation. All but four rhyolites (259B1, 481B1, 482B1 and 495B1) were rejected as well. REE were determined for two rhyolites from each of Cycles I-III; La and Sm were also determined for 482B1. REE variations in these samples were used to construct a field for Belmont rhyolites (Figure 22). The REE content of 489B1, a dacite, was also determined.

With respect to their major and non-REE trace element abundances, Belmont rhyolites are similar to Archean undepleted and modern siliceous volcanics (cf. Condie, 1976); the main difference is in the higher Y contents of the Belmont rhyolites. Condie (1976) pointed out the similar nature of Archean undepleted and modern siliceous volcanics, particularly with respect to their REE patterns. The field of Belmont rhyolites (Figure 22a) conforms well with the field of combined Archean undepleted and modern siliceous volcanics. Figure 22b illustrates the

Figure 21. Chondrite-normalized REE field of Belmont andesites (field bounded by solid lines) compared with envelope of modern calc-alkaline and most Archean andesites (field bounded by dashed lines), and average arc tholeiitic andesite (dotted line). Fields other than Belmont andesite are from Condie and Moore (1977). Belmont andesite field defined by REE variations in samples 478B1 and 053M1.

Figure 22. Chondrite-normalized REE field of Belmont rhyolites (fields bounded by solid lines) compared with fields of a) modern and undepleted Archean siliceous volcanics, and b) depleted Archean siliceous volcanics. Fields other than Belmont rhyolites are from Condie (1976), with minor modifications.

overall lack of correspondence between Archean depleted siliceous volcanics and the Belmont rhyolites.

6.5 Intercycle and Intracycle REE Variations

Chondrite-normalized REE variations for rocks of each of Cycles I-IV are illustrated in Figures 23-26; samples rejected using the criteria advanced in Chapter 6.2 are included, and discriminated using open symbols. Samples 053M1 and 478B1 (Cycle I andesites) are considered to be "unaltered", as previous rejection was based solely on a low University of Ottawa analytical total, unrelated to the REE determinations.

The REE patterns of Cycle I basalts (Figure 23) are highly variable. Cycle I andesites are generally characterized by moderate to strong LREE enrichment, no Eu anomaly, and HREE contents about twenty times chondrite. The dacite and rhyolites of Cycle I are strongly LREE-enriched with roughly constant La/Yb values.

"Unaltered" basalts of Cycle II (Figure 24) are characterized by moderate to strong positive Eu anomalies and variable depletion or enrichment of LREE. Rhyolites of Cycle II (195B1, 008M) have similar LREE and HREE contents, however 195B1 has a strong negative Eu anomaly.

Cycle II basalts differ from those of Cycle I mainly in their lower total REE content and their depletion of LREE. Cycle II rhyolites are generally lower in total REE than Cycle I rhyolites.

Most basalts of Cycle III (Figure 25) have flat REE patterns, or are slightly enriched or depleted in LREE, and have weak to strong

Figure 23. Chondrite-normalized REE patterns for individual basalts (circles), andesites (triangles), dacite (diamond) and rhyolites (squares) of Cycle I. Closed and open symbols correspond, respectively, to relatively unaltered and altered rocks.

Figure 24. Chondrite-normalized REE patterns for individual basalts (circles) and rhyolites (squares) of Cycle II. Closed and open symbols correspond, respectively, to relatively unaltered and altered rocks.

Figure 25. Chondrite-normalized REE patterns for individual basalts (circles) and rhyolites (squares) of Cycle III. Closed and open symbols correspond, respectively, to relatively unaltered and altered rocks.

Figure 26. Chondrite-normalized REE patterns for individual basalts of Cycle IV. Closed and open symbols correspond, respectively, to relatively unaltered and altered rocks.

positive Eu anomalies. Cycle III rhyolites are characterized by strong enrichment of LREE.

Cycle III basalts differ from those of Cycle I mainly in their flat REE patterns, the consistently pronounced positive Eu anomalies, and the lower total REE contents. Relative to Cycle II basalts, those of Cycle III are slightly higher in total REE contents, and have generally flatter REE patterns.

Cycle III rhyolites differ from those of Cycles I and II mainly in their lower HREE contents.

Basalts of Cycle IV (Figure 26) show slight to moderate enrichment of LREE; HREE content is about twenty-five times chondrite.

Cycle IV basalts are similar to those of Cycle I in their slight to moderate LREE enrichment (though generally less pronounced than in Cycle I), and in the total REE contents; the main variance is in the generally smooth patterns of Cycle IV relative to Cycle I. Cycle IV basalts differ from those of Cycles II and III mainly in their enrichment of LREE and in their higher total REE contents.

6.6 Regional Paleotectonic Implications

REE patterns and discriminant diagrams involving Ti, Zr and Sr illustrate that, in general, Belmont basalts closely resemble ocean floor basalts. Field evidence, however, indicates that the Belmont volcanics and sediments did not form at abyssal levels in a mid-ocean ridge-type environment: rocks of all cycles show evidence of subaerial to shallow subaqueous deposition; extensive felsic volcanic deposits

and platform-type carbonate sediments are foreign to the ocean ridge environment.

Ti-Zr and Ti-Zr-Sr discrimination diagrams suggest that the Belmont basalts are not related to an island arc; in addition, andesites are tholeiitic, yet have REE patterns dissimilar to andesites of the arc tholeiite series. However, the general similarity, and close proximity of the Belmont Lake Metavolcanic Complex to island arc-associated rocks (Brown *et al.*, 1975; Condie and Moore, 1977) of the Bishops Corners-Donaldson area, 60 km to the east, suggests that the Belmont rocks may have been part of a volcanic arc system (though not part of the main arc). Trace element geochemistry of basalts favours a back-arc environment (cf. Saunders *et al.*, 1980). Field evidence does not refute this; Karig (1971) stated that large, subaerial felsic volcanic deposits are commonly associated with extensional volcano-tectonic depressions related to inter-arc (back-arc) basins.

Some Belmont basalts (cf. Table 12) have higher K, Sr, La and Ce contents relative to ensimatic back-arc tholeiites (cf. Hawkesworth *et al.*, 1977); mainly characteristic of Cycles I and II basalts, this relative enrichment may be due to contamination of the parent melt by assimilation of continental crust of the Superior craton to the west.

Thus the model that best fits the geochemical and field evidence involves formation of the complex as a volcanic field in a shallow, in part ensialic-founded, back-arc basin at the leading edge of the Superior craton.

CHAPTER 7

SUMMARY AND CONCLUSIONS

7.1 Evolution of the Belmont Lake Metavolcanic Complex

The complex records the occurrence and interplay of four distinct Helikian volcanic events, interpreted in this chapter.

The base of Cycle I is not exposed in Belmont Township. Rocks in the north part of Cycle I document the growth of a composite volcano with a well-defined vent. The volcano was constructed by accumulation of calc-alkaline rhyolite lavas and pyroclastics, tholeiitic andesite lavas and pyroclastics, tholeiitic basalt lavas and rare tholeiitic dacite pyroclastics. The dominant structural feature of Cycle I, this volcano supplied most of the material in the remainder of the cycle; volcanic conglomerate formed mainly on the south flank of the volcano; ash flows deposited dacite and rhyolite tuff, and air-fall tuff accumulated south of the volcano. Basalt issued from one or more minor vents associated with the gabbro bodies in the central to south parts of Cycle I. All of the volcanic rocks of Cycle I were erupted and deposited in a shallow sea or in a subaerial environment; some basalts formed subaqueous, possibly sub-glacial hyaloclastite and pillow lava deposits in upland areas on the volcano, whereas at least some ash flows came to rest on land in downslope areas.

Subsidence and erosion affected the cycle as a whole, returning at least downslope areas to a subaqueous environment; that catastrophic subsidence occurred in the vent area of the main volcano is not conclusively proven, however a large, possibly closed depression formed in this area and allowed the deposition of a thick accumulation of shallow to relatively deep water carbonates.

Fumarolic activity occurred in the waning stages of volcanism, contributing to the deposition of the carbonate unit and leading to the deposition of chert and sulphide facies iron formation in the south part of the cycle.

Although the precise nature of the relationship between Cycles I and II is uncertain, the simplest interpretation has tholeiitic basalt lavas with intercalated intermediate lavas and pyroclastics accumulating to form a composite cone on the east flank of the main volcano of Cycle I. Mafic dykes cutting the marble of Cycle I may have been feeders for part of Cycle II.

One or more cinder cones erupted most or all of the tholeiitic basalt in the south part of Cycle II. Agglomerates in this area were erupted and deposited subaerially. A restricted basin formed between this area and the main volcano in the north part of the cycle. During an hiatus in local volcanism, exhalative activity, possibly related to a linear fissure system, led to the deposition of silicate facies iron formation in the restricted basin. Relative subsidence in the south part of Cycle II resulted in a southward breaching of the basin. Shallow water carbonates were deposited atop the silicate facies iron

formation; further south the deepening shelf-type environment was a depository for deeper water carbonates.

Felsic volcanism succeeded deposition of carbonates in the south, and basaltic and andesitic volcanism in the central and northern parts of the cycle, and resulted in the deposition of calc-alkaline rhyolite volcanoclastics. Although the degree of reworking of these rocks is unknown, facies relationships suggest that they may have been erupted from the main volcano in the north part of the cycle. Although in part subaqueous, deposition of these rocks may have been mainly subaerial in this area, whereas further to the south deposition of mudstone occurred in the southwardly deepening sea.

Cycle III volcanism commenced with extrusion, into a submarine environment, of predominantly tholeiitic basalt lavas. An ash cone developed in the south-central part of the cycle, erupting andesite and rhyolite tuff, some of which was subsequently reworked. One or more small composite volcanoes formed in the north part of the cycle; basalt lavas and subordinate andesite lavas and pyroclastics issued from vents associated with high-level gabbro and diorite bodies. A restricted basin in the central part of the cycle was the site of deposition of oxide facies iron formation; a thick accumulation of basaltic flows, including pillowed flows, and hyaloclastites erupted from a fissure system into the basin. In an overall sense, subsidence kept pace with rock accumulation, resulting in subaqueous deposition throughout the volcanic part of the cycle.

A composite volcano formed in the south part of the cycle; andesite and rhyolite (and dacite ?) lavas and pyroclastics built, from a subaqueous base, a cone with considerable subaerial exposure. Domes and (or) spines may have contributed abundant fragmented material that was later reworked to form the Belmont Lake formation conglomerates. Welded ash flow tuffs associated with the volcano were deposited in areas nearby.

Marginal to, and contemporaneous with the volcanics of Cycle III, limestone, siliceous chemical sediments and fine siliciclastic rocks of the Vansickle formation were deposited in a submarine environment, in part under euxinic conditions. Reworked andesitic volcanics may have been derived from a nearby Cycle III source, no longer exposed.

Dolostone of the Marmora formation was deposited in a shallow sea adjacent to, or in part covering the volcanics of Cycle III. Erosion of the composite volcano in the Belmont Lake area led to the deposition of much of the clastic rocks of the Belmont Lake formation; material was transported down the east flank of the volcano during several different intervals, and was, in general deposited in a sub-aerial to shallow subaqueous environment. Syn- or post-volcanic faulting and (or) regional tumescence associated with volcanism exposed to erosive processes parts of the Cordova Lake formation, from which clasts of chert and oxide facies iron formation were derived. Periodic erosion of proximal upland carbonates yielded material to form a minor component of the Belmont Lake clastic unit. Carbonate deposition continued in areas marginal to the area of clastic deposition.

Eruption of calc-alkaline rhyolitic ash flow tuff occurred toward the close of Cycle III sedimentation.

Cycle IV volcanism commenced with outpourings of tholeiitic basalt lavas from poorly defined vents; deposition was in a subaerial to shallow subaqueous environment. This stage of volcanism produced a shield volcano. Later volcanic activity included predominantly subaerial eruption of basalt and andesite lavas and agglomerates along a linear fissure system; this activity marks the evolution to a mature shield volcano. Subordinate felsic volcanism resulted in the deposition, possibly in a pond on the volcano, of airfall tuff; felsic lavas and (or) tuff, no longer exposed, were eroded and re-deposited as clasts in a thin conglomerate unit.

Near the close of Cycle IV volcanism, limestone was deposited, possibly in a (crater ?) lake on the volcano.

The area was then subjected to intense deformation; the earliest phase resulted in regional isoclinal folding, manifested in Belmont Township as the essentially homoclinal succession of rocks with a penetrative planar fabric. Major north-trending faulting occurred in the eastern part of the area. The Cordova gabbro was probably emplaced in the late stages of the first phase of deformation. Upper greenschist to middle amphibolite facies metamorphism outlasted the first phase of deformation, and continued well into the second phase, during which open to close folding produced map-scale structures in areas of relatively high grade metamorphism. The granite body was emplaced before deformation ended.

Volcanism, metamorphism and deformation had ceased by Ordovician time, when limestone was deposited on a regional scale.

7.2 Conclusions

Approximate correlation with similar rocks 60 km east of the study area leads to the inference that rocks of the Belmont Lake Metavolcanic Complex were formed in Helikian time, about 1300 Ma.

The complex comprises volcanic and sedimentary rocks that group naturally into four mafic-to-felsic volcanic cycles on the scale of Anhaeusser's (1971) major-cycle. The combined average thickness of all cycles is about 12 km.

The base of Cycle I is not exposed in the study area; the cycle consists mainly of rhyolite pyroclastics and flows, with subordinate basalt, andesite and dacite flows and pyroclastics. Sedimentary rocks, mainly carbonates, occur at the top of the cycle.

The base of Cycle II consists mainly of basalt and andesite flows and pyroclastics; rhyolite volcanoclastics form most of the upper part of the cycle. Silicate facies iron formation and marble occur in the south part of the cycle, as does mudstone which caps the cycle.

Cycle III volcanics are mainly basalt and andesite flows and pyroclastics, with minor felsic flows and pyroclastics. These are separated by a fault from the predominantly sedimentary upper part of the cycle; sedimentary units include carbonate and siliciclastic sediments.

Cycle IV consists mainly of basalt and andesite flows and pyroclastics. Minor marble occurs near the top of the cycle.

Volcanic rocks of all cycles were erupted both subaerially and subaqueously, and deposited mainly in shallow subaqueous to subaerial environments.

In general, basalts, andesites and dacites are tholeiitic; rhyolites are calc-alkaline. Belmont basalts containing less than and greater than 0.2% K_2O are, on the basis of REE data, respectively similar to depleted and enriched Archean tholeiites. Trace element discriminators illustrate that Belmont basalts most closely resemble modern ocean floor and back-arc basin basalts.

Based on REE and Zr data, Belmont andesites bear a close resemblance to Archean andesites, and differ markedly from modern andesites of the arc tholeiite series. Major and trace element abundances in Belmont rhyolites are similar to Archean undepleted and modern siliceous volcanics.

On the basis of stable metamorphic mineral assemblages in mafic and intermediate volcanic rocks the study area can be divided into three zones corresponding to greenschist and amphibolite facies, and the transition between them. By analogy with low- and intermediate-pressure facies series, it is concluded that metamorphism was the intermediate-pressure type.

Geochemical and field evidence suggests that the complex formed as a volcanic field in a shallow, in part ensialic back-arc basin at the leading edge of the Superior craton.

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APPENDIX A

Nomenclature

Volcanic rocks were classified in the field and in hand specimens and thin section studies according to colour index, for which the following parameters apply:

<u>Compositional group</u>	<u>Colour index</u>
mafic	>35
intermediate	10-35
felsic	<10

Mineral modes were estimated; in addition to percentages, qualitative terms were used throughout the text to define the abundance of minerals. The qualitative terms used, and their corresponding percentages are as follows:

essential	>15%
varietal	5-15%
minor	1-5%
accessory	<1%

Grain size of phaneritic rocks is described as:

very coarse-grained	>10 mm
coarse-grained	5-10 mm

medium-grained	1-5 mm
fine-grained	<1 mm

The terminology used to define grain size of epiclastic and pyroclastic fragments is that proposed by Fisher (1961); and is outlined in Table A1. Mixture terms and end-member terms used for rocks composed of pyroclastic fragments (Figure A1) are those proposed by Fisher (1966). Fisher (1966) did not propose precise percentage boundaries for the mixtures; the present study considers the boundaries to mark thirds.

The terminology adopted by Lajoie (1979, after Fisher, 1961, 1966) is used in this study to define volcanoclastic, pyroclastic, and epiclastic rocks. Volcanoclastic rocks include all fragmental volcanic rocks that result from any mechanism of fragmentation. Epiclastic fragments result from the weathering of volcanic rocks. Pyroclastic rocks are deposits of fragments that are formed by explosion and are projected from volcanic vents. The important point is that pyroclastic and epiclastic refer to different processes of fragmentation, but not necessarily to different processes of deposition (Fisher, 1966). Processes of fragmentation are commonly difficult or impossible to discern when dealing with ancient terranes.

"Agglomerate", as used in this study, follows the definition of Williams and McBirney (1979): "a poorly sorted or stratified deposit composed chiefly of monolithologic bombs of intermediate or basaltic composition; the matrix consists mainly of scoriaceous fragments."

Grade size (mm)	Epilastic fragments	Pyroclastic fragments	
256	Boulders (and "blocks")	Coarse	Blocks and bombs
	Cobble	Fine	
64	Pebble	Lapilli	
2	Sand	Coarse	Ash
1/16	Silt	Fine	
1/256	Clay		

Table A1. Terminology used to define grain size of epiclastic and pyroclastic fragments (after Fisher, 1961).

Figure A1. Mixture and end-member terms used for rocks composed of pyroclastic fragments (after Fisher, 1966).

Agglomerates result from rapid accumulation within or close to eruptive vents.

Bedding thickness of rocks displaying primary layering is defined, in general terms, according to a metric scale (e.g., centimetre-scale); in some, more specific, cases the classification used in this study is adapted from Ingram (in Krumbein and Sloss, 1963):

Thinly laminated	<0.3 cm
Thickly laminated	0.3-1 cm
Very thinly bedded	1-3 cm
Thinly bedded	3-10 cm
Medium bedded	10-30 cm
Thickly bedded	30-100 cm
Very thickly bedded	1-3 m
Extremely thickly bedded	>3 m

Some rocks (e.g., rusty-weathering schists of Member B, Whitney Creek formation) have been assigned descriptive rather than genetic names where, in the course of field mapping, the progenitor was uncertain. In addition, descriptive names are, for most rocks of the present study area, more appropriate for classifying rocks on the basis of thin section study. The major descriptive names used for metamorphic rocks in the present study area are:

Schist: a fine- to coarse-grained rock characterized by a strong planar fabric, expressed by abundant (>15%) plates of micas, chlorite, etc.

Semi-schist: a fine- to coarse-grained rock having a weaker planar fabric than a schist, expressed by <15% mica, chlorite, etc. plates.

3 3
OF / DE

Fels: a massive metamorphic rock lacking schistosity.

Rock name modifiers include essential and varietal minerals present in the rock; these are listed in increasing order of abundance.

Granitic rocks are classified according to Streckeisen (1976).

APPENDIX B

Sample Location and Petrographic Description

Localities from which samples were taken for thin section and (or) whole rock analysis are illustrated in Figure B1. For ease of illustration, sample numbers have been made more concise; correspondence between the two numbering systems is given in Tables B1 and B2..

Table B1 summarizes the mineralogy and textural data for most rocks from which thin sections were made. An asterisk (*) following a sample number indicates that the sample was chemically analyzed. Chemically analyzed rocks are described in detail in Table B2.

Abbreviations used in Tables B1 and B2 are:

Textures

- a - aphanitic
- b - fine-grained
- c - medium- to coarse-grained
- d - layered
- e - size-graded
- f - <5% amygdules
- g - >5% amygdules
- h - <10% plagioclase phenocrysts
- i - >10% plagioclase phenocrysts
- j - ophitic
- k - trachytic
- l - pilotaxitic
- m - felty
- n - massive
- o - foliated
- p - nematoblastic
- q - weak schistosity
- r - moderate to strong schistosity
- s - decussate

Figure B1. Sample location map showing boundaries of lithologic units (refer to Fig.3 for lithology). Sample description and correspondence between locality number and sample number are given in Tables B1 and B2. Localities marked with "x" refer to chemically analyzed samples. Crosses and associated numbers refer to UTM grid, zone 18.

t - granoblastic
 u - simple- to complex-interlocking
 v - complex-interlocking
 w - seriate
 x - poikiloblastic
 y - altered
 z - flow banding

Minerals

ab: albite	gt: garnet	ph: phlogopite
ac: actinolite	hm: hematite	py: pyrite
ap: apatite	hb: hornblende	qz: quartz
bi: biotite	Kf: K-feldspar	sc: sericite
cc: calcite	ky: kyanite	ti: titanite
ch: chlorite	mt: magnetite	to: tourmaline
cm: cummingtonite	mu: muscovite	tr: tremolite
cz: clinozoisite	og: oligoclase	zr: zircon
ep: epidote	ox: Fe/Ti oxide	
gf: graphite	pc: plagioclase of unknown composition	

Rock Names

dyke - dyke
 flow - flow
 frag - non-pyroclastic fragmental rock
 gab. - gabbro
 gran - granite
 hyalo - hyaloclastite or broken pillow breccia
 marb - marble
 qzmon - quartz monzonite
 sed - siliceous rock of probable sedimentary origin
 skarn - skarn
 tuff - tuff
 volc - volcaniclastic

Table B1
Petrographic Data on Rocks of Belmont Township
(excluding coarse fragmental rocks)

Formation Member		Rock Name	Mode (% - visually estimated)							CI	Textures
No. on Fig. B1	Sample No.		<1	1-5	6-10	11-15	16-25	26-35	36-50	51-65	>65
OAK LAKE FM. Member A											
1.	142B1*	flow	ep	mt					hb	pc	47 bn
2.	469B3*	flow	ap	ox					hb	pc	46 hr
3.	109B1*	flow	qz, ti,	bi, ep				hb		pc	40 ips
4.	150B3	flow	mt	ti,					hb	pc	45 bhpr
5.	166B1	hyalo	ap	mt	ch	hb				pc	37 bprx
6.	487B1*	flow	hm	qz,					pc, hb		52 bgpt
7.	107B1	tuff	ti, py	ep,	pc	qz	sc		hb		43 bcd
8.	Member B 480B1*	flow	ap, hb, zr	ch, mt, ti, cc, qz	bi						15 bpqx

Table B1 (cont'd)

Formation Member		Rock Name	Mode (% - visually estimated)											CI	Texture
No. on Fig. B1	Sample No.		<1	1-5	6-10	11-15	16-25	26-35	36-50	51-65	>65				
9.	479B1*	flow	ap, ox	cc, mt, qz, ti, mu	bi					pc	pc	14	bqt		
10.	478B1*	flow	sc	qz, mt, ti, ap, ep		bi				pc	pc	14	bqt		
11.	483B1*	flow	cc, ap, cc	mt, ti, ep	qz, bi					og	og	12	bq		
12.	* 165B1*	flow	ap, cc	ep, bi, mt, ap	hb, qz				pc	pc	pc	23	bpqt		
13.	141B1	flow	ap, ep, ap, cc	hb, mt, ti, ep, hb	qz, bi					pc	pc	14	bq		
14.	053M1*	flow	ap, ep, ap, cc	mt, ti, ep, hb	qz					pc	pc	18	bq		
Member C															
15.	238E1	volc	bi	mt, hm, ep				qz	ab			1	bdtx		
2.	469B2	volc	zr, ep, ap	mu, cc	bi			qz	pc			8	bdrt		
16.	477B1	tuff	ap, ti, ap	cc, qz, bi, mt, mu, bi, ep, ox		ep			pc			5	bty		
17.	482B1*	tuff	ap, cc	mu, bi, ep, ox		qz, mc			pc			4	bqt		
18.	481B1*	volc	ti, ep, ap	bi, cc	mc	mu	pc, qz					3	betx		

Table B1 (cont'd)

Formation Member		Rock Name	Mode (% - visually estimated)											CI	Texture
No. on Fig. B1	Sample No.		<1	1-5	6-10	11-15	16-25	26-35	36-50	51-65	>65				
19.	149B1	sed	tl, bi, ap	Kf, mt	mu			og	qz			2	bux		
20.	151B1	tuff	ch	mu, ox				og, qz	Kf			0	bt		
21.	150B5	tuff	ox, ap, ti	bi, mu, cc				qz		ab		5	bqtx		
22.	163B1	tuff	ep	bi, mu, ox, cc, ap		Kf	ab		pc			6	bst		
23.	108B2	volc	ap	ox, Kf, bi, sc				qz	pc			9	bdqt		
24.	162B1	flow	ep	Kf, mu, mt				qz		pc		1	bqxz		
7.	107B2	sed	ep, ap, zr, to	mt	bi, mu, ky	pc				qz		12	bpqtx		
25.	097B1	volc	ap, ch, ti, cc	Kf, bi, mt			mu	qz	pc			4	aetx		
26.	484B1*	tuff	ch, cz	ep, sc, bi, py, cc	pc, mu			Kf	qz			2	bqu		
27.	102B1	volc	ap, ep, gt	mu, sc, bi, mt, cc					pc, qz			3	bvw		

Table B1 (cont'd)

Formation Member		Rock Name	Mode (% - visually estimated)							CI	Texture
No. on Fig. B1	Sample No.		<1	1-5	6-10	11-15	16-25	26-35	36-50	51-65	>65
148.	489B1*	tuff		Kf, bi, mu, mt, ep, ap			pc		qz		bqt
28.	148B1	volc	ap, ti, cc	mu, bi, mt				qz	pc		aqt
29.	095B1	volc	py, ap	cc				qz	pc		art
30.	486B1*	tuff	ch, ap	cc, mt, ep, bi, mu	bi			qz	pc		botv
31.	137E1	volc	ep, py	bi, mu					qz, pc		anrtw
32.	001B2	tuff	ox	mu, bi, cc					qz, pc		adqtwx
33.	144B1	volc	ep, ap, cc	bi, Kf, mt			pc, mu		qz		bdrtx
34.	229B1*	tuff	mt, ch	Kf, bi, mu, sc, cc				qz	pc		brv
35.	178B2	tuff	ap, mt	bi, mu, cc					qz, pc		arux
36.	490B1*	volc	ap	bi, cc		mu			qz, pc		aux
37.	082B1	tuff	ap	bi, mu, cc					qz	pc	adruwx
38.	491B1*	tuff	ap, ox	bi, cc		mu			qz, pc		bqtwx
39.	495B1*	tuff	ap, ox	bi, cc		mu			qz, pc		bqtx

Table B1 (cont'd)

Formation Member		Rock Name	Mode (% - visually estimated)											CI	Texture
No. on Fig. B1	Sample No.		<1	1-5	6-10	11-15	16-25	26-35	36-50	51-65	>65				
40.	131B1	tuff	ap, cc	mu, bi					qz, pc			4	aqtz		
LITTLE WHITNEY LAKE FM.															
41.	106B3	sed	to	pc, ep, bi, cc, mt		Kf	mu		qz			4	bdost		
WHITNEY CREEK FM.															
Member A															
42.	168B2	flow	ep	mt, sc			hb				pc	25	btwy		
43.	158B1*	flow	ox, ap	qz, ep, ti		qz			pc	hb		58	bot		
44.	226B2	tuff		bi, mt		qz, ep	hb			pc		25	bdort		
45.	227B1	flow	mt, gt	qz, ep				hb		pc		43	bglot		
46.	002B1	tuff?	mt	ep, cc		qz, hb					pc	13	bgo		
47.	084B1	tuff	ox	ep	qz			hb		pc		27	bgot		
48.	153B1*	flow	ap	qz, bi, ep, mt				hb		pc		36	bpt		
49.	492B1*	flow		ep, py					pc	hb		55	bot		
50.	085B1	tuff?	ox	ep	qz, ch		hb		ab			35	bdlot		
51.	159B1	frag		qz, ep, cc, ti			hb			pc		25	bgity		
52.	494B1*	flow		qz, ep, ox					hb	pc		40	bhot		
53.	135B1*	flow	ti, mt	qz, ep				pc	hb			53	bot		

Table B1 (cont'd)

Formation Member		Rock Name	Mode (% - visually estimated)											CI	Texture
No. on Fig. B1	Sample No.		<1	1-5	6-10	11-15	16-25	26-35	36-50	51-65	>65				
54.	169B1*	flow	py, cc, ap	ch, mt, ep										52	bot
54.	169B2	frag?	bi, ox, pc	ch								ac		98	aboy
55.	174B1*	flow	ox	qz, ox	pc, ep		sc			hb				55	cnty
56.	470B1	flow	zr	qz, cc	bi		hb, ch		pc					47	bhrty
57.	224B1	volc		mu, cc, py, bi, ch				qz		pc				4	abdr
58.	472B1	volc	ap, ti	bi, mt, cc	ch			qz, pc, hb						42	aot
59.	136B1	volc	ep, ti	sc, op					pc, ch					50	bd
Member B															
60.	133B2	sed	ep, ap	bi, py	sc	gf	mu	pc	qz					5	ast
61.	003B2	sed			qz	cm					gt			93	cqx
Member C															
62.	471B1	marb	pc, Kf	qz								cc		0	bcu
Member D															
63.	137B2	volc	ch, ox	bi, mu					pc, qz					5	adrx
64.	261B1*	volc	ap, ti	bi, sc					qz, pc					4	art
65.	259B1*	volc		bi, mu, Kf, mt				qz		pc				6	adr

Table B1 (cont'd)

Formation Member		Rock Name	Mode (% - visually estimated)								CI	Texture
No. on Fig. B1	Sample No.		<1	1-5	6-10	11-15	16-25	26-35	36-50	51-65	>65	
66.	260B1*	flow?	ep	bi, ch, mt, sc, cc bi, mu, gf					pc, hb		57	bfmt
67.	195B1*	tuff	mt, cc					qz		pc	3	adqux
68.	008M*	tuff	ep, mt, gt	bi, mu, gf				qz		pc	3	adrtwx
69.	006M	volc		bi, mu, ox, gf					pc, qz		3	artwx
70.	156B1	volc	ox, ap	bi, mu					pc, qz		4	adruwx
71.	232B1	sed	mt,	bi, mu,	ch, gt	sc		bi	qz		50	berxy
72.	166E1	sed	cc, ti	gf					qz, ab		5	bdruw
73.	091B1	sed		pc, sc, py, gf			mu			qz	10	brvw
74.	099B1	sed	mu, py	gf	pc, bi						6	abdgw
CORDOVA LAKE FM. Member A												
75.	262B1	tuff	mt, zr	qz, bi, ep					ab, hb		45	bduw

Table B1 (cont'd)

Formation Member		Rock Name	Mode (% - visually estimated)										CI	Texture
No. on Fig. B1	Sample No.		<1	1-5	6-10	11-15	16-25	26-35	36-50	51-65	>65			
76.	192B1	hyalo	ep, mt	qz, ch	cc			hb	ab			35	bfhou	
77.	308B1	tuff	ox	ep, Kf						ab		5	buw	
78.	093B2	tuff		ep, mt	ch			hb	pc			38	bertx	
79.	071B1	frag?	mt	ch, ep, cc		qz		pc		hb		65	bhnsu	
80.	296E1	sed	ap, bi	hb, mt	cm	gt	ch		qz			40	bcrx	
81.	207B1*	flow	qz	ep, mt, cc					pc, hb			52	bnt	
82.	209B2	tuff	zr, cc	cc	qz		ch		pc			30	brtw	
82.	209B3	frag	ox					pc, qz, ch				30	bstw	
83.	212B1*	flow	qz	ep, mt					hb	pc		46	bkot	
84.	023B1	tuff?	ap, bi	mu					pc, qz			3	bortw	
85.	074B1*	flow	cc, ox									65	bghnu	
86.	070B1	sed	ch	ep, ox			ch	pc		hb	qz	29	bdrtwx	
86.	070B4	tuff?	hm, mt, gt	mt, qz, ep, ox			ch				pc	25	bdor	
87.	068B1	flow	cc	cc								53	blny	
88.	067B2*	dyke	ox	ep, cc, ch				hb			pc	55	bly	
89.	007B1	flow	ch	ti, ch	ep				hb	pc		70	bly	
			ch	ep, cc					pc	hb				

Table B1 (cont'd)

Formation Member		Rock Name	Mode (% - visually estimated)										CI	Texture
No. on Fig. B1	Sample No.		<1	1-5	6-10	11-15	16-25	26-35	36-50	51-65	>65			
99.	028B1	sed	ti	mt, ep, ch	sc	pc		bi	qz			31	brtvy	
100.	020B1*	dyke	bi, cc	qz, ox		ch	pc, ep		hb			60	bhovy	
100.	020B2	dyke	ti	ep, mt				pc		hb		66	bhnt	
101.	015B1	flow	ch	ep, mt, cc		pc					hb	84	bfhuy	
102.	016B3	sed	ch, mt	cm		qz		ch	gt			87	cdrx	
103.	016B4	volc	ti, cc	sc, mt	pc, ep		qz, hb		ch			63	bdrt	
103.	016B6	volc		ep, mt					ch	pc		42	bortv	
104.	012B1*	flow	mt	ep, sp	ch		pc				hb	75	bru	
105.	315B1*	flow	hm	qz, ep, mt, cc		ch	pc			hb		70	bo	
106.	465B1	sed	mu, ap, zr	bi, ch, ep, mt					pc, qz			7	bdrt	
107.	066B3	flow		qz, bi, ep, mt	ch				pc, hb			49	brtx	
108.	216B1*	flow	ch, cc	ep, mt					pc, hb			52	bnu	
109.	215B1*	dyke	cz, cc	bi, mt					pc, hb			52	bnv	
110.	220B1	flow	mt	ep, ti, cc				pc			hb	68	bfhntu	

Table B1 (cont'd)

Formation Member		Rock Name	Mode (% - visually estimated)											CI	Texture
No. on Fig. B1	Sample No.		<1	1-5	6-10	11-15	16-25	26-35	36-50	51-65	>65				
111.	117E1	sed	cm, bi	hm	ch, mt, gt						qz	29	cqtx		
Member B															
112.	034B2	flow	ox	bi, ep		hb	qz			pc		18	bfqux		
112.	034B3*	tuff?	ox, bi					qz		ep		4	bnty		
113.	035B1	tuff	hb	ch, mt	ep	qz, hb				pc		20	brx		
113.	035B3	flow		ch, bi, ep, mt		qz	hb			ab		20	befmr		
114.	038B2	flow	ti, zr	bi, ep, mt	ch			qz		pc		8	bfmqu		
115.	052E2	sed		ch, bi, ep, mt, cc			sc			qz		11	bdortx		
116.	056E1	flow	ap, ox	ch, sc, cc			qz			ab		5	bfmnu		
VANSICKLE FM.															
Member B															
117.	123B2	sed		ch, ox, hm	cm, bi			gt	qz			59	cdrx		
118.	124B2	sed	ch, ep, gt	bi, ox		cc					qz	2	bdq		
119.	130B1	sed	ap	ac, mt, cc, hm	gt	qz				cm		69	cdtx		
120.	159B1*	sed	ep, ox	bi, cc			pc				qz	2	aqt		

Table B1 (cont'd)

Formation Member		Rock Name	Mode (% - visually estimated)								CI	Texture
No. on Fig. B1	Sample No.		<1	1-5	6-10	11-15	16-25	26-35	36-50	51-65	>65	
MARMORA FM. 121.	064B1	marb	ep, qz, ph gf								0	bdr
BELMONT LAKE FM. 122.	039B1	sed	ap, pc, ch, ox		bi					qz	20	bdrx
123.	018B2	flow?	qz, ch, sc, mt, cc					ab, bi			42	bfm
124.	002E1	tuff.	ox, sc cc, Kf		qz					ab	1	aiqw
125.	222B1*	tuff	mt, sc, cc ap, ti, bi					qz, abrog			1	see Table B2
126.	398B1*	flow?	to ox, qz, sc							ab	1	bhy
CROWE RIVER FM. Member A 127.	113B1	flow	ti, mt, ep sc, cc					pc	hb		56	bhnu
128.	022M1*	flow	thin section data not available									
129.	115B1	flow	ti			ep		pc	hb		48	bfhy
130.	256B2*	flow	cz, ep, mt ti			pc				hb	77	ant
131.	234B1	flow	ti	ac, ep	ch		hb	hb	ab		45	bfm
132.	240B1*	flow	ti ox	ox	ep		pc	pc	ch		60	brty

Table B1 (cont'd)

Formation Member		Rock Name	Mode (% - visually estimated)										CI	Texture
No. on Fig. B1	Sample No.		<1	1-5	6-10	11-15	16-25	26-35	36-50	51-65	>65			
133.	251B1	flow	ap, cz	qz, hb, ti, mt	ep		ch			ab		25	bn	
134.	237B2*	flow		ti, mt	ch	ep		ac	pc			38	bfquy	
135.	236B1	flow		ti, mt, ch	ac	ep					pc	15	ahly	
136.	255B2*	flow	ti	mt			pc				ac	72	afot	
137.	474B1*	flow		ch, ep, ti, mt				pc		ac		60	ant	
138.	116B1	tuff	ap, ox			qz, pc					ep	0	adety	
138.	116B2	flow		ti, mt	ep	ac					pc	20	bgm	
139.	473B1*	flow		ch, bi, ti, mt		ac, ep			pc			29	bfhmy	
140.	301E6	flow		mt					pc, hb			65	bj	
Member B														
141.	256E4	marb	pc	ch			tr				cc		bot	
142.	330B1	skarn			qz, tr	ep					gt		cdx	
INTRUSIVE ROCKS														
143.	146B1*	gab	ox, bi, mu		ch, ep		pc, sc		hb			55	bchjtwy	
144.	179B1*	gab	sc, ti						hb	pc		50	bht	
145.	145B1	gab	ep, mt						hb					
			ep, sc, ti, mt						hb	pc		40	behtw	

Table B1 (cont'd)

Formation Member		Rock Name	Mode (% - visually estimated)										CI	Texture
No. on Fig. B1	Sample No.		<1	1-5	6-10	11-15	16-25	26-35	36-50	51-65	>65			
146.	202B1*	gran	ox	bl,mu, sc			pc	qz	Kf			2	bcvw	
147.	Q44M2*	qzmon	hb, ox, zr,ap ti,mt,ep	bl,sc		qz		og	Kf			3	bcuw	

Table B2

Description of Chemically Analyzed Rocks (see also Table B1)

No. on Fig. B1	Sample No.	Description
1.	142B1	Mafic flow: black; dark grey-weathering; massive (amphibolite).
2.	469B3	Mafic flow: black; black-weathering; schistose; blastoporphyrritic, 5-10% og phenocrysts (3 mm).
3.	109B1	Mafic flow: dark green-grey; dark green-grey-weathering; schistose; blastoporphyrritic; 5-10% pc phenocrysts.
6.	487B1	Mafic flow: black; dark brown-grey-weathering; nematoblastic; 5% amygdules (3 mm).
8.	480B1	Intermediate flow: medium grey; medium brown-grey-weathering; nematoblastic; 10-15% qz xenocrysts (?) (1.5 mm).
9.	479B1	Intermediate flow: medium grey; medium brown-grey-weathering.
10.	478B1	Intermediate flow: grey; light brown-grey-weathering.
11.	483B1	Intermediate flow or tuff: medium grey; light brown-white-weathering; some bi-rich lenticles up to 1 cm wide; schistose.
12.	165B1	Intermediate flow: medium grey; dark grey-weathering; schistose; may be blastoporphyritic (hb after ?, 2-4 mm).
14.	053M1	Intermediate flow: medium grey; brown-grey-weathering; schistose; may be blastoporphyritic (hb, 1 mm).
17.	482B1	Felsic tuff: light pink-grey; pink-white-weathering; schistose; uniform.
18.	481B1	Felsic volcaniclastic: medium grey; white-grey-weathering; schistose; uniform; mu poikiloblasts (1-3 mm); one lithic fragment (quartzofeldspathic, 1-2 mm).
26.	484B1	Felsic tuff: medium grey-pink; white-weathering; uniform; ep + mu wisps, 5-30 mm long, 0.5 mm wide define foliation (pumice?); some pc crystals (2 mm).

Table B2 (cont'd)

No. on Fig. B1	Sample No.	Description
30.	486B1	Felsic ash flow tuff: medium grey; light brown-grey-weathering; eutaxitic foliation; fragmental; matrix: fragments = 35:65; fragment types: 1) ab crystals, 35% of rock, 1 mm, normally zoned; 2) qz crystals and composite grains, 10% of rock, 0.5-1 mm; 3) recrystallized pumice, 20% of rock, 0.5-9 mm, deformed around crystal fragments.
34.	229B1	Felsic tuff: medium grey; light grey-brown-weathering; subtle layering; poorly sorted.
36.	490B1	Felsic volcanoclastic: medium grey; grey-white-weathering; mm-cm-scale layering: compositional and size grading; mu poikiloblasts.
38.	491B1	Felsic tuff: dark grey; light brown-grey-weathering; cm-scale layering: compositional and size grading; some qz, pc crystal fragments; mu poikiloblasts.
39.	495B1	Felsic tuff: medium pink-grey; medium brown-grey-weathering; subtle cm-scale layering; moderate foliation defined by thin septa, 3-10 mm long; mu poikiloblasts.
43.	158B1	Mafic flow: dark grey; medium grey-brown-weathering; uniform; foliated.
48.	153B1	Mafic flow: dark grey; nematoblastic; uniform.
49.	492B1	Mafic flow: dark grey; brown-grey-weathering; uniform; weakly foliated.
52.	494B1	Mafic flow: dark grey; brown-grey-weathering; uniform; strongly foliated; rare pc microphenocrysts; may be subtly layered on mm-cm-scale.
53.	135B1	Mafic flow: dark grey; dark grey-weathering; uniform; foliated.
54.	169B1	Mafic flow: dark grey; brown-weathering; uniform; moderately foliated.
55.	174B1	Mafic flow: dark grey; brown-weathering; uniform; massive; highly altered.
64.	261B1	Felsic volcanoclastic: dark grey; rusty brown-weathering; extensive brecciation post-dates schistosity, minor matrix, breccia fragments mm-cm.
65.	259B1	Felsic volcanoclastic: dark grey; brown-weathering; mm-cm-scale layering: compositional and size grading; schistose.

Table B2 (cont'd)

No. on Fig. B1	Sample No.	Description
66.	260B1	Mafic flow or dyke: dark grey; rusty brown-weathering; 3% qz amygdules; mm wide cataclastic zones.
67.	195B1	Felsic tuff: grey; grey-weathering; mm-cm-scale layering; weak schistosity; mu poikiloblasts.
68.	008M1	Felsic tuff: grey; grey-weathering; mm-cm-scale layering; weak schistosity; mu poikiloblasts; gt. porphyroblasts.
81.	207B1	Mafic flow: uniform; moderate schistosity; minor ep-rich veinlets.
83.	212B1	Mafic flow or hypabyssal rock: dark green grey; medium brown-grey-weathering; uniform.
85.	074B1	Mafic flow: dark grey; medium brown-grey-weathering; uniform; 3% pc phenocrysts (1-3 mm); 10-15% qz amygdules (1-2 mm, round).
88.	067B2	Mafic dyke: weak schistosity; nematoblastic; 25-30% pc phenocrysts (3-30 mm); altered.
89.	475B2	Mafic dyke: dark grey; medium grey-weathering; uniform; weak foliation.
90.	476B1	Mafic flow: dark grey; brown-grey-weathering; uniform; massive.
93.	488B1	Mafic flow: dark grey; medium grey-weathering; uniform.
97.	025B1	Mafic flow: dark grey; medium brown-grey-weathering; uniform; weak foliation.
100.	020B1	Mafic dyke: dark grey; medium grey-weathering.
104.	012B1	Mafic flow: medium green-grey; brown-grey-weathering; uniform; schistose.
108.	216B1	Mafic flow: dark green-grey; medium brown-grey-weathering; uniform; massive.
109.	215B1	Mafic dyke: dark grey; brown-grey-weathering; uniform; massive.
112.	034B3	Felsic tuff?: light grey-green; light beige-green-weathering; uniform; massive; highly altered to epidote.
120.	159B1	Siltstone: dark grey; medium brown-weathering; uniform; massive.

Table B2 (cont'd)

No. on Fig. B1	Sample No.	Description
125.	222B1	Felsic ash flow tuff: pink-grey, light beige-weathering; fragments: matrix = 20:80; fragment types: 1) blue, dipyrnidial qz, 4 mm; 2) colourless qz, equant to elongate, 1-2 mm; 3) pc: smaller (< 0.5 mm) og, larger (1 mm) ab; 4) pumice; 5) pc-rich hypabyssal lithic fragments, 1-5 mm; 6) siliceous carbonate lithic fragments, 0.5-4 mm; 7) felsic lava fragments, 0.3->5 mm; fragment type 3 predominates, followed by 1, 2, 4, 6, 7, 5; matrix: essentially qz and pc; fine dusting of mt accentuates shard morphology; cataxitic foliation defined by flattening of shards and common alignment of flattened fragments 4, 6.
126.	398B1	Cobble-size clast in conglomerate: dark green-grey; dark brown-weathering; uniform; og phenocrysts, 5%, 0.6-2 mm, altered; matrix to phenocrysts is predominantly pc; irregular patches of Kf are metasomatic.
128.	022M1	Mafic flow: dark green; grey-green, locally rusty brown-weathering; uniform; weak schistosity.
130.	256B2	Mafic flow: dark green-grey; red-brown-grey-weathering; uniform; massive.
132.	240B1	Mafic flow: uniform; moderate schistosity.
134.	237B2	Mafic flow: weak foliation; pc microphenocrysts (rare, 0.5 mm).
136.	255B2	Mafic flow: dark green-grey; brown-grey-weathering; uniform; minor qz amygdules.
137.	474B1	Mafic flow: medium green-grey; light beige-weathering; some ac-qz-ep-ti-mt stringers.
139.	473B1	Mafic flow: medium green-grey; light green-brown-grey-weathering; uniform; ab microphenocrysts (1%, 1-2 mm); < 1% ac-ep-qz amygdules; matrix pc partly altered to ep.
143.	146B1	Gabbro: medium grey; medium grey-weathering; uniform; oikocrystic; 20-40% pc phenocrysts, highly altered to sc, 2-4 mm.

Table B2 (cont'd)

No. on Fig. B1	Sample No.	Description
144.	179B1	Gabbro: dark grey; brown-grey-weathering; uniform; 5% pc phenocrysts, 3-6 mm, normally zoned, cores altered to ep + sc. Granite: pink; pink-weathering; massive; uniform. Quartz monzonite: pink; grey-pink-weathering; 5 mm; uniform. Felsic lapilli tuff: medium grey; light brown-grey-weathering; uniform. matrix : fragments = 60:40; fragments more felsic than matrix, comprise 3 types: single and composite qz grains; mica-rich fragments, 3 mm, elongate; qz-rich, mica-poor fragments, 2.5-6 mm; matrix is quartzofeldspathic and weakly schistose.
146.	202B1	
147.	044M2	
148.	489B1	

APPENDIX C .

Analytical Results

Table C1 is a compilation of analytical results determined by X-ray Assay Laboratories Ltd., and the University of Ottawa. Although Ga, Mo, Sn, and Gd were determined by X-ray Assay Laboratories Ltd., they were all below detection limit for every sample, and are thus not included in Table C1.

Although Table C1 includes results obtained from two different labs, most manipulations of data have been made using the University of Ottawa's results. The reasons for this include the desire to maintain uniformity of data, greater general confidence in the results, and greater access to the writer of computer-assisted manipulation techniques at the University of Ottawa.

Table C1

Chemical Composition of Rocks of the Belmont
Lake Metavolcanic Complex

- . See Tables B1 and B2 for sample description.
- . Analysts: UO - University of Ottawa
 - XRA - X-Ray Assay Laboratories Ltd.,
Don Mills, Ontario.
- . Major elements (SiO_2 to Total) are expressed in weight %.
- . Trace elements (Ba to Th) are expressed in ppm.
- . C.I.P.W. normative minerals are expressed in % cation equivalents; determined using chemical analysis recalculated to 100%.
- . Footnotes:
 1. FeO, S, CO_2 , H_2O^+ , and H_2O^- , determined by Geoscience Laboratories, Ontario Geological Survey (GLOGS), Toronto. FeO recalculated to include Fe_2O_3 in excess of $(\text{TiO}_2 + 1.5)$ (cf., Irvine and Baragar, 1971). S also determined at University of Ottawa, and listed in UO column.
 2. Fe_2O_3 calculated by subtracting FeO from FeO^* and multiplying by 1.11; if value is greater than $(\text{TiO}_2 + 1.5)$, excess is converted to FeO (see above).
 3. Total in XRA column calculated using Fe_2O_3^2 and FeO^1 (see above), and S, CO_2 , H_2O^+ , and H_2O^- , as determined by GLOGS.
 4. S.G. = Specific Gravity (g/cc), determined by GLOGS.
- . "—" indicates below detection limit.
- . Fe_2O_3^* = total iron expressed as Fe_2O_3 (UO data only).
- . FeO^* = total iron expressed as FeO (XRA data only).

Sample No	012B1		020B1		025B1		034B3		067B2		074B1		109B1		135B1	
No. in Fr. Ct	104		100		97		112		88		85		3		53	
Analyst	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA
SiO ₂	47.10	45.9	45.77	44.1	46.82	46.7	53.62	52.5	46.52	44.9	49.22	46.9	51.57	49.7	48.88	46.8
Al ₂ O ₃	14.98	14.8	17.39	17.0	14.63	14.6	15.96	15.2	21.00	20.7	15.41	15.0	17.70	17.2	16.39	15.9
Fe ₂ O ₃ *	13.88		13.13		14.72		10.42		8.72		13.47		10.94		12.13	
Fe ₂ O ₃ ¹		3.32		3.18		3.14		2.48		2.44		3.04		2.77		2.90
FeO*		12.3		11.70		13.20		9.20		7.52		11.70		9.60		10.60
FeO ¹		9.43		9.02		10.65		7.23		5.47		9.01		7.24		8.06
MnO	7.22	7.49	6.48	6.80	6.36	6.48	1.14	0.85	5.19	5.32	6.99	7.05	4.89	5.03	7.37	7.71
CaO	9.11	9.64	10.47	10.8	11.82	11.9	18.67	14.4	11.33	11.4	10.23	10.4	9.44	9.51	10.73	10.7
Na ₂ O	2.73	2.74	2.06	2.07	0.78	1.45	0.0	0.16	3.30	3.19	2.34	2.57	3.13	2.95	2.08	2.31
K ₂ O	0.10	0.10	0.16	0.15	0.11	0.11	0.09	0.08	0.11	0.11	0.16	0.16	0.42	0.64	0.22	0.22
TiO ₂	1.69	1.82	1.58	1.68	1.51	1.64	1.11	1.18	0.89	0.94	1.44	1.54	1.21	1.27	1.33	1.40
P ₂ O ₅	0.03	0.18	0.0	0.13	0.0	0.13	0.34	0.49	0.0	0.07	0.0	0.13	0.13	0.24	0.0	0.11
Mn ₂ O	0.19	0.19	0.20	0.20	0.19	0.19	0.15	0.14	0.14	0.13	0.20	0.19	0.17	0.16	0.19	0.18
Si ¹	0.08	0.10	0.03	0.05	0.07	0.18	0.04	0.11	0.00	0.01	0.08	0.14	0.01	0.01	0.01	0.09
CO ₂ ¹		0.17		0.44		0.25		1.26		0.82		0.10		0.08		0.01
H ₂ O ¹		1.72		1.63		0.33		0.31		1.33		0.63		0.33		0.26
H ₂ O ⁻¹		0.64		0.57		0.84		0.34		0.91		0.42		0.47		0.48
LOI		2.70		2.70		1.62		2.77		3.47		1.16		1.03		1.23
Total ¹	97.22	98.14	97.51	97.82	96.43	97.59	96.83	97.03	97.28	97.74	99.66	97.28	99.72	97.60	99.43	97.13
S.G. ⁴		3.04		3.05		3.13		3.11		2.94		3.07		2.97		3.06
Ba	29	250	69		22		68		81		38		189		75	
Cr	279	280	265	270	267	270	0		102	70	171	160	106	100	321	320
Zr	129	50	134	60	129	40	196	190	108	40	134	70	189	100	122	50
Sr	95	90	178	210	110	140	454	540	202	220	126	140	404	480	139	200
Rb	7	10	12	0	10	0	10	10	11	0	12	0	15	20	11	0
Y	35	30	31	20	33	30	47	50	22	20	35	30	22	20	25	20
Zn	91	43	71	42	96	28	35	30	46	34	83	27	83	22	73	17
Ni	63	35	45	20	69	44	18		56	20	42	17	47	11	79	24
Li		12		11		9		7		9		8		12		15
Ba																
Sc		56		51		50		18		34		46		31		46
V		430		360		410		22		240		350		340		300
Co		23		22		19		5		19		14		9		12
Cu		44		35		79		22		11		34		91		76
La	4.94	6		7	3.44	5		24		3	6.02	7	13.21	19	3.80	4
Ce	13.4	13		19	9.68	14		69			15.5	18	26.9	44	9.6	11
Nd		13		17		10		37		9		15		32		12
Sm	3.10	4.4		4.5	2.15	4.2		8.2		2.6	3.51	4.3	2.81	6.0	2.24	3.5
Eu	1.32	1.7		2.3	1.18	1.8		2.2		1.0	1.21	2.0	1.45	2.3	1.11	1.7
Dy		7		5		7		9		4		8		5		5
Tb	0.85				0.81						0.79		0.71		0.63	
Yb	3.60	5		5	3.68	5		7		3	3.06	4	2.50	4	2.49	4
Hf	2.4				2.2						2.4		2.3		2.23	
Pb		4										4				
U		0.2		0.2		0.2		1.0		0.1		0.3		0.6		0.1
Th	0.0			1.0	0.0			3.0		0.5	0.0	1.0	1.57	2.0	0.0	
Q	0.00		0.00		6.04		25.03		0.00		1.22		2.12		0.92	
C	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
OR	0.62		0.99		0.70		0.59		0.67		0.97		3.74		1.34	
AB	24.07		19.41		7.58		0.40		27.23		21.60		28.66		19.15	
AN	29.79		39.60		39.85		46.22		43.37		31.96		33.07		35.64	
NE	0.00		0.00		0.00		0.00		1.94		0.00		0.00		0.00	
DI	9.29		7.82		10.35		6.28		8.13		10.51		6.95		10.44	
HE	4.74		4.11		7.02		14.99		3.43		5.68		4.12		4.74	
EN	18.09		11.91		13.82		0.35		0.00		14.99		10.21		15.65	
FS	6.48		6.37		9.38		0.85		0.00		7.88		6.11		7.11	
FO	2.41		2.45		0.00		0.00		8.00		0.00		0.00		0.00	
FA	1.23		1.40		0.00		0.00		3.38		0.00		0.00		0.00	
WO	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
MT	3.51		3.38		3.40		3.03		2.57		3.18		2.89		3.04	
IL	2.48		2.31		2.28		1.72		1.28		2.09		1.72		1.90	
CR	0.05		0.05		0.05		0.00		0.02		0.03		0.02		0.05	
HM	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
AP	0.07		0.00		0.00		0.79		0.00		0.00		0.28		0.00	
PO	0.29		0.11		0.34		0.15		0.00		0.21		0.04		0.04	

Sample No.	142B1		146B1		153B1		158B1		159B1		165B1		169B1		174B1	
Na on Fe Cl	1		143		48		43		120		12		54		55	
Analyst	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA
SiO ₂	51.35	48.9	48.00	45.9	49.34	48.8	48.64	46.3	70.99	70.2	54.01	53.4	48.78	46.4	51.18	50.7
Al ₂ O ₃	14.35	13.8	22.34	21.9	17.70	18.1	15.35	14.7	9.19	9.32	13.17	13.5	13.07	13.5	17.86	17.8
Fe ₂ O ₃	15.25		8.48		12.67		12.09		2.02		15.53		17.50		9.10	
Fe ₂ O ₃ ²		4.02		2.10		2.72		3.05		0.42		3.90		3.33		2.05
FeO		13.80		7.54		11.40		11.20		1.76		14.10		15.60		8.09
FeO ¹		9.76		5.67		9.36		8.47		1.80		10.90		12.40		6.24
MgO	4.98	4.44	5.00	5.25	2.07	3.43	4.47	7.12	0.84	0.73	1.95	2.19	5.60	5.49	5.05	4.33
CaO	9.40	9.40	10.17	10.00	8.71	8.84	12.28	12.00	6.64	7.01	5.91	6.16	6.15	6.20	7.98	7.94
Na ₂ O	2.65	2.53	2.35	2.27	2.70	2.84	2.17	2.24	8.27	3.34	3.45	3.01	3.91	3.81	0.60	0.90
K ₂ O	0.31	0.34	0.71	0.70	1.15	1.12	0.18	0.17	0.75	0.74	0.57	0.55	0.14	0.14	2.33	2.39
TiO ₂	2.40	2.32	0.84	0.89	1.14	1.22	1.48	1.55	0.18	0.21	2.25	2.40	3.70	3.91	0.79	0.86
P ₂ O ₅	0.20	0.32	0.80	0.10	0.04	0.19	0.00	0.15	0.00	0.05	0.99	0.94	0.50	0.51	0.07	0.18
MnO	0.21	0.20	0.14	0.13	0.24	0.24	0.23	0.22	0.05	0.04	0.25	0.24	0.39	0.39	0.20	0.20
Si	0.00	0.01	0.00	0.01	0.00	0.01	0.02	0.00	0.04	0.05	0.00	0.01	0.03	0.17	0.00	0.01
CO ₂ ¹		0.00		0.19		0.07		0.11		5.21		0.21		0.32		0.18
H ₂ O ¹		0.53		0.75		0.19		0.21		0.64		0.03		1.10		1.07
H ₂ O ²		0.39		0.47		0.60		0.51		0.47		0.49		0.56		0.60
LOI		0.80		1.85		1.16		1.16		5.31		0.31		1.00		2.00
Total ²	101.18	97.74	97.45	97.67	96.70	97.73	100.21	96.90	94.00	101.01	98.18	98.73	100.44	98.93	96.06	97.53
SG ⁴		3.06		2.93		2.97		3.08		2.67		2.97		3.04		2.98
Ba	110	50	224	250	148	50	38	250	243	—	47	150	0	150	323	200
Cr	95	70	129	130	11	0	300	290	1	0	0	63	30	80	60	60
Zr	194	170	112	50	190	110	183	50	137	110	314	260	195	180	110	40
Sr	219	240	461	530	309	320	173	190	180	200	247	260	261	310	196	240
Rb	11	0	21	40	31	20	12	0	29	30	19	0	9	0	32	10
Y	57	40	16	20	45	50	30	20	24	30	84	70	55	50	23	20
Zn	110	22	73	24	96	57	76	10	37	47	177	59	110	19	57	10
Ni	44	5	57	17	17	—	61	17	17	—	17	2	33	11	47	3
Li	—	14	—	89	—	27	—	13	—	10	—	15	—	14	—	43
Be	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Sc	—	46	—	21	—	30	—	50	—	6	—	40	—	52	—	23
V	—	370	—	190	—	210	—	380	—	—	—	85	—	510	—	240
Co	—	7	—	8	—	12	—	7	—	3	—	5	—	28	—	4
Cu	—	70	—	7	—	3	—	41	—	8	—	1	—	140	—	14
La	15.05	18	—	4	—	14	3.23	10	—	12	—	24	5.93	6	7.15	7
Ce	35.5	50	—	11	—	34	8.8	16	—	32	—	64	16.00	17	—	15
Nd	—	37	—	5	—	24	—	9	—	18	—	53	—	22	—	12
Sm	7.17	9.2	—	2.3	—	5.7	1.43	4.2	—	4.2	—	14.0	5.44	6.8	3.17	3.2
Eu	2.06	3.2	—	1.0	—	2.3	1.22	1.8	—	1.0	—	4.6	2.01	3.1	—	1.5
Tb	—	11	—	4	—	7	—	5	—	6	—	16	—	10	—	4
Dy	1.27	—	—	—	—	—	0.72	—	—	—	—	—	1.22	—	—	—
Yb	5.63	7	—	2	—	6	3.04	4	—	5	—	10	5.64	7	—	3
Hf	4.8	—	—	—	—	—	2.1	—	—	—	—	4	4.7	—	—	—
Pb	—	—	—	—	—	—	—	4	—	4	—	4	—	—	—	—
U	—	0.6	—	0.2	—	0.5	—	0.3	—	0.9	—	1.4	—	0.7	—	0.4
Th	—	2.0	—	—	—	2.0	—	—	—	3.0	—	3.0	—	1.0	—	1.0
Q	6.17	—	0.00	—	2.77	—	0.00	—	39.92	—	13.91	—	2.19	—	9.24	—
C	0.00	—	0.00	—	0.00	—	0.00	—	0.00	—	0.00	—	0.00	—	0.01	—
OR	1.89	—	4.22	—	7.27	—	1.09	—	4.83	—	3.62	—	0.86	—	14.69	—
AB	24.51	—	28.52	—	25.09	—	19.92	—	31.93	—	33.27	—	36.27	—	5.74	—
AN	27.14	—	44.04	—	35.02	—	32.05	—	8.90	—	20.16	—	20.55	—	41.73	—
NE	0.00	—	1.02	—	0.00	—	0.00	—	0.00	—	0.00	—	0.00	—	0.00	—
DI	9.08	—	3.70	—	3.63	—	16.03	—	5.05	—	1.16	—	3.89	—	0.00	—
HE	6.56	—	1.63	—	4.95	—	8.17	—	0.00	—	2.34	—	2.19	—	17.22	—
EN	9.62	—	0.00	—	6.65	—	10.96	—	0.00	—	5.20	—	14.03	—	7.40	—
FS	6.94	—	0.00	—	9.05	—	5.58	—	0.00	—	10.54	—	7.89	—	0.00	—
FO	0.00	—	9.18	—	0.00	—	0.52	—	0.00	—	0.00	—	0.00	—	0.00	—
FA	0.00	—	4.03	—	0.00	—	0.27	—	0.00	—	0.00	—	0.00	—	0.00	—
WO	0.00	—	0.00	—	0.00	—	0.00	—	8.25	—	0.00	—	0.00	—	0.00	—
MT	4.20	—	2.46	—	2.75	—	3.14	—	0.29	—	4.21	—	5.62	—	2.55	—
IL	3.44	—	1.18	—	1.70	—	2.11	—	0.27	—	3.37	—	5.33	—	1.17	—
CR	0.08	—	0.02	—	0.00	—	0.05	—	0.00	—	0.00	—	0.01	—	0.01	—
HM	0.00	—	0.00	—	0.00	—	0.00	—	1.00	—	0.00	—	0.00	—	0.00	—
AP	0.43	—	0.00	—	0.13	—	0.00	—	0.00	—	2.23	—	1.00	—	0.16	—
PO	0.00	—	0.00	—	0.00	—	0.07	—	0.65	—	0.00	—	0.11	—	0.00	—

Sample No.	179B1		195B1		202B1		207B1		212B1		215B1		216B1		222B1	
No. on Fig. C1	144		67		146		81		83		109		108		125	
Analyst	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA
SiO ₂	48.58	47.2	76.54	73.4	74.48	71.2	48.86	47.4	50.34	48.3	49.15	46.8	48.54	47.2	76.34	72.0
Al ₂ O ₃	18.96	15.7	13.76	13.8	14.45	14.7	14.69	14.5	15.98	15.4	14.59	13.2	13.54	14.3	14.45	14.3
Fe ₂ O ₃ ^a	12.18		1.76		1.65		12.74		12.67		14.81		17.93		1.93	
Fe ₂ O ₃ ^b		2.01		0.71		0.84		3.22		2.68		3.44		3.44		1.32
FeO ^a		10.80		1.33		1.33		11.50		11.20		16.10		13.20		1.51
FeO ^b		8.99		0.89		0.57		8.35		9.98		13.00		10.07		0.32
MnO	6.83	7.12	0.62	0.42	0.51	0.24	6.37	6.68	6.48	6.64	5.83	4.57	4.58	5.99	0.45	0.11
CaO	10.87	10.80	0.39	0.46	0.47	0.66	11.16	11.30	9.98	9.94	9.52	8.34	8.28	9.72	0.77	0.81
Na ₂ O	2.18	2.43	6.81	6.02	3.07	3.19	2.51	2.34	3.28	3.21	2.71	3.30	3.18	3.03	6.13	5.93
K ₂ O	0.24	0.28	0.79	0.79	5.22	5.43	0.14	0.14	0.20	0.21	0.27	0.64	0.56	0.26	2.27	2.24
TiO ₂	1.29	1.37	0.23	0.24	0.23	0.24	1.60	1.72	1.10	1.18	2.08	3.57	3.30	2.14	0.29	0.31
P ₂ O ₅	0.00	0.13	0.01	0.04	0.01	0.04	0.20	0.33	0.00	0.10	0.07	0.58	0.42	0.19	0.05	0.05
MnO	0.19	0.19	0.04	0.04	0.03	0.02	0.20	0.19	0.21	0.20	0.17	0.26	0.24	0.16	0.03	0.02
Si	0.02	0.21	0.02	0.07	0.00	0.00	0.03	0.02	0.00	0.01	0.00	0.16	0.51	0.09	0.00	0.01
CO ₂ ¹		0.09		0.61		0.12		1.16		0.19		0.62		0.71		0.50
H ₂ O ⁺		0.61		0.60		0.00		0.64		0.48		0.36		0.44		0.00
H ₂ O ⁻¹		0.44		0.77		0.44		0.34		0.46		0.39		0.70		0.44
LOI		0.93		0.93		0.70		1.93		1.54		0.93		1.85		1.31
Total ¹	98.47	97.87	101.04	98.28	101.42	97.29	98.60	99.33	100.51	98.20	99.48	101.18	100.70	98.64	103.04	98.24
SG ⁴		3.04		2.66		2.63		3.04		3.03		3.10		3.04		2.66
Ba	64	100	258	50	428	300	0	150	62	250	20	—	0	650	723	700
Cr	287	300	0	20	0	0	220	220	124	110	78	20	55	60	0	0
Zr	124	60	149	160	212	180	135	50	123	50	165	170	189	110	154	130
Sr	164	220	31	20	85	90	200	230	123	160	159	160	142	160	109	120
Rb	9	20	23	30	163	140	11	20	9	0	12	40	18	0	39	30
Y	32	20	27	30	30	50	34	30	31	20	42	60	55	40	17	30
Zn	73	11	17	18	20	23	86	19	94	22	87	35	97	21	4	3
Ni	57	34	20	—	16	—	49	18	42	6	27	11	43	8	14	—
Li		16		8		9		12		10		19		10		6
Ba		—		—		—		—		—		—		—		—
Sc	43		7		4		41		41		48		47		3	
V	310		24		—		340		320		510		410		—	
Co	22		4		3		9		8		17		19		—	
Cu	99		6		1		78		18		70		25		3	
La	5	23.23	25		180	505	9		6	12.30	15		9	19.64	21	
Ca	10	51.9	61		370	14.1	21		14	29.5	38		27	40.2	42	
Ni	9		29		160		20		14		32		16		21	
Sm	3.5	5.08	5.9		19.0	2.74	5.2		3.3	5.27	9.3		5.0	3.77	3.9	
Eu	1.6	0.86	1.2		2.4	1.64	2.6		1.3	2.56	3.3		1.7	0.67	1.0	
Dy	5		7		7		7		5		11		8		4	
Tb		0.99					0.74			1.36				0.58		
Yb	3	46.0	5		3	3.04	4		4	5.61	8		6	3.21	4	
Hf		5.6				2.3				4.9				4.8		
U	0.2		2.2		7.4		0.3		0.4		0.5		0.7		2.9	
Th	0.5	6.17	5.0		22.0	1.81	0.5		1.0	2.91	1.0		1.0	6.62	8.0	
Q	0.83		29.28		32.32		1.45		0.00		2.28		2.50		26.63	
C	0.00		1.07		3.32		0.00		0.00		0.00		0.00		0.85	
OR	1.60		4.59		30.82		0.84		1.20		1.66		3.45		13.10	
As	20.80		60.07		27.52		23.44		29.60		25.29		29.76		53.22	
AN	34.24		1.84		3.25		29.53		28.60		27.92		21.92		3.38	
NE	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
DI	11.59		0.00		0.00		14.87		10.67		10.08		7.87		0.00	
HE	5.79		0.00		0.00		7.28		6.49		6.49		6.57		0.00	
EN	13.77		1.68		1.41		11.24		8.98		11.64		9.24		1.20	
FS	6.88		0.00		0.00		5.83		5.44		7.53		7.71		0.00	
FO	0.00		0.00		0.00		0.00		2.82		0.00		0.00		0.00	
FA	0.00		0.00		0.00		0.00		1.71		0.00		0.00		0.00	
WO	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
MT	3.03		0.00		0.00		3.17		2.75		3.09		5.23		0.00	
IL	1.84		0.85		0.07		2.12		1.55		3.01		4.79		0.25	
CR	0.05		0.00		0.00		0.04		0.02		0.01		0.01		0.00	
HM	0.00		1.19		1.15		0.00		0.00		0.00		0.00		1.21	
AP	0.00		0.02		0.02		0.44		0.00		0.15		0.92		0.10	
PO	0.07		0.07		0.00		0.11		0.00		0.00		0.04		0.00	
RV	0.00		0.12		0.12		0.00		0.00		0.00		0.00		0.07	

Sample No.	229B1		237B2		240B1		255B2		256B1		008M		022M1		044M2	
No. on Fig. C1	34		134		132		136		130		68		126		147	
Analyt	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA	UO	XRA
SiO ₂	76.92	74.2	47.75	45.5	47.69	45.7	44.76	47.8	50.34	48.3	69.53	67.3	49.02	47.4	61.04	58.8
Al ₂ O ₃	12.54	12.5	15.43	15.2	17.28	17.0	14.86	14.6	14.16	13.8	15.34	15.3	15.07	14.9	18.91	18.9
Fe ₂ O ₃	2.45		15.53		11.78		14.96		15.10		3.94		14.63		4.05	
FeO ⁺		0.59		3.95		0.00		3.97		4.03		0.70		3.87		1.75
FeO ⁺		2.31		13.80		10.50		13.40		12.30		3.47		13.00		3.44
FeO ⁺		1.78		10.72		11.30		10.23		9.85		2.84		9.96		1.84
MgO	0.80	0.60	4.92	4.97	7.23	7.73	4.72	4.87	4.99	5.08	1.04	1.00	5.13	5.28	1.34	1.53
CaO	1.85	1.67	9.54	9.61	8.18	8.13	9.08	9.19	9.49	9.95	1.18	1.17	9.39	9.56	2.20	2.14
Na ₂ O	5.32	4.91	3.51	3.52	2.57	2.60	2.21	2.37	2.14	2.18	5.10	5.46	3.15	2.93	4.65	4.42
K ₂ O	0.48	0.47	0.22	0.24	0.20	0.21	0.45	0.45	0.46	0.48	2.22	2.14	0.64	0.60	5.37	5.27
TiO ₂	0.24	0.30	2.37	2.45	1.57	1.65	2.34	2.47	2.41	2.53	0.86	0.60	2.12	2.23	0.75	0.77
R ₂ O ₃	0.03	0.05	0.18	0.30	0.07	0.17	0.19	0.30	0.18	0.29	0.09	0.10	0.19	0.31	0.19	0.21
MnO	0.06	0.06	0.24	0.23	0.13	0.13	0.23	0.22	0.22	0.21	0.14	0.14	0.19	0.18	0.06	0.07
Si ⁺	0.62	0.09	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	0.03	0.16	0.00	0.01	0.01	0.04
CO ₂		0.59		0.07		0.42		0.11		0.08		0.37		0.07		0.28
H ₂ O ⁺		0.32		1.49		2.97		1.47		1.07		0.51		0.91		0.32
H ₂ O ⁺		0.45		0.51		0.55		0.55		0.49		0.39		0.50		0.52
LOI		1.47		2.16		4.08		2.47		2.31		1.31		1.31		1.39
Total ¹	101.04	98.57	99.99	98.76	96.80	98.56	98.89	98.41	99.60	97.95	100.22	98.27	99.52	98.21	99.09	96.88
S.G.		2.67		3.05		2.94		3.05		3.09		2.70		3.04		2.69
Ba	258	300	38	—	44	200	65	150	68	100	828	700	45	100	2520	2100
Cr	0	0	99	90	120	110	62	40	97	70	0	0	104	70	0	0
Zr	149	100	173	160	147	180	173	140	191	190	139	100	181	150	405	740
Sr	31	90	326	350	190	230	263	330	192	230	171	190	230	270	987	930
Rb	23	0	14	0	13	0	19	30	16	10	57	30	14	10	110	110
Y	27	10	41	40	34	48	43	40	58	50	44	40	53	50	44	30
Zn	17	21	103	70	96	68	96	68	106	40	116	110	117	30	68	71
Hf	20	—	34	15	67	40	27	11	32	10	19	—	28	4	21	—
Li		12		12		35		80		11		22		13		28
Be		—		—		—		25		—		—		—		—
Sc		8		41		34		38		48		10		43		11
V		—		390		280		400		440		—		370		46
Co		6		24		26		24		14		4		10		5
Cu		8		3		6		44		46		4		4		6
La		13	940	12	9.04	10	12.77	13	15.50	17	22.76	23		17		95
Ce		33	26.9	30	23.2	25	28.4	31	29.6	44	54.8	55		44		190
Nd		24		28		24		27		34		26		36		110
Sm		41	4.55	6.7	4.88	5.8	6.08	6.8	6.32	9.0	7.98	7.6		83		16.0
Eu		14	1.46	2.7	1.75	2.3	2.62	2.8	2.27	3.3	1.74	2.3		2.8		4.7
Dy		3		7		7		8		11		7		9		8
Tb			1.00		0.93		1.09		1.40		1.05					
Yb		3	4.06	5	3.54	4	4.02	6	5.49	7	4.77	5		6		4
Hf			3.6		3.3		3.9		4.9		4.1					
Pb		4		—		—		—		—		—		—		—
U		0.9		0.5		0.3		0.5		0.7		1.8		0.7		3.4
Th		4.0	2.10	1.0	1.99	0.5	1.94	1.0	2.96	1.0	4.74	4.0		2.0		12.0
R		36.61		0.00		0.61		6.95		7.34		20.41		0.30		6.72
C		0.58		0.00		0.00		0.00		0.00		1.29		0.00		2.08
OR		2.85		1.34		1.24		2.81		2.84		13.07		3.31		31.92
AB		48.02		32.54		24.19		20.96		20.18		53.42		29.32		41.96
AN		7.54		27.11		36.72		30.96		21.07		5.34		26.33		9.72
NE		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
DI		0.00		9.29		3.06		7.02		8.99		0.00		9.70		0.00
HE		0.00		7.16		1.21		6.24		6.33		0.00		6.85		0.00
EN		2.22		4.79		19.39		10.26		9.97		2.88		9.83		3.77
FS		0.00		3.69		7.66		7.66		7.02		0.51		6.95		0.00
FO		0.00		3.44		0.00		0.00		0.00		0.00		0.00		0.00
FA		0.00		2.45		0.00		0.00		0.00		0.00		0.00		0.00
WO		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00
MT		1.37		4.18		3.36		4.24		4.21		2.14		3.92		2.28
IL		0.36		3.41		2.29		3.44		3.53		0.78		3.06		1.05
CR		0.00		0.02		0.02		0.01		0.02		0.00		0.02		0.00
HM		0.32		0.00		0.00		0.00		0.00		0.00		0.00		0.05
AP		0.06		0.39		0.16		0.42		0.40		0.19		0.41		0.40
PD		0.07		0.00		0.00		0.04		0.00		0.10		0.00		0.04

Sample No	053M1	25981	26081	26181	39881	46983	47381	47481	47582	47681	47881	47981	48081	
No on Fig c1	14	65	66	64	126	2	139	137	89	90	10	9	8	
Analyst	UO	XRA	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	UO	
SiO ₂	57.11	58.3	73.21	48.85	76.11	69.13	51.89	49.46	49.54	48.30	48.44	56.58	55.70	56.21
Al ₂ O ₃	15.20	16.0	13.24	14.48	12.44	12.76	13.99	15.24	13.83	14.22	13.89	13.93	13.59	13.19
Fe ₂ O ₃ ^o	8.67		3.77	14.60	2.81	2.89	13.68	13.42	16.31	13.95	14.01	9.02	9.33	8.19
Fe ₂ O ₃ ²		2.68												
FeO ^o		8.02												
FeO ¹		5.94												
MgO	1.95	2.21	1.29	5.16	1.35	0.43	5.41	4.69	4.64	7.11	6.92	2.37	1.48	1.60
CaO	5.83	5.28	1.39	8.37	0.48	2.34	8.85	9.01	8.17	10.58	11.09	3.80	5.56	5.40
Na ₂ O	3.62	4.47	4.59	2.61	5.44	0.85	3.71	4.54	3.71	2.96	2.40	3.19	3.72	4.17
K ₂ O	1.24	1.22	2.03	0.85	1.14	9.18	0.34	0.45	0.28	0.15	0.15	2.44	1.95	0.85
TiO ₂	1.67	1.18	0.65	1.49	0.33	0.28	1.47	1.84	2.75	1.63	1.69	1.68	1.61	1.53
RO ₂	0.15	0.21	0.10	0.85	0.05	0.00	0.07	0.16	0.24	0.00	0.00	0.67	0.59	0.67
MnO	0.18	0.15	0.05	0.25	0.05	0.03	0.23	0.21	0.22	0.21	0.21	0.15	0.15	0.19
Si ¹	0.00	0.01	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO ₂ ¹		0.00												
H ₂ O ¹		0.31												
H ₂ O ⁻¹		0.38												
LOI		0.59												
Total ³	94.30	98.42	100.37	97.22	100.32	98.02	99.43	98.55	99.77	99.31	99.12	98.97	94.00	92.30
SG ⁴		2.83												
Ba	210	250	450	97	324	576	68	175	27	11	37	334	289	87
Cr	17	0	0	44	0	1	106	89	63	321	257	9	5	9
Zr	194	130	148	149	154	222	161	170	189	132	133	253	247	247
Sr	325	350	418	260	70	56	222	266	213	113	9	254	228	257
Rb	38	30	47	24	26	61	16	21	13	10	7	60	50	19
Y	37	60	28	31	24	19	45	45	52	33	25	48	54	47
Zn	83	69	169	124	8	0	92	74	73	73	85	180	120	102
Ni	18	2	16	46	19	23	40	43	51	57	58	32	20	19
Li		14												
Be		—												
Sc		21												
V		150												
Co		11												
Cu		1												
La	15.45	18				29.93	7.39	10.79			5.61	26.80		
Ce	39.7	41				50.6	20.6	23.0			16.5	55.1		
Nd		27												
Sm	4.33	5.7				5.79	2.98	3.59			1.98	7.45		
Eu	1.55	1.9				0.96	1.53	1.53			1.19	2.05		
Dy		7												
Tb	0.91					0.65	0.94	0.97			0.67	1.27		
Yb	3.86	5				1.94	4.12	4.16			3.05	4.70		
Hf	3.6					8.0	3.5	3.7			2.4	5.6		
Pb		—												
U		1.4												
Th	4.19	3.0				3.77	3.00	3.00			2.22	6.18		
O	15.74		21.74	2.33	34.39	24.25	1.26	0.00	1.62	0.00	0.45	17.11	13.60	16.81
C	0.00		1.95	0.00	1.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OR	7.46		12.10	5.36	6.75	56.85	2.87	3.93	1.72	0.91	0.92	15.80	12.42	5.58
AB	35.28		41.62	25.00	49.00	7.99	34.34	38.14	34.68	27.35	22.36	31.56	34.54	41.54
AN	23.41		6.29	25.82	2.06	4.06	21.16	19.77	21.10	26.09	27.69	15.94	16.00	16.38
NE	0.00		0.00	0.00	0.00	0.00	0.00	2.11	0.00	0.00	0.00	0.00	0.00	0.00
DI	1.05		0.00	7.40	0.00	2.49	11.67	11.95	8.68	14.48	15.17	0.00	4.08	4.45
HE	1.05		0.00	5.44	0.00	0.00	7.25	8.33	6.90	7.92	8.95	0.00	3.89	3.21
EN	5.32		3.59	11.50	3.73	0.00	9.57	0.00	9.00	6.30	12.24	7.16	3.08	2.67
FS	5.32		0.21	8.46	0.00	0.00	5.94	0.00	7.16	3.46	6.74	4.10	2.89	1.93
FO	0.00		0.00	0.00	0.00	0.00	0.00	5.59	0.00	5.01	0.00	0.00	0.00	0.00
FA	0.00		0.00	0.00	0.00	0.00	0.00	4.04	0.00	2.75	0.00	0.00	0.00	0.00
WO	0.00		0.00	0.00	0.00	2.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
MT	2.92		2.16	3.89	1.43	1.89	3.74	3.57	4.63	3.37	3.46	3.64	3.56	3.51
IL	1.62		0.77	2.96	0.46	0.41	2.83	2.62	3.19	2.38	2.44	2.56	2.45	2.37
CR	0.00		0.00	0.01	0.00	0.00	0.02	0.02	0.01	0.05	0.04	0.00	0.00	0.00
HM	0.00		0.00	0.02	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AP	0.34		0.21	0.78	0.11	0.00	0.15	0.84	0.52	0.00	0.00	1.54	1.35	1.54
PO	0.00		0.07	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00

[illegible]

Table C2. Data used to classify volcanic rocks.
 SiO_2 values are normalized to a volatile-free
 basis. Asterisk (*) indicates altered sample.

Sample No.	No. on Fig. 16	SiO_2 (wt. %)	CI	Rock name as per Fig. 16	Rock name used in this study
109B1	3	52.03	40	basalt	basalt
142B1	1	51.40	47	basalt	basalt
146B1*	143	48.66	55	basalt	basalt (gabbro)
179B1	144	49.89	50	basalt	basalt (gabbro)
469B3*	2	52.00	46	basalt	basalt
487B1	6	50.16	52	basalt	basalt
135B1	53	49.69	53	basalt	basalt
153B1	48	51.67	36	basalt	basalt
158B1	43	49.09	58	basalt	basalt
169B1*	54	49.16	52	basalt	basalt
174B1*	55	53.74	55	basalt	basalt
012B1	104	49.07	75	basalt	basalt
020B1	100	47.47	60	basalt	basalt
025B1	97	49.13	72	basalt	basalt
067B2*	88	48.19	55	basalt	basalt
074B1	85	50.00	65	basalt	basalt
207B1	81	50.12	52	basalt	basalt
212B1*	83	50.87	46	basalt	basalt
215B1	109	50.26	52	basalt	basalt
216B1	108	48.95	52	basalt	basalt
475B1	89	49.25	60	basalt	basalt
476B1	90	49.68	70	basalt	basalt
488B1	93	49.11	51	basalt	basalt
315E1*	105	53.12	70	basalt	basalt
237B2*	134	48.41	38	basalt	basalt
240B1*	132	49.80	60	basalt	basalt
255B2	136	50.98	72	basalt	basalt
256B1	130	51.22	77	basalt	basalt
022M1	128	49.90	—	basalt	basalt
473B1*	139	50.49	29	tho. andesite	basalt
474B1*	137	50.35	60	basalt	basalt

Table C2 (cont'd)

Sample No.	No. on Fig. 16	SiO ₂ (wt. %)	CI	Rock name as per Fig. 16	Rock name used in this study
165B1*	12	55.80	23	andesite	andesite
053M1*	14	61.06	18	andesite	andesite
478B1*	10	60.71	14	andesite	andesite
479B1*	9	59.76	14	andesite	andesite
480B1*	8	61.33	15	tho. andesite	andesite
483B1	11	60.98	12	tho. andesite	andesite
034B3*	112	56.39	4	basalt	andesite
486B1*	30	65.19	5	dacite	dacite
489B1*	148	67.43	7	andesite	dacite
229B1*	34	76.41	4	rhyolite	rhyolite
481B1	18	70.53	3	dacite	rhyolite
482B1	17	69.16	4	rhyolite	rhyolite
484B1*	26	75.57	2	basalt	rhyolite
490B1*	36	77.90	3	rhyolite	rhyolite
491B1*	38	75.51	4	rhyolite	rhyolite
495B1	39	79.03	2	rhyolite	rhyolite
195B1*	67	75.80	3	rhyolite	rhyolite
008M*	68	69.62	3	rhyolite	rhyolite
259B1	65	73.15	6	rhyolite	rhyolite
261B1*	64	75.99	4	rhyolite	rhyolite
159B1*	120	75.57	2	dacite	rhyolite
222B1*	125	74.17	1	rhyolite	rhyolite
398B1*	126	70.68	0	dacite	rhyolite

APPENDIX D

Analytical Procedures, Precision and Accuracy

Samples Q12B1 to 053M1 (see Table C1) were chemically analyzed by X-ray Assay Laboratories Ltd. Major elements and Rb, Sr, Zr, Cr, Ga, Ba, and Y were determined by an x-ray spectrometer on a fused glass bead (the proportion of rock powder to other substances was not reported). Li, Co, Ni, Cu, Zn, Mo, Ag and Pb were determined by atomic absorption; Be and Sn by emission spectrography; Sc, V, La, Ce, Nd, Sm, Eu, Dy, Yb and Th by neutron activation; and U by delayed neutron counting.

Detection limits for analyses are as follows: major elements: 0.01%; U and Sm: 0.1 ppm; Eu and Th: 0.5 ppm; Sc, Co, Ni, Cu, Zn, Ag, La, Dy, and Yb: 1.0 ppm; Li, Mo and Pb: 2.0 ppm; Sn: 3.0 ppm; Nd: 5.0 ppm; Be, Rb, Sr, Zr, Ce, Cr and Y: 10.0 ppm; V and Ga: 20.0 ppm; Ba and Gd: 50.0 ppm.

Total iron was reported as FeO. Individual volatiles were not determined, however weight % loss on ignition was reported. The Geo-science Laboratories of Ontario Geological Survey determined S, FeO, CO₂, H₂O⁺ and H₂O⁻, all in weight %.

Three samples were analyzed as duplicates, and five reference standards were included. On the basis of comparison with these results Dr. C. Riddle (written communication, 1981) assessed the precision and accuracy of the data; his assessment is compiled in Table D1.

Table D1. Assessment of precision and accuracy for chemical analyses performed by X-ray Assay Laboratories Ltd. (from C.Riddle, written communication, 1981).

Major Elements: Precision is excellent. Accuracy is acceptable with the exception of SiO_2 , which is reported consistently low by ca. 3-4% (e.g. 47.7 reported for 49.5%).

Trace Elements:

<u>Component</u>	<u>Precision</u>	<u>Accuracy</u>	<u>Comments</u>
Chromium	Good	Fair	Stds. 510 for 620 290 for 250 360 for 290 130 for 150
Zirconium	Fair	Fair	Duplicates 50/80 170/160 130/90 Stds. 60 for 45 150 for 240 230 for 260 110 for 140
Strontium	Fair	Good	
Rubidium	Fair	Fair	Duplicates 10/10 40/10 30/30 Stds. 30 for 1 90 for 87 30 for 46 60 for 40
Lithium	Good	Good	(77 for 92)
Beryllium	Fair	Good	<10/25
Scandium	Excellent	Good	
Vanadium	Excellent	Fair	Stds. <20 for 190 <20 for 20 <20 for 25 54 for 60 45 for 51 25 for 24

Table D1 (cont'd)

<u>Component</u>	<u>Precision</u>	<u>Accuracy</u>	<u>Comments</u>
Cobalt	Excellent	Fair	11 for 53 otherwise OK
Nickel	Good	Fair	57 for 224 otherwise OK
Copper	Poor	Bad	Duplicates 94/68 70/51 1/2 Stds. 49 for 80 190 for 360 42 for 74
Zinc	Excellent	Bad	18 for 101 86 for 240
Gallium	Good	Fair	
Molybdenum	Good	Fair	<2 for 4 20 for 30
Silver	Good	Good	
Tin	Good	Fair	
Barium	Bad	Bad	Duplicates 250/<50 100/350 <50/100 Stds. 150 for 60 <50 for 430
Lanthanum	Good	Fair	
Cerium	Excellent	Good	
Neodymium	Fair	Good	650 for 800
Samarium	Good	Good	
Europium	Good	Good	
Gadolinium	Fair	Good	<50 for 55
Dysprosium	Fair	Good	110 for 80
Ytterbium	Excellent	Good	
Lead	Fair	Fair	
Uranium	Excellent	Excellent	
Thorium	Good	Good	
Yttrium	Fair	Fair	210 for 740

Table D1 (cont'd)

Note: (1)

XRAL reran SiO₂, Co, Ni, Cu, Zn, and Ba. The poor quality of the data in their original report they put down to incomplete acid digestion for Co, Ni, Cu, and Zn; and under-fusion for SiO₂ (and Ba?).

(2) Precision is good on the new data. Accuracy may be assessed from the following data on reference materials:-

		MRB-7	MRB-8	MRB-1	GXR-5	SY-3
SiO ₂ : (%)	XRAL (Old)	47.7	74.5	71.1	38.9	-
	XRAL (New)	48.1	76.2	71.8	39.4	-
	expected value	49.5	76.7	72.2	42.1	-
Co: (ppm)	XRAL (Old)	11	2	6	26	2
	XRAL (New)	16	3	4	28	-
	expected value	53	4	5	30	12
Ni: (ppm)	XRAL (Old)	57	6	6	66	4
	XRAL (New)	64	6	8	62	-
	expected value	224	5	7	63	11
Cu: (ppm)	XRAL (Old)	49	3	8	190	17
	XRAL (New)	82	8	16	350	-
	expected value	80	5	14	360	16
Zn: (ppm)	XRAL (Old)	18	22	51	41	86
	XRAL (New)	22	20	55	44	-
	expected value	101	27	64	50	240
Ba: (ppm)	XRAL (Old)	150	450	100	1600	< 50
	XRAL (New)	60	620	100	1760	< 20
	expected value	60	545	290	1800	430

SiO₂ is acceptable at the 70% level but still poor at the 40-50% level. Co, Ni, and Zn show no significant change. Cu has improved and is now acceptable. Ba has improved in two cases but remains poor in one and bad in two other cases, overall it is not acceptable.

All samples (cf. Table C1) were analyzed at the University of Ottawa; those samples analyzed by X-ray Assay Laboratories Ltd., were re-analyzed because of low confidence in the accuracy of certain elements, particularly SiO_2 , and to achieve consistency within the data base; re-analysis was done on aliquots of the original rock pulp analyzed.

Major elements and Ba, Cr, Sr, Rb, Y, Zn and Ni in samples analyzed at the University of Ottawa were determined on a fused glass disc containing 1.500 g rock powder, 4.500 g lithium tetraborate, 0.500 g lithium carbonate, and 0.07 g ammonium nitrate, by means of a Phillips PW 1410 spectrometer and a peak-to-background ratio method. La, Ce, Sm, Eu, Tb, Yb, Hf and Th were determined by neutron activation; accuracy of this method is as follows: $\pm 5\%$ for La, Ce, Sm, Eu, Yb and Th; $\pm 10\%$ for Tb and Hf (C. R. Pride, written communication, 1982).

Total iron was reported as Fe_2O_3 . Individual volatiles or weight % loss on ignition were not determined.

Duplicate fusions were made of four samples (plus two samples from Marmora Township, not incorporated in this thesis). Seven reference control standards were analyzed. Assessment of accuracy, as determined by Dr. C. Riddle (written communication, 1982), is tabulated in Table D2. Table D3 is a compilation of precision estimates for the data.

Table D2. Assessment of accuracy of chemical analyses performed at the University of Ottawa (from C.Riddle, written communication, 1982).

Identified stds. are BCR, GSP, GA, GH all run several times.

All look good but may have been used in the calibration(?) -only poor values are:-

MAJORS BCR -1 : Na consistently low (3.0 for 3.3) but within expected variation.

GSP -1 : Al 14.8 for 15.3

GA : OK

GH : Mg 0.33 for 0.03

SY-3 : Mg 2.2 for 2.7 , Si 58.8 for 59.7

MRB-7 : Mg 7.5 for 8.2
Na 2.5 for 2.0
P 0.0 for 0.11

MRB-12 : Mg 11.1 for 12.0
Na 2.1 for 1.2

TRACES BCR-1 : Cr 30 for 15; Ni 20 for 10

GSP-1 : Cr 0 for 12; Ni 23 for 9
Zr(2) 366 for 500

GA : Cr 0 for 12; Ni 38 for 7

GH : Ba 90 for 22; Y 70 for 5, Zn 60 for 85

Table D2 (cont'd)

SY-3 : Ni 63 for 11; Zr 240 for 320, Ba 490 for 430, Ni 20 for 3
 MRB-7 : Zr 122 for 35, Sr 230 for 280
 MRB-12 : Ba 80 for 40; Zr 87 for 24; Sr 96 for 128, Zn 49 for 71
 Ni 194 for 260

CONCLUSIONS:

The major elements appear to be generally well determined by conventional XRF standards although the calibration for Mg and Na is suspect as unusually large inaccuracies are noted.

There are more problems with the trace elements. Ni and Cr are poor, especially at low level; this is a common problem with XRF determination of these elements because of their presence in the tube or instrument.

Four Zr values are poor, as is one Y - these have interferences from Sr and Rb and poor corrections may have been made. Some Ba values are high, while some Sr values are low.

Precision is generally excellent and overall a high standard of analysis was achieved.

Table D3. Precision at 99% confidence level for chemical analyses performed at the University of Ottawa (from J. R. Hartree, written communication, 1982).

	Concentration range				
	0.1-1%	1-10%	10-20%	20-50%	50-100%
SiO ₂					± 1.8
Al ₂ O ₃	± 15.0		± 2.0		
Fe ₂ O ₃ *		± 2.0	± 2.0		
MgO	± 25.0	± 2.7			
CaO	± 7.0		± 2.0		

	0.1-2%	2-5%
Na ₂ O	± 13.0	± 3.5
K ₂ O	± 3.0	± 1.0

	0.1-1%	1-3%
TiO ₂	± 3.0	± 1.0
P ₂ O ₅	± 10.0	
MnO	± 10.0	
S	± 10.0	

ppm	<20	10-40	>40
Ba	± 100%	± 50%	± 10%

ppm	<20	20-50	50-500	>500
Cr	± 100%	± 50%	± 15%	± 10%
Zr	± 100%	± 50%	± 15%	± 10%

ppm	<20	>20
Sr	± 100%	± 10%
Rb	± 100%	± 10%
Zn	± 100%	± 10%

ppm	<40	40-100	>100
Y	± 100%	± 25%	± 25%
Ni	± 100%	± 50%	± 10%

Fig.4

3 of

Fig.4

Ministry of
Natural
Resources

Hon. Alan W. Pope
Minister
W. T. Foster
Deputy Minister

ONTARIO GEOLOGICAL SURVEY

MAP. P. 2488

GEOLOGICAL SERIES - PRELIMINARY MAP

PRECAMBRIAN GEOLOGY
OF

BELMONT AND SOUTHERN METHUEN TOWNSHIPS

SOUTHERN ONTARIO

Scale 1:15 840

NTS Reference 31 C/5, 31 C/12
ODM-GSC Aeromagnetic Map 14G
ODM Geological Compilation Map None

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Parts of this publication may be quoted if credit is given and the material is properly referenced

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LOCATION MAP

Scale: 1:1 584 000
or 1 inch to 25 miles

LEGEND*

PHANEROZOIC
CENOZOIC
QUATERNARY

LEGEND

PHANEROZOIC

CENOZOIC

QUATERNARY

RECENT

Stream, lake and swamp deposits

PLEISTOCENE

Glacial, glaciofluvial, and glaciolacustrine deposits

UNCONFORMITY

PALEOZOIC

ORDOVICIAN

- 14a Red conglomerate, sandstone, siltstone, shale
- 14b Interlayered limestone, sandy limestone, dolomitic limestone, shale ("Pamela" member)
- 14c Grey, chalky-weathering limestone ("Leray-Lowville" member)

UNCONFORMITY

PRECAMBRIAN

LATE PRECAMBRIAN

METAMORPHOSED INTRUSIVE ROCKS*

FELSIC INTRUSIVE ROCKS

- 13a Massive biotite granite
- 13b Porphyritic granite
- 13c Foliated granite
- 13d Pegmatite, granite, aplite dykes
- 13e Fine-grained and/or porphyritic leucodiorite, trondhjemite, syenite, felsite

- 12 Biotite granodiorite, quartz monzonite

INTERMEDIATE TO MAFIC INTRUSIVE ROCKS

- 11a Diorite
- 11b Plagioclase-phyric diorite
- 11c Quartz diorite

INTRUSIVE CONTACT

- 10a Medium-grained to coarse-grained gabbro
- 10b Fine-grained gabbro
- 10c Plagioclase-phyric gabbro
- 10d Coarse-grained gabbro with 3-5 cm amphibole-rich clots
- 10e Biotite lamprophyre

GRENVILLE SUPERGROUP*

METASEDIMENTS

CLASTIC METASEDIMENTS

- 9a Cobble to granule, polymictic conglomerate, felsic and intermediate volcanic detritus dominant
- 9b Cobble to granule, polymictic conglomerate; siliceous sedimentary detritus dominant
- 9c Cobble to granule, polymictic conglomerate, mafic volcanic detritus dominant
- 9d Cobble to granule, polymictic conglomerate, carbonate sedimentary detritus dominant
- 9e Dark red sandstone, siltstone
- 9f Dark grey siltstone, claystone, graphitic claystone
- 9g Dark grey dolomitic marble, carbonate-bearing clastic metasediments

UNCONFORMITY (?)

CARBONATE METASEDIMENTS

- 8a Dolomitic marble
- 8b Calcitic marble
- 8c Interlayered calcitic, dolomitic marble
- 8d Dolomitic marble with abundant lenses and layers of chert

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Belopor

UNCONFORMITY (?)

CARBONATE METASEDIMENTS

- 8a Dolomitic marble
- 8b Calcitic marble
- 8c Interlayered calcitic, dolomitic marble
- 8d Dolomitic marble with abundant lenses and layers of chert
- 8e Tremolite marble
- 8f Skarn

INTERLAYERED CARBONATE AND SILICEOUS METASEDIMENTS

- 7a Thinly layered, interbedded marble and wacke or tuff
- 7b Interlayered dark marble, mudstone, chert
- 7c Carbonate-bearing wacke, mudstone
- 7d Interlaminated calcitic marble and siliceous clastic metasediments

SILICEOUS CLASTIC METASEDIMENTS

- 6a Arenite, wacke
- 6b Mudstone, sandy mudstone, phyllite, mica schist
- 6c Garnet-bearing schist
- 6d Cumingtonite-bearing schist
- 6e Magnetite-bearing schist
- 6f Interlayered cherty mudstone and chert
- 6g Pyritic, rusty-weathering mudstone, schist
- 6h Quartzofeldspathic schist, gneiss of probable sedimentary origin

LITHIC CLASTIC METASEDIMENTS

- 5a Lithic wacke, volcanic detritus dominant
- 5b Conglomerate, volcanic detritus dominant
- 5c Intermediate, mafic schist, gneiss of probable sedimentary origin

SILICEOUS CHEMICAL METASEDIMENTS

- 4a Chert
- 4b Magnetite-bearing chert
- 4c Magnetite ironstone

METAVOLCANICS

FELSIC METAVOLCANICS

- 3a Feldspar-phyric, quartz-feldspar-phyric extrusive rocks
- 3b Flow breccia
- 3c Pyroclastic breccia, tuff-breccia
- 3d Tuff, lapilli-tuff, lapillistone
- 3e Dykes, sills, small intrusions
- 3f Chlorite, and/or biotite-quartz-feldspar schist-gneiss of probable volcanic origin

INTERMEDIATE METAVOLCANICS

- 2a Flows
- 2b Pillowed flows, flow breccia
- 2c Pyroclastic breccia, tuff-breccia
- 2d Tuff, lapilli-tuff, lapillistone
- 2e Dykes, sills, small intrusions
- 2f Biotite, hornblende and/or chlorite schist of probable volcanic origin

MAFIC METAVOLCANICS

- 1a Flows
- 1b Amygdaloidal flows
- 1c Plagioclase-phyric flows
- 1d Pillowed flows, pillow breccia, hyaloclastite
- 1e Flow breccia
- 1f Pyroclastic breccia, tuff-breccia
- 1g Tuff, lapilli-tuff, lapillistone
- 1h Dykes, sills, small intrusions
- 1j Plagioclase-phyric dykes, sills, small intrusions
- 1k Chlorite schist, chlorite-amphibole schist, amphibole of probable volcanic origin
- 1m Flows of basaltic composition, typically plagioclase-phyric and amygdaloidal

4
st

MARCO

BELMONT METHUEN

LOCATION AND ACCESS

The map-area includes all of five lots of Methuen Township. Mines are situated in the south Belmont Township. Highway 7, Township, County Roads 44, the western, north-central, and numerous township, concess roads provide excellent access and Long Lakes in Methuen and Crowe Lakes in Belmont. Four lakes are only partially in

MINING AND EXPLORATION

Magnetite iron ore was explored and iron and gold have been mined in the area (Belmont, Cordova). has been explored for base metals. The only present metal producer and dumps at the Cordova Mine operated a quarry for properties in the area are described by Carter (1980).

GENERAL GEOLOGY

Approximately one-half of Belmont is composed of Precambrian rocks, predominantly limestone and conglomerate. The Paleozoic geology was mapped in 1979 as part of the Terrain Geology Section of the USGS. Thus the attention given the 1980 season was minimal. Between Precambrian and Paleozoic

The Precambrian stratigraphic group, are mostly volcanic

19 or

4
St

Gravel
Pit
Rush Point

MARGINAL NOTES

20 of

BELMONT AND SOUTHERN METHUEN TOWNSHIPS

LOCATION AND ACCESS

The area includes all of Belmont Township and the southernmost part of Methuen Township. The towns of Havelock and Cordova are situated in the southwest and northeast parts, respectively, of Belmont Township. Highway 7 traverses the southern part of the Belmont Township. County Roads 44, 46 and 48 provide access to, respectively, the western, north-central, and southeastern sections of the map-area. Township, concession, fire access, farm, and private cottage roads provide excellent access to most of the areas, as do Oak, South Bay, and Round Lakes in Methuen Township and Round, Cordova, Belmont, and We Lakes in Belmont Township. The rivers connecting the latter two are only partially navigable.

Mining and Exploration Activity

Iron ore was exploited as early as 1820 at the Blairton Mine, and gold have been mined at various times since the turn of the century (Belmont, Cordova, Ledyard Deposits). More recently the area has been explored for base and precious metals and industrial minerals. The present metal production is the recovery of gold from tailings dumps at the Cordova Mine, by Laisir Limited. 3M Canada Incorporated operates a quarry for the production of roofing granules. Mineral resources in the area are described in more detail below and also by (1980).

General Geology

Mostly one half of Belmont Township is underlain by Paleozoic rocks, predominantly limestone with minor basal sandstone and conglomerate. The Paleozoic geology of Belmont and Methuen Townships was mapped in 1979 as part of a regional survey by the Engineering and Geology Section of the Ontario Geological Survey (Carson 1979). The attention given the Paleozoic rocks in the map-area during the mapping season was minimal, save for the delineation of the contact between Precambrian and Paleozoic rocks.

The Precambrian stratified rocks, which belong to the Grenville Supergroup, are mostly volcanic flows and fragmental deposits that range in composition from basalt to dacite and rhyolite. Twenty percent of the

Within the marbles are lenses and irregular masses of interlayered carbonate and siliceous metasediments and lithic clastic (volcanic) metasediments. The most notable occurrence of the latter rock type is west of Cordova Mines. Here the rocks are mainly conglomerate and wacke with felsic and intermediate volcanic detritus dominant, intermediate to mafic schists crop out peripherally to the conglomerates.

Within the marble unit east and northeast of Belmont Lake are layers (Unit 7) comprising interlaminated calcitic marble and siliceous clastic metasediments, and interlayered dark marble and mudstone or chert. Thinly layered interbedded wacke or tuff and carbonate-bearing wacke and mudstone are minor. The rocks underlying the northeastern and central parts of Belmont Lake are mainly polymictic, granule to cobble, commonly clast-supported conglomerate, with subordinate sandstone and mudstone. The predominant clast types are felsic volcanic rocks and chert, carbonate sedimentary rocks, intermediate and mafic volcanic types are less common. Distinction between some of the rocks of this unit and those of Unit 6 is tenuous, in this area they may be stratigraphic equivalents. Most of the rocks of Unit 9 contain abundant hematite, magnetite, and carbonate in the matrix. These sediments were probably derived from a nearby weathered source terrain and deposited in a shallow marine (emergent?) environment. On Crowe River Point on Belmont Lake and on the east side of Big Island, thin units of dolomitic marble crop out adjacent to, and at least in some places, in fault contact with, the fine to coarse clastic rocks of Unit 9. These rocks contain abundant silica segregations, regularly laminated on a small scale, which are probably algal mats. Marbles containing these features also occur as subangular clasts in Unit 9 conglomerates.

Lying within Unit 9 sandstones and siltstones on the east shore of Belmont Lake is a pyroclastic layer about 25 m wide. It is uniform, possessing no evident layering. The presence of quartz and feldspar euhedra with flammé-like fragments suggests it may be an ash-flow deposit representing the final events of Cycle III volcanism.

In the area immediately east of the ash-flow deposit, a conglomerate containing felsic volcanic and carbonate sedimentary clasts, is conformably overlain by mafic volcanic rocks representing the base of a fourth volcanic cycle. The greatest area of exposure of the rocks of this cycle is east and southeast of Belmont Lake. The westernmost rocks of the cycle

ECONOMIC

Metallic Minerals

Four types of

a) Stratiform mineralization in parts of Cycle III schists, pyrrhotite, and grained lithology of pyrite. The Young schists are schists. The Young schists are the principal source of 300 million values are Young, per

b) Stratiform mineralization in Cycle III within 0.5 km of Belmont Lake, about 10% of the area may be traced to fine-grained of similar to the vicinity of Belmont Lake bearing chert.

Both from exhalation

c) Stratiform mineralization along the Crowe River Mine (3).

Round 655 Lake

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ECONOMIC GEOLOGY¹

Metallic Minerals

Four types of occurrences have been recognized in Belmont Township

a) *Stratiform Sulphide Mineralization*. Concentrations of sulphide mineralization in volcanogenic metasediments occur within the upper parts of Cycles I, II and III. Fine-grained, rusty-weathering, siliceous graphitic schist, derived from siltstone, contains up to 25% pyrite and/or pyrrhotite with sphalerite and chalcopyrite. Associated strata are fine-grained lithic wackes and/or tuffs with cherty layers and lesser amounts of pyrite. Examples include the Round Lake sulphide occurrence (15), rusty schists within Cycle II south of Little Whitney Lake, and pyritic schists immediately below and above the felsic tuff unit (3e) of Cycle II. The Young-Cumming (Deer Lake) property (18) east of Cordova Lake is the principal occurrence. There the sulphidic schists attain a thickness of 300 m in a D₁ fold hinge, and are continuously mineralized, average values are 0.5% Zn, 0.05% Cu, and 0.2 ounce/ton Ag (Carter, 1980, C.R. Young, personal communication). A surface grab sample from the property assayed 3.0% Zn. At this property and within Cycle III basalt, garnet-cummingtonite schists also exhibit anomalous base and precious metal values.

b) *Stratiform Iron Oxides*. Magnetite-bearing cherts are found intercalated with mafic flows, breccias, and epiclastic sediments in Cycle III within 0.5 km of the top (east side) of the unit. At the Young-Purdy Occurrence (20), the rock is granular, centimeter-layered and averages about 10% magnetite by visual estimation. The unit is 15 m thick and can be traced along strike for 400 m. The immediately enclosing rock is a fine-grained chlorite schist, with or without garnet. Magnetite-silica rocks of similar types are locally present at the same stratigraphic level, from the vicinity of the foot of Cordova Lake, south to Breckenridge Bay on Belmont Lake, where drill holes penetrated magnetite- and hematite-bearing cherts below Paleozoic cover.

Both sulphide and oxide-rich stratiform deposits appear to result from exhalative activity associated with volcanism.

c) *Skarn Deposits*. Contact skarns were formed in calcite marble along the western margin of the Cordova gabbro, at the Belmont Iron Mine (3). The Blairton Mine (5) is similar, but may be related to a separate

24 OF

RIVER

MARMORA TP

BELMONT TP

Line-

Freeman

- 1g Tuff, lapilli-tuff, lapillistone
- 1h Dykes, sills, small intrusions
- 1j Plagioclase-phyric dykes, sills, small intrusions
- 1k Chlorite schist, chlorite-amphibole schist, amphibole of probable volcanic origin
- 1m Flows of basaltic composition, typically plagioclase-phyric and amygdaloidal

NOTES

- a) This is basically a field legend and may be changed as a result of subsequent laboratory investigations
- b) Succession of intrusive rock units is not in general established
- c) Numerical succession does not imply order of deposition, many units are repeated stratigraphically or are laterally equivalent

SYMBOLS

	Fault
	Small bedrock outcrop
	Area of bedrock outcrop
	Bedding, top unknown (inclined, vertical)
	Bedding, top known (inclined, vertical, overturned)
	Bedding, top (arrow) from grain gradation
	Bedding, top (arrow) from cross-bedding
	Lava flows, top (arrow) from pillow shape and packing
	Schistosity (inclined, vertical)
	Parallel schistosity and layering (inclined, vertical)
	Foliation (horizontal, inclined, vertical)
	Lineation with plunge
	Geological boundary, observed
	Geological boundary, position interpreted
	Joints (inclined, vertical)
	Minor fold with axis and plunge, vergence shown by shape of symbol
	Axial surface trace of antiform, synform
	Quartz vein
	Shaft
	Quarry

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SOURCES OF INFORMATION

Base map derived from National Topographic Series Sheets 31 C/5 and 31 C/12, with additions by J. R. Bartlett and M. J. Murray

Assessment Files Research Office, Ontario Geological Survey, Toronto

Personal files of C. R. Young, Havelock.

Some contacts in northern Belmont and southern Methuen Townships are based in part on D. F. Hewitt (1960), E. Heidecker (1963), and R. V. Beavon (unpublished manuscript 1964)

Magnetic declination is 10°27'W.

Geology is not tied to surveyed lines.

CREDITS

The Precambrian stratigraphic group, are mostly volcanic in composition from basalt to area is underlain by rock with less abundant clastics. The attention given the 1980 season was minimal between Precambrian and Paleozoic.

The Precambrian stratigraphic group, are mostly volcanic in composition from basalt to area is underlain by rock with less abundant clastics. The attention given the 1980 season was minimal between Precambrian and Paleozoic.

The volcanic rocks can be felsic volcanic cycles, two within the map-area. Cycle I, northern boundary of Belmont, because of complex foliation, massive, plagioclase-phyric, contain hyaloclastites and strata two horizons, with a maximum date and felsic parts of the and probably reworked pyroclastic. Felsic tuff is the dominant felsic pyroclastic rocks range as, with local pyroclastic both lithic fragments and, may represent ash-flow deposits in the tuffs toward the top of township, in the vicinity of Little both calcitic and dolomitic. cap Cycle I. About 1 km north of cycles I and II is marked by a epiclastic metasediments of thick.

The maximum thickness of the base of the cycle consists of hyaloclastites, with minor and tuff-breccias. Within the Creek, lies a distinctive rusty, tonite, with or without garnet, places is a calcitic and dolomitic km north of the northeast end, north are thin mafic to intermediate felsic portion of Cycle II is mafic flows, which typically of in northern Belmont and southern, intercalated with intermediate overlying unit, which is contained in Methuen Township, is a distinct wacke and mudstone, and of thickness of Cycle II. Typical lithic tuff coarsens to the north, the beds are pyritic. Cycle III, being pyritic siltstone, which is and is intercalated with mudstone.

Cycle III is much thicker than the basal part of the cycle is and pillowed flows and hyaloclastites. Flow and pillow breccias are abundant in the flows. Mafic tuff horizons, as well as sparse netite-cummingtonite-bearing flows in the middle portion of the. These dykes grade magnetite ironstone up to close to the top of the mafic has been observed along a local reports may extend further.

Immediately overlying the Breckenridge Bay area of Belmont of intermediate biotite-hornblende, locally it contains dispersed. These rocks separate the mafic pillowed volcanic flows and

was mapped in 1979 as part of a regional survey by the Engineering and Terrain Geology Section of the Ontario Geological Survey (Carson 1979). Thus the attention given the Paleozoic rocks in the map-area during the 1980 season was minimal, save for the delineation of the contact between Precambrian and Paleozoic rocks.

The Precambrian stratified rocks, which belong to the Grenville Supergroup, are mostly volcanic flows and fragmental deposits that range in composition from basalt to dacite and rhyolite. Twenty percent of the area is underlain by rock clearly of sedimentary origin, mainly marble with less abundant clastics (the distinction between pyroclastic and epiclastic units is difficult in much of the quartzofeldspathic successions) and siliceous chemical precipitates. The layered rocks have been deformed during at least two episodes, regionally metamorphosed and intruded by plutons that range in composition from gabbro to granite. All intrusive rocks in the area have been metamorphosed. In these notes non-metamorphic (protolith) terms are used where they are concise and can be assigned with confidence.

The volcanic rocks can be assigned to at least three distinct mafic to felsic volcanic cycles, two additional cycles are present but incomplete within the map-area. Cycle I is located between Round Lake and the northern boundary of Belmont Township. Its extent is currently speculative because of complex folding. The base of Cycle I is represented by massive, plagioclase-phyric, and amygdaloidal mafic flows which locally contain hyaloclastites and structures resembling pillows. These occupy two horizons, with a maximum thickness of 300 to 350 m each. Intermediate and felsic parts of the cycle are expressed solely as pyroclastic and probably reworked pyroclastic rocks, which typically, are intercalated. Felsic tuff is the dominant lithology, although both intermediate and felsic pyroclastic rocks range from tuffs through lapilli-tuffs to tuff-breccias, with local pyroclastic breccias. The felsic tuffs commonly contain both lithic fragments and, locally, silicified pumiceous fragments, some may represent ash-flow deposits. Magnetite tends to be more common in the tuffs toward the top of the cycle. In the north-central part of the township, in the vicinity of Little Whitney Lake, a marble unit consisting of both calcitic and dolomitic members, and bearing tremolite, appears to cap Cycle I. About 1 km north of Round Lake the contact between Cycles I and II is marked by a 50 m thickness of rusty-weathering, cherty, epiclastic metasediments containing a massive pyritic chert horizon 1-2 m thick.

The maximum thickness of the Cycle II metavolcanics is 1000 m. The base of the cycle consists of mafic pillowed and massive flows and hyaloclastites, with minor amygdaloidal and plagioclase-phyric flows, and tuff-breccias. Within the mafic base of Cycle II west of Whitney Creek lies a distinctive rusty mudstone unit characterized by cumingtonite, with or without garnet and magnetite. Directly overlying this unit in places is a calcitic and dolomitic marble unit which pinches out about 4 km north of the northeast end of Round Lake. Overlying this marble in the north are thin mafic to intermediate massive flows, north of the marble the felsic portion of Cycle II is directly underlain by massive and pillowed mafic flows, which typically contain large porphyroblasts of hornblende. In northern Belmont and southern Methuen Townships the flows are intercalated with intermediate, largely fragmental metavolcanics. The overlying unit, which is continuous from Seright Bay northward into Methuen Township, is a distinctive felsic tuff, which probably includes lithic wacke and mudstone, and constitutes one-third to one-half of the total thickness of Cycle II. Typically fine-grained and cherty in the south, this lithic tuff coarsens to the north. Toward the stratigraphic top of this unit the beds are pyritic. Cycle II is capped by a thin zone of rusty-weathering pyritic siltstone, which is continuous south of Lost Lake; it thickens and is intercalated with mudstone east of Seright Bay.

Cycle III is much thicker than I or II. The mafic unit which constitutes the basal part of the cycle is about 3.5 km thick and comprises massive and pillowed flows and hyaloclastites, in flow units 20 m to 70 m thick. Flow and pillow breccias are developed locally. This unit is best exposed south of Lost Lake and on Cordova Lake. Cherty space fillings are locally abundant in the flows. Magnetitic intermediate and, more rarely, felsic tuff horizons, as well as sparse magnetite, magnetite-garnet, and magnetite-cumingtonite-bearing mudstones are intercalated with the mafic flows in the middle portion of the mafic unit. In the upper part, fine- to medium-grained, locally plagioclase-phyric mafic dikes cut the mafic metavolcanics. These dykes grade in places into gabbroic rocks. A quartz-magnetite ironstone up to 20 m thick is present within chlorite schist close to the top of the mafic unit, near the north end of Belmont Lake. It has been observed along a strike length of 2 km, and on the basis of local reports may extend further north.

Immediately overlying the mafic volcanic rocks of Cycle III in the Breckenridge Bay area of Belmont Lake is a stratum, up to 200 m thick, of intermediate biotite-hornblende-plagioclase schist. This stratum probably represents clastic sediments derived from a volcanic source, as locally it contains dispersed intermediate and felsic volcanic clasts. These rocks separate the mafic volcanic rocks from intermediate, locally pillowed volcanic flows and from predominantly dolomitic marble which

Belmont Lake is a pyroclastic layer about 25 m wide. It is uniform, possessing no evident layering. The presence of quartz and feldspar euhedra with flammé-like fragments suggests it may be an ash-flow deposit representing the final events of Cycle III volcanism.

In the area immediately east of the ash-flow deposit, a conglomerate containing felsic volcanic and carbonate sedimentary clasts is conformably overlain by mafic volcanic rocks representing the base of a fourth volcanic cycle. The greatest area of exposure of the rocks of this cycle is east and southeast of Belmont Lake. The westernmost rocks of the cycle are typically amygdaloidal and/or plagioclase-phyric flows of basaltic composition. About 2 km east of Belmont Lake highly amygdaloidal blocky flows with extensive flow-top breccias are common. Intermediate tuff-breccias are locally intercalated. Massive and amygdaloidal flows predominate west of the Crowe River, north of Crowe Lake. This cycle probably formed in a dominantly subaerial environment, as opposed to a submarine environment for Cycles I, II, and III. Evidence for this contention includes an absence of pillow structures, the presence of abundant oxide minerals throughout the cycle, a proliferation of generally large amygdules, the presence of blocky flows and abundant flow breccias.

In the region of Oak Lake and Long Lake in southern Methuen Township there occur intermediate and felsic tuffs and epiclastic rocks with rare narrow mafic flows. Previously mapped as meta-arkoses (Hewitt 1960), these metavolcanics probably belong to a cycle which precedes Cycle I, although their stratigraphic position is questionable because of polyphase folding.

Metamorphosed gabbroic and associated intrusive rocks are important in the map-area because the Cordova gabbro is directly related to the formation of most of the previously-mined metallic deposits. The largest mafic intrusive body in the map-area, it exhibits rhythmic layering near its north contact. It intruded a marble unit, which has little surficial expression, to produce skarn deposits such as at the Belmont and Blairton Iron Mines. South of the Town of Cordova Mines the gabbro is locally schistose and cut by mineralized quartz and quartz-ankerite veins. South of the site of the Ledyard Gold Mine the veins become progressively smaller and fewer. Most gabbro occurrences in the map area are similar lithologically to the Cordova gabbro. They are generally medium to coarse, locally very coarse-grained, and consist mainly of amphibole and plagioclase. Fine-grained varieties are typically marginal and are transitional to dykes, such as those south of Cordova Lake. Notable occurrences of gabbro and diorite other than the Cordova gabbro crop out on, and north of, Round Lake, where they intrude intermediate and felsic tuffs, and north of Long Lake, where a large diorite body only partly lies within the map-area.

Granitic rocks, mainly pink, biotite leucogranite and porphyritic granite are confined mainly to the northwestern part of the map-area, where they have intruded felsic and intermediate volcanic rocks. Around the periphery of the diorite body in southwestern Methuen Township, granite grades to diorite through an intervening granodiorite-quartz monzonite zone. On the western margin of the Cordova gabbro, the mafic rocks and volcanic wallrock are intruded and brecciated by heterogeneous, fine-grained leucodiorite to porphyritic granite.

STRUCTURE AND METAMORPHISM | 26 of

The southwestern part of the area resembles a homocline, with rock units striking roughly northerly and dipping moderately to steeply toward the east. This terrain is bounded on the west and north by deformed cleavage and layering, and have a weaker axial-plane crenulation cleavage. They increase in size from hand specimen to outcrop-scale in the south-east, to map-scale in northwest Belmont and southern Methuen Townships. A regional curvature in their axial surface trends is probably related to a third, open folding. D_1/D_2 cleavage intersections and D_2 minor fold axes form a prominent lineation, generally east-trending, which has a major reversal only in the doubly-plunging D_2 antiform of Oak Lake. Pillow orientation in lavas and grain gradation in sediments demonstrate that the successive volcanic cycles become younger eastward (except in the areas of map-scale D_2 folds), and thus lie mainly on a single limb of a D_1 fold. The conglomerates and sandstones of Belmont Lake, however, contain several northerly-striking axial surface traces, locally they appear to lie in discordant contact with adjacent metasediments and metavolcanics.

No major faults were detected with certainty. The aforementioned apparent truncation of rock units along the north-trending contact between Cycle III mafic volcanic rocks, and intermediate volcanic rocks and carbonate and siliceous sedimentary rocks in the Cordova Lake-Belmont Lake area may represent a pre- D_2 thrust fault. Post- D_2 movements are locally important. The contact between the dolomitic marble and the conglomerate at Crowe River Point is a fault. The contacts between these rock types on Big Island and Birch Island may also be faulted. Parts of the west contact of the Cordova metagabbro appear to be faulted, and east-southeast to east-northeast striking fractures in the gabbro, with parallel schistosity, host mineralized quartz-ankerite veins

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be traced along strike for 400 m. The immediately enclosing rock is a
fine-grained chlorite schist, with or without garnet. Magnetite-silica rocks
of similar types are locally present at the same stratigraphic level, from
the vicinity of the foot of Cordova Lake, south to Breckenridge Bay on
Belmont Lake, where drill holes penetrated magnetite- and hematite-
bearing cherts below Paleozoic cover

Both sulphide and oxide-rich stratiform deposits appear to result
from exhalative activity associated with volcanism

c) *Skarn Deposits* Contact skarns were formed in calcite marble
along the western margin of the Cordova gabbro, at the Belmont Iron
Mine (3). The Blairton Mine (5) is similar, but may be related to a sepa-
rate gabbro body south of the Cordova intrusion. The skarns are dense,
fine-grained rocks comprising garnet, pyroxene, amphibole, epidote,
magnetite, pyrite, pyrrhotite, and carbonate, with minor chalcophyrite. At
Blairton the skarn is 70 m wide and at least 400 m long. At the Crowe
River iron deposit (7) massive hematite occurs within the gabbro, and
marlite has been discovered in the river and field immediately west (C R
Young, personal communication 1981). Magnetic anomalies south of the
Blairton Mine have been investigated, the Pershing Occurrence (13)
contains magnetite skarns at 40 m depth immediately below Paleozoic
cover

d) *Vein Deposits* Quartz-carbonate veins with pyrite, gold, and
silver mineralization occupy tabular chlorite schist zones in the Cordova
gabbro, 0.4 to 10 m or more in width, and striking easterly to southeast-
erly. These have been mined at the Cordova (6) and Ledyard (11) de-
posits. At Cordova the average grade was 0.19 ounce/ton Au, and work-
ings extended to at least 270 m depth. Gold is presently being re-
covered from dumps by Laisir Limited of Havelock. Further data are re-
ported by Carter (1980). Anomalous gold assays were obtained from
samples of quartz veins collected during the present survey, from veins
in metabasalt, in Cycle I north of Little Whitney Lake, and Cycle III at
Mine Bay. It is probable that all of these veins were deposited by circula-
ting metamorphic fluids which concentrated metals from the mafic
rocks themselves

Galena occurrences were reported from marble in southeastern Me-
thuen Township, and east of Belmont Lake, one kilometer north of Rock-
dale, minor chalcophyrite is reported to exist in Cycle IV basalt. These oc-
currences were sought, but not found during this survey

Non-Metallic Minerals:

Three rock types are of interest

a) *Metabasalt* Metabasalt of Cycle IV is quarried by 3M Canada
Incorporated near Preneveau (16) for roofing granules. Medium-grained
Cordova gabbro to the northeast (Crowe River Trap Rock, 8) has been
found suitable for road metal but not exploited

b) *Granite* Granite has been quarried as recently as 1978 (Bel-
mont Granite, 2) in northwestern Belmont Township. It is a massive, pink,
medium-grained biotite granite, locally with weak foliation. Massive dior-
ite has been drilled in the Horse Lake area (10), southwest of Methuen
Township

c) *Marble* Both calcitic and dolomitic marble have been ex-
plored by drilling for high-purity deposits suitable for chemical and pig-
ment uses. The principal occurrences are Belmont Calcite (Whitney) (1)
and Vansickle (17) at the top of Cycle I, and Round Lake Dolomite (14) in
Cycle II. Paleozoic limestone near Beloprine Creek (4) has also been
drilled as a potential high-purity calcite deposit

RECOMMENDATIONS

Base and precious metal potential of the volcanogenic metasediments
warrants further exploration. Suitable grade and tonnage are most likely
to be encountered where beds at the top of a volcanic cycle have been
involved in D₁, D₂ interference patterns, as has occurred east of Cordova
Lake. Further vein gold mineralization may be encountered within, and
possibly adjacent to the Cordova metagabbro, and the possibility of
analogous deposits within mafic metavolcanics should not be ignored.
The proximity of the area to urban centres makes industrial mineral pro-
duction favourable, particularly the relatively high-value specialties such
as high-purity carbonates for chemical production

¹Unless otherwise acknowledged, all information is from the Assessment Files in
the Assessment File Research Office, Ministry of Natural Resources, Toronto.
(communication). A surface grab sample from the property assayed 3.0% Zn. At
this property and within Cycle III basalt, garnet-cummingtonite schists also exhibit
anomalous base and precious metal values.

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III

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Campsite
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HASTINGS
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	Geological boundary position interpreted
	Joints (inclined vertical)
	Minor fold with axis and plunge, vergence shown by shape of symbol
	Axial surface trace of antiform, synform
	Quartz vein
	Shaft
	Quarry

SOURCES OF INFORMATION

Base map derived from National Topographic Series Sheets 31 C/5 and 31 C/12, with additions by J. R. Bartlett and M. J. Murray

Assessment Files Research Office, Ontario Geological Survey, Toronto

Personal files of C. R. Young, Havelock

Some contacts in northern Belmont and southern Methuen Townships are based in part on D. F. Hewitt (1960), E. Heidecker (1963), and R. V. Beavon (unpublished manuscript 1964)

Magnetic declination is 10°27'W

Geology is not tied to surveyed lines

CREDITS

Geology by J. R. Bartlett, J. M. Moore Jr., M. J. Murray, and assistants, 1980

Every possible effort has been made to ensure the accuracy of the information presented on this map, however, the Ontario Ministry of Natural Resources does not assume any liability for errors that may occur. Users may wish to verify critical information, sources include both the references listed here, and information on file at the Resident or Regional Geologist's office and the Mining Recorder's office nearest the map area

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Issued 1982

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Bartlett, J. R., Moore, J. M. Jr., and Murray, M. J.
1982. Precambrian Geology of Belmont and Southern Methuen Townships, Southern Ontario, Ontario Geological Survey Map P.2488,

Geological Series Preliminary Map, Scale 1:15 840 or 1 inch to ¼ mile. Geology 1980.

places is a calcitic and dolomitic material. The mafic units are thin mafic to intermediate. The felsic portion of Cycle II is directly overlain by mafic flows, which typically contain quartz. In northern Belmont and southern Methuen Townships, the felsic unit is continuous from the mafic unit. This unit is a distinctive felsic unit, wacke and mudstone, and constitutes the thickness of Cycle II. Typically the mafic unit coarsens to the north. Toward the south the beds are pyritic. Cycle II is capped by pyritic siltstone, which is continuous and is intercalated with mudstone east of the lake.

Cycle III is much thicker than Cycle II. The basal part of the cycle is about 30 m thick and consists of pillowed flows and hyaloclastites. Flow and pillow breccias are developed in the south of Lost Lake and on Cordova Lake. Abundant in the flows. Magnetite ironstone tuff horizons, as well as sparse magnetite-cummingtonite-bearing mudstone, are present in the middle portion of the mafic unit. Grained, locally plagioclase-phyllosilicate volcanics. These dykes grade in place to magnetite ironstone up to 20 m thick. Close to the top of the mafic unit, near the lake, has been observed along a strike. Local reports may extend further north.

Immediately overlying the mafic unit is the Breckenridge Bay area of Belmont Township. This area represents clastic sediments of intermediate biotite-hornblende-plagioclase. Locally it contains dispersed intermediate volcanics. These rocks separate the mafic volcanic unit from the pillowed, volcanic flows and from the felsic unit in the northern part of Belmont Lake. A mafic volcanic unit directly overlies the mafic volcanic unit, separating the mafic volcanic rocks from Belmont Lake, and from the intermediate felsic clastic sediments, and from the south of Cordova Lake, may be tectonically discordant. On the apparent discordance between volcanic rocks to the south and west of Belmont Lake, and are probably equivalent to the felsic unit. These rocks are overlain by intermediate metavolcanic schist, some of which are pyritic. The mafic unit is schist, and garnet-cummingtonite schist, in part, although volcanic exposure significantly to their formation. From tuff to coarse lapilli-tuff, occur metasediments.

Concordantly overlying the intermediate felsic unit are intercalated, relatively thin marble units, some with cherty lenses. These are equivalent to the marble on the northeast of Belmont Lake, the maximum thickness is 2-5 km, however internal deformation has thickened the unit.

with or without garnet and magnetite. Directly overlying this unit in the northeast is a calcitic and dolomitic marble unit which pinches out about 4 km north of the northeast end of Round Lake. Overlying this marble in the north are thin mafic to intermediate massive flows, north of the marble the felsic portion of Cycle II is directly underlain by massive and pillowed mafic flows, which typically contain large porphyroblasts of hornblende. In northern Belmont and southern Methuen Townships the flows are intercalated with intermediate, largely fragmental metavolcanics. The overlying unit, which is continuous from Seright Bay northward into Methuen Township, is a distinctive felsic tuff, which probably includes lithic tuff and mudstone, and constitutes one-third to one-half of the total thickness of Cycle II. Typically fine-grained and cherty in the south, this tuff coarsens to the north. Toward the stratigraphic top of this unit the beds are pyritic. Cycle II is capped by a thin zone of rusty-weathered pyritic siltstone, which is continuous south of Lost Lake, it thickens and is intercalated with mudstone east of Seright Bay.

Cycle III is much thicker than I or II. The mafic unit which constitutes the basal part of the cycle is about 3.5 km thick and comprises massive pillowed flows and hyaloclastites, in flow units 20 m to 70 m thick. Lava and pillow breccias are developed locally. This unit is best exposed south of Lost Lake and on Cordova Lake. Cherty space fillings are locally abundant in the flows. Magnetitic intermediate and, more rarely, felsic horizons, as well as sparse magnetite, magnetite-garnet, and magnetite-cummingtonite-bearing mudstones are intercalated with the mafic flows in the middle portion of the mafic unit. In the upper part, fine- to medium-grained, locally plagioclase-phyric mafic dikes cut the mafic metavolcanics. These dykes grade in places into gabbroic rocks. A quartzite ironstone up to 20 m thick is present within chlorite schist close to the top of the mafic unit, near the north end of Belmont Lake. It has been observed along a strike length of 2 km, and on the basis of local reports may extend further north.

Immediately overlying the mafic volcanic rocks of Cycle III in the Seright Bay area of Belmont Lake is a stratum, up to 200 m thick, of intermediate biotite-hornblende-plagioclase schist. This stratum probably represents clastic sediments derived from a volcanic source, as locally it contains dispersed intermediate and felsic volcanic clasts. These rocks separate the mafic volcanic rocks from intermediate, locally pillowed, volcanic flows and from predominantly dolomitic marble which, in the northern part of Belmont Lake and north along the Crowe River, directly overlies the mafic volcanic rocks. The north-trending contact separating the mafic volcanic rocks from the marble north and west of Belmont Lake, and from the intermediate and mafic volcanic rocks, siliceous clastic sediments, and dominantly calcitic marble east and south of Cordova Lake, may be tectonic. This deduction is based largely on the apparent discordance between the latter rock units and the mafic volcanic rocks to the south and west of Cordova Lake. The mafic volcanic rocks occurring to the southeast of Cordova Lake resemble greatly those of Cycle II and are probably equivalent to those of Cycle III. They are apparently overlain by intermediate metavolcanics, wacke, and fine-grained mica schist, some of which are pyritic. These rusty-weathering mudstones, mica schist, and garnet-cummingtonite schist, are believed to be epiclastic in part, although volcanic exhalative processes probably contributed significantly to their formation. Felsic lithic pyroclastic rocks, ranging from tuff to coarse lapilli-tuff, occur at or near the top of the siliceous metasediments.

Concordantly overlying the intermediate volcanic rocks southeast of Cordova Lake are intercalated, relatively pure, calcitic and dolomitic marble units, some with cherty lenses and layers. These rocks are probably equivalent to the marble on the northwest shore of Belmont Lake. In the northeast of Belmont Lake, the maximum apparent thickness is approximately 2.5 km, however internal deformation may have considerably thickened the unit.

granite are confined mainly to the northwestern part of the map area where they have intruded felsic and intermediate volcanic rocks. Around the periphery of the diorite body in southwestern Methuen Township granite grades to diorite through an intervening granodiorite-quartz monzonite zone. On the western margin of the Cordova gabbro, the mafic rocks and volcanic wallrock are intruded and brecciated by heterogeneous, fine-grained leucodiorite to porphyritic granite.

STRUCTURE AND METAMORPHISM

The southwestern part of the area resembles a homocline, with rock units striking roughly northerly and dipping moderately to steeply toward the east. This terrain is bounded on the west and north by deformed cleavage and layering, and have a weaker axial-plane crenulation cleavage. They increase in size from hand specimen to outcrop-scale in the south-east, to map-scale in northwest Belmont and southern Methuen Townships. A regional curvature in their axial surface trends is probably related to a third, open folding. D_1/D_2 cleavage intersections and D_2 minor fold axes form a prominent lineation, generally east-trending, which has a major reversal only in the doubly-plunging D_2 antiform of Oak Lake. Pillow orientation in lavas and grain gradation in sediments demonstrate that the successive volcanic cycles become younger eastward (except in the areas of map-scale D_2 folds), and thus lie mainly on a single limb of a D_1 fold. The conglomerates and sandstones of Belmont Lake, however, contain several northerly-striking axial surface traces, locally they appear to lie in discordant contact with adjacent metasediments and metavolcanics.

No major faults were detected with certainty. The aforementioned apparent truncation of rock units along the north-trending contact between Cycle III mafic volcanic rocks, and intermediate volcanic rocks and carbonate and siliceous sedimentary rocks in the Cordova Lake-Belmont Lake area may represent a pre- D_2 thrust fault. Post- D_2 movements are locally important. The contact between the dolomitic marble and the conglomerate at Crowe River Point is a fault. The contacts between these rock types on Big Island and Birch Island may also be faulted. Parts of the west contact of the Cordova metagabbro appear to be faulted, and east-southeast to east-northeast striking fractures in the gabbro, with parallel schistosity, host mineralized quartz-ankerite veins.

Rock units in the area are not well-suited to the precise mapping of isograds. Decreasing preservation of primary structures, and increasing coarseness of grain, indicate a westerly increase of metamorphic grade. This gradient is supported by an abundance of chlorite and actinolite in mafic rocks east of Cordova Lake, giving way to a hornblende-plagioclase assemblage further west. Coarse tremolite with calcite similarly takes the place of quartz dolomite. Kyanite was observed north of Little Whitney Lake. In the extreme north part of the map-area muscovite is commonly present in the felsic tuffs, however its incipient breakdown is apparent in the Long Lake area, coincidental with the increasing abundance of granitic veinlets, dykes and larger granite bodies south and west of South Lake.

Metamorphic conditions are thus considered to vary from upper greenschist facies in east-central Belmont Township, to middle-upper amphibolite facies in southern Methuen Township. There is thus a positive correlation between the size of D_2 folds and metamorphic grade.

All the intrusive rocks have been metamorphosed. The granites of southwestern Methuen Township, however, do not show strain or recrystallization comparable to that of the enclosing rocks, and thus appear to have been emplaced late in the tectonic history.

1) Granite - Granite has been quarried in Belmont Township. It is a massive pink medium-grained biotite granite, locally with weak foliation. Massive diorite has been drilled in the Horse Lake area (10), southwest of Methuen Township.

c) **Marble** Both calcitic and dolomitic marble have been explored by drilling for high-purity deposits suitable for chemical and pigment uses. The principal occurrences are Belmont Calcite (Whitney) (1) and Vansickle (17) at the top of Cycle I, and Round Lake Dolomite (14) in Cycle II. Paleozoic limestone near Beloporne Creek (4) has also been drilled as a potential high-purity calcite deposit.

RECOMMENDATIONS

Base and precious metal potential of the volcanogenic metasediments warrants further exploration. Suitable grade and tonnage are most likely to be encountered where beds at the top of a volcanic cycle have been involved in D₂ interference patterns, as has occurred east of Cordova Lake. Further vein gold mineralization may be encountered within, and possibly adjacent to the Cordova metagabbro, and the possibility of analogous deposits within mafic metavolcanics should not be ignored. The proximity of the area to urban centres makes industrial mineral production favourable, particularly the relatively high-value specialities such as high-purity carbonates for chemical production.

Unless otherwise acknowledged, all information is from the Assessment Files in the Assessment File Research Office, Ministry of Natural Resources, Toronto (communication). A surface grab sample from the property assayed 3.0% Zn. At this property and within Cycle III basalt, garnet-cummingtonite schists also exhibit anomalous base and precious metal values.

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LIST OF PROPERTIES AND OCCURRENCES

- 1 Belmont Calcite (Whitney) Occurrence
- 2 Belmont Granite Quarry
- 3 Belmont Iron Mine
- 4 Beloporne Creek Occurrence
- 5 Blairton Iron Mine
- 6 Cordova Gold Mine
- 7 Crowe River Iron Occurrence
- 8 Crowe River Trap Rock Occurrence
- 9 Dominion Gulf Occurrence
- 10 Horse Lake (Tripp) Property
- 11 Ledyard Gold Mine
- 12 Methuen Lead Occurrence
- 13 Pershing Occurrence
- 14 Round Lake Dolomite Property
- 15 Round Lake Sulphide Occurrence
- 16 3M Canada Inc. Quarry
- 17 Vansickle Marble Property
- 18 Young-Cumming (Deer Lake) Property
- 19 Young-Phillips Occurrence
- 20 Young-Purdy Occurrence

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HASTINGS COUNTY
PETERBOROUGH COUNTY

BM 640
CANADIAN

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