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THE STRATIGRAPHY, STRUCTURE AND METAMORPHISM
OF PRECAMBRIAN ROCKS
IN BELMONT AND SOUTHERN METHUEN TOWNSHIPS,
SOUTHEAST ONTARIO

by

© M. Jane Murray, B.Sc.

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

Department of Geology

Carleton University

Ottawa, Ontario

July, 1982

The undersigned hereby recommend to the Faculty of
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ABSTRACT

The map area is on the west side of the Hastings metamorphic low, in the Central Metasedimentary Belt, Grenville Structural Province. It is underlain by metamorphosed volcanic and sedimentary rocks of the Proterozoic Grenville Supergroup. High in the sequence are metasedimentary rocks which may correlate to the Flinton Group. Granitic and gabbroic intrusions are metamorphosed and deformed.

A dome structure at Oak Lake flanks a homoclinal succession dipping moderately east or southeast, facing east, and occupying the rest of the map area. Rocks were deformed during two or three phases. No direct evidence for map-scale faults was found, but the truncation of certain rock units suggests one major fault.

Regional metamorphic grade increases northwestward from upper greenschist to middle to upper amphibolite facies. The chlorite-out "isograd" in mafic rocks bisects the map area. An anomalous chlorite-free region includes most of the small metagabbro intrusions.

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I.1 Purpose

Belmont and southern Methuen Townships required study for several reasons. There was disagreement in the literature about the stratigraphic order of mafic metavolcanic formations in the map area. Metaconglomerate at Belmont Lake (Belmont Township) had been correlated with rocks subsequently defined as the Flinton Group; validity of the correlation had to be examined. Styles and phases of deformation had not been analysed in most of the map area, nor had the metamorphic grade been determined. New information about depositional, deformational and metamorphic environments would be useful to the development of a tectonic history of the area.

Despite previously mined occurrences of gold and magnetite, Belmont Township had not been mapped in detail since 1908. Preservation of primary features in much of Belmont and southern Methuen Townships encouraged the author to believe that the origin and succession of rock units could be determined.

I.2 Location

The map area comprises Belmont Township and the southern five lots of Methuen Township in southeast Ontario, about midway between Toronto and Ottawa (Figure 1). It is

Figure 1: Regional geology (after Baer et al, 1971, Thompson, 1972 and Carmichael et al, 1978), showing location of map area. Dashed line outlines the limit of stable chlorite in the Hastings metamorphic low; dotted line represents the kyanite-sillimanite transition, with kyanite southeast and sillimanite northwest.

located in southeast Peterborough County. Highway 7 passes through southern Belmont Township and Havelock, the largest town in the map area.

I.3 Field and Laboratory Work

Field work for the present study was done by J.M. Moore, Jr., J.R. Bartlett and the author during the summer of 1980, as part of a mapping contract with the Ontario Geological Survey. Traverses were made at variable spacing, averaging one kilometre apart. Data were compiled on overlays to 1:15 840 scale aerial photographs, and transferred to a 1:15 840 scale basemap. A preliminary report and map (Figure 2) at this scale (Bartlett, Moore and Murray, 1982a, 1982b) outline the results of the work.

Thin sections of most rock units were examined by the author. Many rock samples were stained for carbonate or feldspar identification. Structural measurements were geometrically analysed by plotting data from structural domains on stereograms.

I.4 Previous Work and Present Studies

During the last century, the map area was visited by such notables as Sir William Logan and J.W. Dawson of the Geological Survey of Canada, whose interests included occurrences of the supposed Precambrian fossil Eozoon

canadense in marbles at Belmont Lake (Logan, 1865; Dawson, 1865). Alexander Murray mapped part of Belmont Township. His results were included in a compilation map by Vennor (1868). The early work was summarized by Hewitt (1956).

In 1907 and 1908, Miller and Knight mapped several areas in southeast Ontario, including most of Belmont Township. Their results, including a geological map of Belmont Township at 1:15 840 scale, were published in 1914. Figure 3 shows the location of Miller and Knight's study as well as that of more recent studies in the vicinity. Between 1920 and 1925, M.E. Wilson mapped the Marmora area, including Belmont Township, at 1:63 360 scale (Wilson, 1940). During the 1950s Hewitt produced a map of Methuen Township at 1:63 360 scale (Hewitt, 1961b). Doctoral theses of Heidecker (1963) and Lumbers (1967) describe parts of the map area.

Paleozoic geology was recently mapped by Carson (1980) and will not be dealt with in the present study. Pilon's Bachelors thesis describes the coarse clastic rocks at Belmont Lake (Pilon, 1981). Hulme's Bachelors thesis deals with the petrology of metabasalt southeast of Belmont Lake. J.R. Bartlett is preparing a Masters thesis at Carleton University concerned with the stratigraphy and petrochemistry of metavolcanic rocks in Belmont Township. P. Thomas of the University of Ottawa is preparing a Masters thesis about the Cordova gabbro.

Figure 3: Location of reports referred to in text.

1. Bartlett, in prep.; 2. Beavon, 1970; 3. Best, 1966;
4. Carmichael, 1967; 5. Chappell, 1978; 6. Evans, 1964;
7. Heidecker, 1963; 8. Hewitt, 1961b; 9. Hewitt and James, 1956;
10. Hulme, 1982; 11. Lumbers, 1967;
12. Miller and Knight, 1914; 13. Pilon, 1981; 14. Thomas, in prep.;
15. Thompson, 1972; 16. Venkitasubramanian, 1969;
17. Wilson, 1940.

I.5 Regional Precambrian Geology

The map area lies in the western part of the Hastings metamorphic ~~low~~ (Carmichael et al, 1978) within the Central Metasedimentary Belt (C.M.B.) of the Grenville Province, defined by Wynne-Edwards (1972). The C.M.B. consists of Proterozoic metasedimentary and metavolcanic rocks intruded by a variety of plutons; it is a linear zone up to 185 kilometres wide, extending southwest from Kempt Lake, Quebec, to Minden, Ontario; it is buried to the south by flat-lying Paleozoic sedimentary rocks.

Lumbers (1967) assigned layered rocks of the C.M.B. to two conformable groups, the predominantly metavolcanic Hermon Group and the overlying, dominantly metasedimentary Mayo Group. Moore and Thompson (1972) as well as Wynne-Edwards (1972) referred to the layered rocks as the Grenville Supergroup.

The Flinton Group unconformably overlies the Grenville Supergroup; it was defined by Thompson (1972) and Moore and Thompson (1972, 1980). In the 1972 publication of Moore and Thompson, the Flinton Group was included in the Grenville Supergroup; subsequently, however, Moore and Thompson (1980) separated it from the Grenville Supergroup. The Flinton Group comprises six formations. It includes polymictic, iron oxide-rich, framework-supported coarse clastic rocks, with well rounded clasts, derived from a

regionally weathered, subaerial terrain. Rocks typically vary in lithology and clast type over short distances.

Nowhere has a complete section of the six formations been found.

No intrusion has been found to postdate Flinton Group rocks other than pegmatite and lamprophyre dykes (J.M. Moore and A. Davidson, personal communication, 1982). All plutonic rocks intrusive into the Grenville Supergroup are deformed, according to the observations of J.M. Moore (personal communication, 1982). S.B. Lumbers contended that there are posttectonic quartz monzonite stocks and at least one posttectonic pluton of the potassic syenite and monzonite group in the C.M.B. (p. 183, Lumbers, 1967).

At least three major deformations have affected the layered rocks of the C.M.B., one of which preceded deposition of the Flinton Group (Moore and Thompson, 1980).

Metamorphic grade in the C.M.B. ranges from greenschist facies, within the Hastings metamorphic low, to granulite facies on the Frontenac Axis about 130 kilometres east of Havelock (Wynne-Edwards, 1972). The Hastings metamorphic low (Carmichael et al., 1978) is an informally defined area, roughly rectangular, which trends northeast and is covered to the south by Paleozoic sedimentary rocks; metamorphic grade increases outward from the low.

The age range of the Grenville Supergroup is ca

1300-1225Ma; Flinton Group was deposited between 1050 and 1080(+25)Ma (Moore and Thompson, 1980). The earliest known folding event therefore occurred between ca 1225 and 1080Ma; the two later major folding events postdated ca 1050Ma. Bell and Blenkinsop recently provided a 1250Ma Rb-Sr date for extrusion of mafic volcanic rocks of the Hermon Group, the oldest group exposed in the C.M.B.; their dates of plutonic rocks in the C.M.B. range from 1250 to 1100Ma, and suggest two major periods of intrusion at 1250 and 1100Ma, both before Flinton Group deposition (Bell and Blenkinsop, 1980).

I.6 Geology of the Map Area

Most if not all layered rocks in the map area are correlative with the Grenville Supergroup. They consist primarily of mafic to felsic metavolcanic rocks interlayered with clastic and chemical metasedimentary rocks.

The east side of the map area is probably a fault-bounded block; it comprises coarse to fine grained clastic metasedimentary rocks and overlying, probably subaerial, metamorphosed mafic flows and volcanoclastic rocks characterized by well preserved primary textures and abundant amygdules and plagioclase phenocrysts. Metaconglomerate within the fault block is similar to Flinton Group metaconglomerate; the possibility that the metaconglomerate is correlative with the Flinton Group, and

therefore is younger than the Grenville Supergroup, is discussed in Chapter 5.

A large metagabbro body is located north of Crowe Lake (Figure 2; the Cordova gabbro) and another in southeast Methuen Township; numerous small metagabbro bodies and dykes intrude rocks of the map area between Round and Cordova Lakes, and are probably of a different generation than the Cordova gabbro. Complexes of foliated quartz monzonite and quartz diorite with mafic and intermediate xenoliths are located at Oak Lake and north of Long Lake. They are cross-cut by non-foliated granite veins. Three granitic masses intrude Grenville Supergroup rocks in Methuen and northwest Belmont Townships.

Relative ages of most of the intrusive bodies cannot be directly determined on account of geographic separation. Cross-cutting vein and dyke relationships as well as intensity of deformation, suggest that gabbro was the oldest intrusive rock, followed by quartz monzonite and quartz diorite, and then granite.

Where evidence is preserved, the layered rocks young to the east. They have been deformed by up to three folding events, the first two (D1 and D2) having a larger effect than the third (D3). The D1 phase is correlative with the second major folding phase described in the Regional Geology section, i.e. D1 is equivalent to the first post-Flinton

Group folding event. It created minor isoclinal folds with an axial planar schistosity parallel to lithologic contacts. Intersection and mineral lineations are parallel to the fold axis. During the D2 event, there was map-scale folding with axial planes at high angles to primary layering; a strong biotite schistosity developed in some regions and a fracture cleavage in others, parallel to the D2 axial plane; crenulations formed parallel to the fold axis. Warping of schistosity and open folding of the antiform axis at Oak Lake were the result of either inhomogeneous D2 strain or a third folding event (D3).

There is no direct evidence for map-scale faulting. One surface is interpreted as a fault from indirect evidence; lithologic units are truncated along one side of the interpreted fault surface.

Stable metamorphic mineral assemblages represent a range from upper greenschist to middle to upper amphibolite facies, increasing in grade to the northwest. The chlorite-out isograd of fine grained mafic rocks bisects the map area. The chlorite-out isograd of all rock types has an irregular pattern; it is dependent on rock type in most places. One anomalous area free of chlorite is also the region in which most of the small gabbro bodies are situated, suggesting a causative relationship between the intrusion of small gabbro bodies and the lack of chlorite in host rocks. The pressure during metamorphism was probably

II.2.12 Unit L

Fine grained, pale grey to white, laminated or massive calcitic marble is interlayered on a large scale with grey to pink (siliceous) dolomitic marble, some of which contains a network of white dolomite veinlets. Muscovite and talc are accessory minerals. There is a layer of calcite-muscovite-chlorite semi-schist near the lower contact of the unit. At the Cordova gabbro margin is a talc-pyrrhotite-calcite-dolomite skarn (3803304927740). A few lenses of siliceous metasiltstone occur within the unit.

Marble laminae are tightly folded, with v-shapes in places. Mica-bearing rocks generally have a weak muscovite-chlorite schistosity. There is a bedding/schistosity intersection lineation in semi-schist, and rods of quartz aggregates in dolomitic marble. There are boudins of siliceous layers in some impure marbles. One sample of fine grained, laminated calcitic marble has narrow, darker, medium grained calcite layers subparallel to the tightly folded laminae; the dark layers appear to define surfaces on which there was solution before folding.

A rhyolite porphyry dyke two metres wide truncates folded marble laminations (3777404936030); it is similar to and may be coeval with a rhyolite tuff layer near the top of unit M. There are also many small basaltic dykes in the marbles on the northwest shores of Belmont Lake.

Permanent residents and cottagers in the study area were kind to allow us on their land. Mr. and Mrs. C. Roger Young and Mr. and Mrs. Walter Hood, all of Belmont Township, were most helpful to us, both during and after the field season. Judy Baker, Ross Taylor, Harold Ellwand and Peter Jones of Carleton University provided technical assistance. My family and friends supported me with encouragement and interest.

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II: STRATIGRAPHY

II.1 Introduction

Stratigraphic order can be discussed only after the lithology of map units has been described. This chapter includes a description of stratigraphic units, followed by evidence for stratigraphic order of layered rocks and intrusions.

Proterozoic rocks of the map area were examined in outcrop, hand sample and thin section. Study of about 120 thin sections involved determining mineralogy as well as primary and metamorphic textures. Plagioclase compositions were determined by the Michel-Levy method (Kerr, 1959); amphibole compositions were estimated from pleochroism, optic sign and the angle between γ and z (Kerr, 1959). Several quartzofeldspathic rocks were stained to determine relative quantities of quartz and the feldspars. Carbonate minerals were stained in several hand samples. The identification of mica, talc, tremolite and garnet was confirmed in a few rock samples by X-ray diffraction.

All rocks of the map area are metamorphic. In most, there is textural or structural evidence of the original rock type. Sedimentary and volcanic protoliths are classified according to the conventions of the Ontario Geological Survey (Blackburn et al, 1978, and Trowell et al,

1978). Grain size of rocks is described as very fine (aphanitic), fine (visible grains up to 1 millimetre diameter), medium (1 to 3 millimetres), coarse (3 to 10 millimetres) and very coarse (greater than 10 millimetres). The meaning of metamorphic rock names and of composition terms used in this report are given below.

Metamorphic rocks are classified as gneiss, schist, semi-schist and meta(rock name) in order of decreasing coarseness of recrystallized grains. A gneiss (AGI Glossary, 1972) is a medium to coarse grained rock in which quartz-feldspar layers alternate with iron-magnesium-rich layers. A schist (AGI Glossary, 1972) is a medium to coarse grained rock in which oriented platy minerals and mineral aggregates define closely spaced planes along which the rock generally breaks. A semi-schist is a medium to coarse grained, dominantly quartzofeldspathic rock with some parallel planes defined by oriented platy minerals and mineral aggregates; it does not break easily along any plane. A rock which is fine to medium grained and has little or no macroscopic planar metamorphic fabric, but is the metamorphic product of an obvious protolith, is named by adding to the beginning of the protolith name the prefix "meta" or the adjective "metamorphosed." A marble is a recrystallized rock containing more than fifty percent carbonate minerals.

Metaplutonic and metavolcanic rocks are named by

composition according to Streckelsen (1976, 1979). The names of layered rock types are modified by the composition terms felsic (colour index of less than ten), intermediate (colour index of ten to thirty-five) or mafic (colour index of greater than thirty-five). Where the mineralogy of a rock is given as part of the name, major minerals are listed in order of increasing abundance; minerals which are present in some samples but not in others precede the major minerals in parentheses.

Rocks are assigned general lithologic unit numbers 1 through 14 on the geological map (Figure 2) and divided into subunits (1a, 1b, etc) where suitable. The classification is based mainly on protolith. Map unit numbers take stratigraphic order into account only in the division of clastic metasedimentary rocks into units 5 and 9. Unit 9, located at Belmont Lake, is lithologically distinctive from and more extensive than the other coarse clastic rocks, and may be much higher in the stratigraphic sequence. For convenience of description in this thesis, and to emphasize stratigraphic order, strata of different rock types have been grouped into stratigraphic units A through Q (Table 1; Figure 4). The most common rock type(s) of each unit is (are) described in this chapter. The volcanic cycles of Bartlett (personal communication, 1982) are indicated in Table 1. Localities of special interest which are described in the text are located by Universal Transverse Mercator

Table 1: Stratigraphic units of this thesis.

predominant rock type: map unit number ¹	strat. unit	cycle ²	thickness (m) ³	protolith
limestone: 14			20	limestone, mudstone and limey conglomerate
UNCONFORMITY				
granite, syenite: 13	P			porphyritic to massive biotite granite and syenite
metamorphosed quartz mon- zonite to diorite: 12	Q			biotite quartz mon- zonite to quartz diorite
amphibolite: 10, 11 syenite	O			layered to massive gabbro; diorite to
metabasalt, metamorphosed intermediate volcaniclastic rocks: 1 (2, 3, 8) felsic tuff	N	IV	4700 +	amygdaloidal, plagio- clase-phyric basalt flows and dykes; inter- mediate tuff and tuff- breccia; volcanic conglomerate; minor
clastic meta- sedimentary rocks: 9, 6 (2, 3, 4, 5, 7, 8)	M		800	coarse to fine clastic sediments; clasts of felsic and mafic volcanic rocks, chert, silt- stone, sandstone and conglomerate in clay and carbonate matrix; minor "Eozoon" dolostone
UNCONFORMITY?				
dolomitic and calcitic marble: 8 (1, 2, 5, 6, 7)	L		200 - 2000	massive quartzose dolostone inter- layered with lamin- ated limestone; "Eozoon" dolostone

rock type: map units (cont.)	strat. unit	cycle	thickness (m)	protolith
rusty schist, intermediate metatuff and carbonate schist: 6, 2 (1, 2, 3, 5, 7)	K	III	0 - 1600	laminated pyritic siltstone inter- layered with inter- mediate volcanoclas- tic rock and marl
calcitic marble and metawacke: 6, 8 (1, 2, 3, 5, 7)	J		0 - 2000	laminated limestone interbedded with silty limestone and wacke; minor conglomerate
metamorphosed basalt and intermediate volcani- clastic rocks: 1 (2, 3, 4, 5, 6)	I		0 - 2800	massive and pillow basalt, pillow breccia and hyalo- clastite; basaltic dykes; intermediate pyroclastic rocks; minor chert and shale layers
felsic meta- tuff to cherty metasiltstone: 1, 2 (3, 6, 7, 8)	H	II	25 - 600	felsic tuff to lapilli tuff; cherty siltstone; pyritic near top
metabasalt and inter- mediate metatuff: 1, 2 (3, 6, 7, 8)	G		300 - 1100	amygdaloidal, plagioclase-phyric basalt flows; intermediate tuff; layers of limestone and dolostone
calcitic and dolomitic marble and mica schist: 8 (2, 5, 6 7, 8)	F		0 - 1000	laminated limestone interlayered with massive dolostone; narrow siltstone layer at top

rock type: map unit (cont.)	strat. unit	cycle	thickness (m)	protolith
intermediate to felsic metamorphosed clastic rocks and calcareous conglomerate: 2, 3, 5 (1, 6, 8)	E	I	0 - 2800	intermediate to felsic volcanoclastic rock; polymictic, calcareous conglomerate layers form base and top of unit
metabasalt, felsic metatuff and meta-sediment: 3, 1 (2, 5)	D		300 - 1400	amygdaloidal basalt flow between layers of felsic to intermediate tuff; minor conglomerate
muscovite-schist to semi-schist: 3, 6, 2 (1, 5)	C		1200 - 1500	layers of felsic tuff, ash flow tuff and feldspathic sandstone; minor conglomerate
calcite marble and pyritic schist: 6, 8 (7)	B		40	laminated limestone lies beneath pyritic siltstone
hornblende-biotite-muscovite gneiss and schist: 2, 3 (7)	A		400 +	clastic, possibly volcanoclastic rock; medium to coarse clasts

1. Map unit numbers are the lithologic units described in the legend of Figure 2.
2. Volcanic cycles in Belmont Township proposed by Bartlett (personal communication, 1982).
3. Calculated thicknesses perpendicular to the average dip of each unit. Tectonic alteration of original thicknesses is not taken into account.

coordinates in parentheses, the six digit easting followed by the seven digit northing.

II.2 Lithology

II.2.1 Unit A

Intermediate to felsic (biotite, hornblende, epidote) muscovite-quartz-feldspar gneiss and schist at Oak Lake is the structurally lowest rock in the map area, in the centre of a dome. It is granoblastic, coarse to medium grained, and has few centimetre to few millimetre scale gneissic layering as well as mica schistosity. In places, cobble size ovoid masses of more felsic rock, suggesting a coarse clastic protolith, are the only recognizable primary structures in the unit.

A striking shoreline outcrop (sample 90, Appendix II) of carbonate-augite-quartz-oligoclase gneiss has spherical aggregates of grossular garnet with epidote rims, a few centimetres in diameter. The millimetre scale gneissic layering wraps around the spheres, and is folded sigmoidally.

The base of the unit is not exposed. At one position (2682604941780), there is a tourmaline-amazonite, alaskite dyke near the upper contact and subparallel to it. The uppermost rock of this unit is carbonate-rich semi-schist, which gives way within 15 metres to calcareous marble of

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unit B.

II.2.2 Unit B

Two continuous, narrow layers, together about 40 metres thick, overlie unit A and outline the dome structure at Oak Lake. The lower layer is white to pale grey, medium grained, granoblastic tourmaline-muscovite-calcite marble with coarse layering; calcite grains in the marble are highly strained, with bent lamellar twins. Above the marble is dark grey, fine grained pyrite-cummingtonite-muscovite schist. The compositions of the two rock types suggest that the rocks were impure limestone overlain by iron-rich mudstone, before metamorphism.

The upper contact of the unit was not located; it is mainly beneath Oak Lake.

II.2.3 Unit C

Pale red to orange-red, granoblastic, medium grained felsic (biotite) muscovite-plagioclase-quartz-potassic feldspar semi-schist of this unit has millimetre scale layering. Quartz and feldspar mineral aggregates are flattened parallel to layering and muscovite schistosity. Original as well as recrystallized oligoclase phenocrysts in some strata are lath shaped.

Stretched cobble to boulder size mica-poor masses

predominate in some discontinuous layers, signifying that the protolith was a coarse clastic rock, probably a conglomerate of felsic rock clasts in a sand and clay matrix. The rest of the felsic rocks have been classified metavolcanic or metasedimentary on the basis of texture and composition: rocks which have phenocrysts or have less than 50 per cent quartz had a volcanoclastic origin, while rocks with no phenocrysts and greater than 50 per cent quartz were deposited as feldspathic sandstone. Layers of uniform rock rich in large oligoclase grains are interpreted as metamorphosed dacitic ash flow tuff.

Intermediate (epidote) hornblende-biotite gneiss and schist, layered as well as massive, were andesitic volcanoclastic rocks and flows before metamorphism; spheroidal quartz amygdules in a massive intermediate rock indicate that it was a fluid lava.

The top of the unit is metamorphosed sandstone. At one locality (3714004941220), the exposed contact of this unit with the overlying intermediate schist is an abrupt change in lithology and is parallel to the schistosity surface.

II.2.4 Unit D

Pale pink fine to medium grained felsic (biotite) muscovite schist and semi-schist as well as dark green mafic

and intermediate semi-schist to schist lie structurally above unit C. The matrix of the rocks is granoblastic. Schistosity consists of muscovite grain orientation, the disposition of flattened clasts, and the plane containing hornblende prisms. Lineation is formed by elongation of biotite aggregates and the orientation of hornblende prisms.

Some felsic rocks contain sodic plagioclase phenocrysts and many reveal intricately shaped lapilli on weathered or stained surfaces. The protoliths were probably dacitic tuff and lapilli tuff. Plagioclase phenocrysts and rare quartz amygdules in mafic schist indicate that the protolith was volcanic flow.

There is metamorphosed polymictic breccia at one locality (3691404937200). Subangular cobbles of felsic biotite semi-schist have biotite layering at different attitudes to each other (Figure 5). The biotite layers may be the recrystallized remains of a pre-depositional schistosity surface. Alternatively, the foliations may be post-depositional; the clasts may have rotated into different attitudes after the schistosity formed. The significance of metamorphic rock clasts is discussed in Chapter 5.

In places, polymictic pebble metaconglomerate marks the top of this unit; elsewhere it is absent. The contact between units D and E is thus interpreted as conformable,

II: STRATIGRAPHY

II.1 Introduction

Stratigraphic order can be discussed only after the lithology of map units has been described. This chapter includes a description of stratigraphic units, followed by evidence for stratigraphic order of layered rocks and intrusions.

Proterozoic rocks of the map area were examined in outcrop, hand sample and thin section. Study of about 120 thin sections involved determining mineralogy as well as primary and metamorphic textures. Plagioclase compositions were determined by the Michel-Levy method (Kerr, 1959); amphibole compositions were estimated from pleochroism, optic sign and the angle between γ and z (Kerr, 1959). Several quartzofeldspathic rocks were stained to determine relative quantities of quartz and the feldspars. Carbonate minerals were stained in several hand samples. The identification of mica, talc, tremolite and garnet was confirmed in a few rock samples by X-ray diffraction.

All rocks of the map area are metamorphic. In most, there is textural or structural evidence of the original rock type. Sedimentary and volcanic protoliths are classified according to the conventions of the Ontario Geological Survey (Blackburn et al, 1978, and Trowell et al,

with local epiclastic layers.

II.2.5 Unit E

Fine to medium grained (muscovite, chlorite, hornblende) biotite semi-schist and schist is intermediate to felsic and weathers pale grey to pink. The rock is mainly fine grained, granoblastic quartz and feldspar. Schistosity is composed of parallel biotite grains. A later, cross-cutting, weak schistosity is composed of oblate aggregates and individual grains of biotite. There is a strong lineation of biotite grains and aggregates, hornblende prisms, and crenulation of schistosity (which forms distinct lines on the weathered or broken surface).

Centimetre scale layering and pebble-like masses of quartz and feldspar suggest fine to medium grained epiclastic protoliths for most rocks. Euhedral plagioclase phenocrysts or xenocrysts in some layers indicate either a volcanic protolith or a volcanic source of detritus for those layers.

There are a few layers of polymictic metaconglomerate, with pebbles of chert, marble and fine grained felsic to intermediate rock in a matrix of micas and carbonate (3696504936540). One narrow metaconglomerate layer is distinctive because both clasts and matrix contain rhombic aggregates of calcite rimmed by biotite, which may

have replaced ankerite. Carmichael (1967) made this conclusion for similarly rhombic aggregates of quartz rimmed by biotite in the Whetstone Lake area.

One kilometre northwest of Little Whitney Lake is the only observed occurrence of an aluminosilicate mineral in the map area (sample 39, Appendix II). The rock is kyanite-muscovite-biotite schist in which the muscovite schistosity contains a lineation of elongate biotite and kyanite grains.

The upper contact of the unit is against sulphide-bearing schist and mafic schist (unit G) and marble (unit F). The contact with marble is seen in outcrop, and is an abrupt transition.

II.2.6 Unit F

A 100-metre thick layer of laminated grey-white, fine to medium grained calcitic marble in Methuen Township expands southward into a bulbous mass of laminated calcitic marble and pale beige fine to medium grained dolomitic marble with coarse tremolite and minor calcite. Within the marbles is an area of calcite-epidote-biotite schist. Along the upper margin of the unit is a ten-metre thick layer of (chlorite, muscovite) garnet-biotite schist. In Paleozoic cover near Vansickle is an inlier of unit F, revealing fine grained laminated pale grey quartzite overlying siliceous dolomitic marble.

Primary features were not observed in the unit; the marble laminations of this and all other stratigraphic units probably represent bedding transposed along a cleavage plane. Flat tremolite lenticles in marble define a metamorphic foliation; platy minerals form the schistosity in other rock types. Acicular tremolite in marble forms a lineation; linear biotite aggregates constitute a lineation in some schists.

The protoliths are chemical or clastic carbonate rocks, pure and impure, and minor claystone and quartz sandstone. Dolomitic marble west of Little Whitney Lake is so pure in one area that it is being assessed for extraction as an industrial mineral.

The upper contact of the unit is defined within 30 metres. No lithologic gradation was observed. The southern contact of the unit against unit E is abrupt, cutting across the bedding of this unit. It is also the site of marked map scale folding of both units E and F. The contact here is therefore probably folded and faulted; no shearing was observed in the rocks.

II.2.7 Unit G

Most of the unit is fine to medium grained, dark grey-green, locally rusty weathering chlorite-hornblende schist with a granoblastic plagioclase matrix; the rest

comprises intermediate to felsic (muscovite, hornblende, pyrite) biotite schist, and calcitic and dolomitic marbles. The mafic rocks have a strong hornblende lineation and a weak hornblende schistosity. Mica schists have a stronger schistosity, of biotite, and a lineation of bedding intersecting the schistosity.

In intermediate chlorite schist, there are lapilli-like forms with delicate projections, but primary structures are not generally recognizable. The protoliths for this unit are mafic flows and dykes, intermediate to felsic volcanoclastic rocks, and chemical precipitates of limestone and dolostone.

A narrow layer near the base of the unit (3720604934560) is medium grained magnetite-cummingtonite-garnet schist, with radiating cummingtonite. Immediately above this (3722804934560) is very pure, buff-coloured massive dolomite, which has been assessed for extraction as an industrial mineral.

The upper contact has been located within ten metres, and is a change from mafic schist or marble (unit G) to a more resistant felsic rock of unit H.

II.2.8 Unit H

Very fine grained grey, pale grey weathering, layered felsic muscovite-biotite semi-schist, forms a stratigraphic

unit of constant thickness through most of the map area. The top of the unit is mainly rusty weathering siliceous schist. Minor siliceous calcitic marble occurs within the unit (374920494212Q). The matrix of the unit is not granoblastic, but composed of quartz and feldspar grains with sutured boundaries indicating incomplete recrystallization. The schistosity is composed of small parallel biotite grains. Larger, randomly oriented, poikiloblastic muscovite grains truncate and therefore postdate the schistosity. There is a pervasive bedding/schistosity intersection lineation.

Many of the rocks have lapilli with delicate projections and are therefore metamorphosed felsic tuff and lapilli tuff. Some are cherty and others have a sugary texture, suggesting the protoliths cherty siltstone and sandstone respectively. There is graded bedding in some cherty metasiltstone (3728004933730).

The upper contact of the unit was located within 30 metres and is a change in lithology from felsic semi-schist (unit H) to mafic and intermediate schist (unit I) in Belmont Township, and to marble (unit J) in Methuen Township.

II.2.9 Unit I

Dark green, fine grained mafic (chlorite) hornblende

schist and intermediate to mafic layered (magnetite, garnet) biotite-chlorite schist compose most of unit I. The mafic rocks have a granoblastic plagioclase matrix; some intermediate non-layered rocks have a felty microlitic texture, suggesting andesitic lava as their protolith. There are abundant metamorphosed basaltic dykes. Chlorite and biotite grains form the schistosity; acicular hornblende is aligned in the schistosity. Epidote has replaced all original minerals in places.

Layered intermediate rocks near the top of the unit contain lapilli size fragments and abundant magnetite and biotite porphyroblasts. The well defined layering and high magnetite and biotite content suggest an oxidized volcanic epiclastic protolith. Some massive mafic rocks contain very elongate plagioclase aggregates which may have been phenocrysts. Fine grained, dark rims outline flattened pillows, pillow breccia and hyaloclastite in mafic rocks, clearly visible on the islands of southern Cordova Lake. The mafic rocks are therefore metamorphosed massive as well as pillowed basalt flows, pillow breccia and hyaloclastite.

At Belmont Lake and northward along the Crowe River, the upper contact of unit I is parallel to layering of unit I, but discordant to that of units K and L, suggesting that it is a fault. At Cordova Lake, the contact of pillowed metabasalt (unit I) with marble (unit J) cuts across layering of both units, although bedding of both units is

parallel; this suggests that the contact is deformed into numerous minor folds on the limb of a major fold, or that it represents a primary facies change. At Belmont Lake the upper contact is gradational over tens of metres from intermediate and mafic schist to marble of unit L; there are lenses of marble in the schist near the contact. Further north, the upper contact is abrupt against siliceous rusty schist of unit K. At southern Cordova Lake, marble of unit J immediately above the contact is locally brecciated (3758204938160) or marked by rusty weathering or white vein quartz (3750804939440).

II.2.10 Unit J

Calcitic and dolomitic marbles, some with a siliceous or pelitic component, as well as fine to very fine grained siliceous, quartzofeldspathic and carbonate-bearing semi-schists, overlie unit I at Cordova Lake. Polymictic metaconglomerate of chert and siltstone clasts in a micaceous matrix outcrops near Vansickle (3760004943900) and is the rock described by Hewitt as typical of his Vansickle formation (Hewitt, 1961a). Near Vansickle (3761004943940) is an outcrop of ferrodolomitic marble containing calcite, pyrite and magnetite. Most rocks of this unit weather rusty pale grey due to sulphide content. There is a weak mica schistosity. The lineations are bedding/schistosity intersection and rods of quartz aggregates in dolomitic

marble.

Laminations in siliceous rocks as well as a metasandstone layer in the metaconglomerate are bedding planes. Graded bedding was noted at three localities. South of Vansickle (3756804942420), an outcrop of marble contains angular clasts of marble and mica schist; the latter have a strong schistosity at a different attitude in each clast. The clasts of schist may have been metamorphosed before deposition; on the other hand, they may have developed a schistosity after deposition and been subsequently rotated to different attitudes. Protoliths of the unit are chemical and clastic carbonates, chert, siltstone, greywacke, sandstone and conglomerate. Some wackes contain a large component of felsic rock fragments and clastic feldspar crystals, suggesting felsic tuff detritus.

The upper contact of the unit is a gradual or abrupt transition from marble to metawacke of unit K. A tongue of mafic schist, possibly metamorphosed hyaloclastite, is found in unit K near the contact. The mafic schist may be contiguous with similar rock of unit I, but scarcity of outcrop makes the contacts of the mafic schist uncertain.

II.2.11 Unit K

Unit K overlies unit J. Pale grey to rusty

weathering, very fine grained siliceous sulphide-chlorite-muscovite schist has alternating siliceous and rusty micaceous laminae, and forms about half of unit K. Grain boundaries vary from serrated to granoblastic. The other half consists of green weathering, fine grained, intermediate carbonate-bearing chlorite-hornblende-biotite schist as well as a thin layer of dolomite-muscovite-ferrocalcite schist. The main schistosity is composed of parallel chlorite and muscovite grains. There is a later weak biotite schistosity. The main schistosity is crenulated, forming a prominent lineation in the siliceous and carbonate-rich schist, both of which have tightly folded bedding and schistosity. Laminae in the siliceous schist are bedding planes. They wrap around nodules of chert (3761504937280). The protolith of this unit was a clay- and sulphide-rich cherty chemical precipitate, with a minor clastic component. The intermediate schist contains oligoclase phenocrysts and in places has lapilli of similar intermediate rock; its protolith was an andesitic lapilli tuff or pebbly volcanic greywacke. The protolith of the carbonate schist was a marl.

The upper contact of unit K was defined within several metres (3772204937410). Biotite-chlorite-hornblende-epidote schist of unit K outcrops near calcitic marble of unit L. The outcrop distribution at this locality suggests that the contact is a minor fault.

II.2.12 Unit L

Fine grained, pale grey to white, laminated or massive calcitic marble is interlayered on a large scale with grey to pink (siliceous) dolomitic marble, some of which contains a network of white dolomite veinlets. Muscovite and talc are accessory minerals. There is a layer of calcite-muscovite-chlorite semi-schist near the lower contact of the unit. At the Cordova gabbro margin is a talc-pyrrhotite-calcite-dolomite skarn (3803304927740). A few lenses of siliceous metasiltstone occur within the unit.

Marble laminae are tightly folded, with v-shapes in places. Mica-bearing rocks generally have a weak muscovite-chlorite schistosity. There is a bedding/schistosity intersection lineation in semi-schist, and rods of quartz aggregates in dolomitic marble. There are boudins of siliceous layers in some impure marbles. One sample of fine grained, laminated calcitic marble has narrow, darker, medium grained calcite layers subparallel to the tightly folded laminae; the dark layers appear to define surfaces on which there was solution before folding.

A rhyolite porphyry dyke two metres wide truncates folded marble laminations (3777404936030); it is similar to and may be coeval with a rhyolite tuff layer near the top of unit M. There are also many small basaltic dykes in the marbles on the northwest shores of Belmont Lake.

The upper contact of this unit is against unit M metasedimentary rocks and unit N metavolcanic rocks; and is truncated by the Cordova gabbro. Unit M appears to pass along strike into marbles of unit L, so the two units may be time equivalent. Their contact is seen within 20 metres on Birch Island, Belmont Lake; marble of unit L grades into carbonate-rich wacke of unit M. The contact is therefore probably conformable. The contact with unit N is not exposed; it may be the site of shearing, as unit L marble laminations are at a high angle to the probable contact, while unit N metabasalt has a schistosity parallel to the contact. Calcitic marble at the margin of the Cordova gabbro (3789504935740) is coarser grained than is usual, probably as a result of heating by the intruding gabbro.

II.2.13 Unit M

Pale grey, pink, or rusty weathering metamorphosed conglomerate, sandstone, wacke and siltstone compose most of this unit; there are also layers of siliceous dolomitic marble, quartz-ferrodolomite metasandstone and quartz-oligoclase-phyric rhyolite metatuff. The felsic rocks are notably rich in magnetite and hematite, and have well preserved primary structures, despite outcrop scale folding. Most of the rocks contain a weak muscovite schistosity, which is parallel to the flattening plane of clasts. Linear fabric was not observed in the rocks, other

than intersection lineations and crenulations. Matrix grains have sutured boundaries indicating a small amount of metamorphic recrystallization.

Metaconglomerate contains rounded pebbles, cobbles and boulders of felsic porphyry, chert, siltstone, calcite and ferrocalcitic marble, amygdular basalt, sandstone and conglomerate, in a matrix of sand, micas and carbonate. The clasts are generally matrix-supported; where they touch, they indent each other. Clasts range from undeformed to flattened, with a length:width ratio up to 5:1. Discontinuous layers of metasandstone outcrop within the metaconglomerate. The metasandstone is trough cross-bedded. Metamorphosed siltstone and sandstone interlayers have graded bedding and flame structures.

Clasts in conglomerate of this unit are predominantly volcanoclastic and epiclastic rocks; they were not metamorphosed before deposition. One clast was found of possibly predepositional schist (3753704929920). Although polymictic throughout, the conglomerate varies in main clast type over short distances along and across strike, indicating various sources of detritus and some mixing during transport. Vesicular basalt cobbles and marble clasts were too weak to have survived a lengthy transport, and therefore came from a local source. Layers of marble in unit M and clasts of vesicular basalt suggest that carbonate precipitation and basalt extrusion were taking place at the

same time as deposition of unit M clastic rocks. Clasts of sandstone and conglomerate which are identical to layers within unit M indicate that there were intermittent periods of erosion and again indicate a local source of detritus.

The large volume of felsic tuff and chert clasts probably came from local rocks which were entirely removed by erosion. Outcrop distribution shows that the clastic rocks were laid down on marble of unit L. The provenance of clasts for the conglomerate is therefore mainly local, and the period of deposition interrupted by episodes of erosion. A 30-metre thick rhyolite porphyry layer near the top of the unit indicates local coeval felsic volcanism.

The siliceous dolomitic layers on Big Island and Birch Island (Belmont Lake) contain resistant laminae of silica in a beige, massive dolomite matrix; in places, the silica layers are parallel and closely spaced. They are indistinguishable from siliceous dolomitic marbles of unit L. After examination of an outcrop on Big Island (3757604930160), M. Bourke concluded that it is a clear example of fossil algal mats (M. Bourke, personal communication, 1981). The fossils closely resemble diagrams of Eozoon canadense in Logan (1865) and Miller and Knight (1914). Miller and Knight (1914) and Moore and Bartlett (personal communication, 1982) concluded that the layers of siliceous dolomitic marble are part of an underlying unit (unit L of this thesis), and appear within the conglomerate

by virtue of folding and faulting. The author, however, considers the marble units on Big Island to have been deposited within unit M, for the following reasons: there are no anticlinal folds in the marble layers, and the rock types on the east and west sides of the marble layers are different from each other; this is not the configuration one would expect for an anticline. The presence or absence of adjacent faults was not proven. The author concedes that she does not know whether algal mats could exist in a high energy environment in which coarse clastic sediment is being deposited.

The upper contact of unit M metasandstone with unit N metabasalt is seen in outcrop (Figure 6) (3764004930570). The metasandstone is not altered, but metabasalt at the contact is coarser grained than metabasalt away from the contact, and contains numerous calcite veinlets. The contact therefore appears to be a conformable one; there is evidence neither for faulting nor for a long period of weathering before volcanic activity.

II.2.14 Unit N

Overlying units L and M is unit N, aphanitic to fine grained, grey-green metabasalt flows, breccias and dykes, and intermediate tuff, all of which contain magnetite. The rocks have a weak chlorite schistosity, especially near the unit's margins. There are a few intersection, mineral and

Figure 6: Contact between units M (3 and 9) and N (unit 1), on the east shore of Belmont Lake (3764804930620). Metasandstone (9b) has cross-bedding which indicates top to the east. A 30-metre wide layer of metamorphosed rhyolite tuff (3e) is conformable with layers of metasandstone and metaconglomerate (9c). Overlying amygdaloidal metabasalt (1a, b) of unit N is seen in contact with metasandstone.

crenulation lineations. The volcanic rocks are generally plagioclase-phyric, with or without amygdules of chlorite, epidote, calcite or quartz. The matrix of the rocks contains plagioclase microlites in places. Plagioclase phenocrysts, microlites and metabasalt matrix are locally replaced by fine grained epidote.

Lapilli to bomb size clasts of amygdular metabasalt in a massive metabasalt matrix resembles flow-top breccia. In other places, the metabasalt is homogeneous, probably the centres of flows. A breccia layer contains clasts of fine grained mafic rock and granite in a matrix of plagioclase, biotite and two-centimetre wide pale green amphibole porphyroblasts (3765204929240). Intermediate metatuff (3803304927760), has xenocrysts or phenocrysts of single pink feldspar crystals five millimetres across.

Dykes of plagioclase-phyric metabasalt are found throughout the unit. A fine grained dyke truncates a medium grained porphyritic dyke indicating a minimum of two generations of dyke intrusion. The dykes were probably feeders to overlying basaltic flows.

The upper part of the unit is truncated by the Cordova gabbro. Large xenoliths of mafic, intermediate and felsic metavolcanic rock in the gabbro body probably belong to unit N or overlying units. Within tens of metres of the gabbro margin is very fine grained siliceous, hematitic,

layered hornfels with lenses of amphibole and chlorite; it is the contact metamorphosed equivalent of basalt and andesite. Lensoid bodies of skarn lie between the metabasalt and the Cordova gabbro.

II.2.15 Unit O

Metagabbro in the map area is medium to very coarse grained amphibolite composed mainly of plagioclase and hornblende, with either weakly pleochroic "uralitized" pyroxene or, in one locality, preserved clinopyroxene. Accessory minerals are chlorite, biotite, epidote, microcline, magnetite, pyrite and ilmenite. Colour index ranges from 40 to 75. Some amphibole grains are zoned, with dark pleochroic hornblende surrounding and coaxial with pale to clear amphibole (biaxial negative, with a ten to twenty degree extinction angle) which may be actinolite, cummingtonite or some of each. Recrystallized plagioclase grains (An16 to An35) are interstitial to larger remnant plagioclase grains which are generally zoned: the rims are 2 to 5 per cent richer in anorthite than the cores; the core-rim boundary is indistinct. Myrmekite of quartz in plagioclase is found next to microcline grains in the highest grade metagabbro (sample 35, Appendix II).

The metagabbros are divided below into two sub-units on the basis of igneous texture: some metagabbro is ophitic whereas some is cumulate.

The part of the Cordova gabbro which was mapped is massive to compositionally layered; remnant plagioclase laths, many recrystallized or altered, are found in most parts of the body, some within ophitic patchy, pale amphibole grains (after cumulus pyroxene). Amphibole grain size ranges up to a few centimetres in diameter. Within the Cordova gabbro is an exposure of medium grained metagabbro (3796004930340) in which coarse, separate pale amphibole grains have parallel bands rich in fine grained plagioclase. The plagioclase bands are absent from the surrounding gabbro matrix, yet are parallel from one coarse amphibole to the next. The origin of the banded amphiboles is not understood.

The other metagabbros are small bodies and dykes, except for one large body north of Long Lake. The small bodies are not layered. Almost all have a remnant igneous texture of amphibole (after cumulus pyroxene) in intercumulate plagioclase. Clinopyroxene is partly preserved in the highest grade metagabbro.

Except for schistose rock in east-striking shear zones, locally bearing gold, the Cordova gabbro is weakly foliated. The small bodies of gabbro with cumulate texture in most cases have a strong hornblende lineation.

Dykes of finer grained mafic rock intrude many of the metagabbros. The Cordova gabbro was intruded by diorite and

syenite veins, which locally compose more than 50 per cent of the rock. The sequence of cross-cutting dykes suggests chemical differentiation of the Cordova gabbro over time from gabbro to syenite.

The contact of the Cordova gabbro is intrusive, as shown by the presence of hornfels at its margins, its non-linear contact along the Crowe River with Unit N, and the coarsening of carbonate grains in unit L marble near the contact. No chilled margin was noted. Mafic lenses in hornfels suggest that there was some shearing along the contact. The contact was also the site of intrusion of syenite lenses. The Cordova gabbro was therefore emplaced by intrusion, but there was later shearing and igneous activity along the intrusive contact.

II.2.16 Unit P

Metamorphosed biotite quartz monzonite to biotite quartz diorite is found at Oak Lake and north of Long Lake. It has a schistosity of oblate biotite aggregates. In both areas, it is intruded by veins of massive granite, and was therefore metamorphosed before granite emplacement.

II.2.17 Unit Q

Medium and coarse grained bodies and dykes of metamorphosed pink biotite granite lie for the most part in

southern Methuen Township and northwestern Belmont Township. The granite contains up to five per cent biotite, green in one thin section, as well as granular microcline, sodic plagioclase and quartz. In places it has microcline phenocrysts. There is biotite schistosity at the margins of the larger granite bodies which is variable in attitude; the centres of the bodies are not foliated. Biotite foliation is found throughout the small granite body at Oak Lake, where it has a constant attitude.

II.3 Stratigraphic Order

Depositional order is denoted by the sequence of letters assigned to the layered rock units. The order has been inferred from field observations of primary features and structural relationships. Stratigraphic contacts dip southeast to east from Oak Lake to Crowe Lake. Therefore the rocks of unit A at Oak Lake lie both structurally and stratigraphically beneath all other rocks in the map area, and unit N rocks at Crowe Lake are on top. The possibility that faults affect the stratigraphic order is discussed in Chapter 3.

Below unit G, primary structures indicating facing direction have been destroyed by recrystallization. Primary top indicators have been seen in most units above unit G; Most top indicators face east. Those that face west, north

or south are on the short limbs or hinges of isoclinal folds.

Metabasalt pillows in units G and I consistently indicate top to the east. The one example of graded bedding seen in unit H metasilstone faces east. Three occurrences of graded beds in metagreywacke of unit J face north and west. A metasilstone layer in unit L has graded bedding which faces east. In unit M, metasandstone layers are generally trough cross-bedded; there are also rip-ups of mudstone into sandstone beds, and graded beds in metasilstone. The structures face predominantly east, but there are examples which face west. Graded beds in volcanic metasedimentary rocks of unit N face east.

The upper contact of unit M is described in the Lithology section of this chapter: east-facing parallel beds of unit M metasandstone are locally truncated and immediately overlain by a calcite-veined metabasalt flow which is coarser grained toward the contact at one locality. The contact therefore indicates that basaltic lava of unit N solidified on a locally eroded surface of flat-lying sand.

II.4 Sequence of Dykes and Veins

A variety of veins and dykes cross-cut country rocks and intrusive bodies. Cross-cutting relationships seen in outcrop were used to deduce age relations. Table 2

Table 2: Time sequence of dykes and veins. The column on the left indicates general types of veins and dykes. The right hand column suggests stratigraphic units with which the veins may be correlative. The oldest veins are on the bottom of the list, and the youngest ones on the top.

Vein/dyke	Correl. strat. unit
calcite	post-Ordovician
felsite	
quartz, ankerite, epidote, sulphides, gold	
pegmatite	
granite	Q
lamprophyre	P?
diabase	N
rhyolite porphyry	M
diabase	I
syenite	O
gabbro	I, O

summarizes the probable sequence of veins. The field evidence is given below.

Calcite veins are found in Paleozoic rocks, and are the youngest veins noted. Very fine grained granite (felsite) dykes intrude quartz veins. Quartz-bearing veins intrude granite dykes. Granite dykes cut across a lamprophyre dyke. A rhyolite dyke cuts straight across folded marble of unit L. Pegmatite veins intrude granite dykes as well as diorite dykes. Metadiabase dykes intrude gabbro bodies. Syenite dykes intrude along the margin of the Cordova gabbro. Metagabbro intrudes rocks as young as unit N.

Some dykes are thought to have intruded at the same time as similar magma was forming nearby intrusive bodies or overlying extrusive layers. The time-equivalent intrusive and extrusive rocks are indicated next to vein types in Table 2. Diabase is entered twice in the Table because, both units I and N contain abundant diabasic and basaltic dykes, which were probably feeders to immediately overlying flows; unit N is probably much younger than unit I, and so its associated dykes would be much younger.

Table 3 indicates the types of veins intrusive into each stratigraphic unit. The location of veins is applied to the discussion of structure in Chapter 3. Unit M is unique in the map area for its paucity of veins and dykes. One

Table 3: Unit locations of dykes, veins and intrusive bodies.
 An x indicates presence of veins or intrusions of
 the specified type in the specified stratigraphic
 unit.

Stratigraphic unit	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	Pal.
<u>Veins and dykes</u>																		
calcite					x				x			x						x
felsite				x										x				
quartz, etc.	x		x	x	x		x	x	x	x	x	x	x	x				
pegmatite	x	x	x	x	x													
granite	x	x	x	x														x
lamprophyre	x				x								x					
rhyolite												x						
diabase				x	x	x	x	x	x	x	x	x	x	x	x			
syenite												x			x			
<u>intrusive bodies</u>																		
granite	x	x	x	x														
qz monz/dior	x		x															
Cordova gabbro												x		x				
small gabbros	x		x	x	x		x		x	x								

- lamprophyre and several mafic dykes, plus a few quartz-rich veins are the only intrusive rocks which cross-cut the unit.

II.5 Stratigraphic Correlation

Table 4 summarizes the names applied to rock units of the study area since the beginning of this century. The conclusions of stratigraphic studies by Miller and Knight (1914), S.B. Lumbers (1967) and the present author are given in the following paragraphs.

Miller and Knight (1914) mapped the part of Belmont Township underlain by units D through Q (of this study) as well as the Tweed-Kaladar area at 1:15 840 scale. They concluded that, in Belmont Township, "Grenville Series" rocks (units D through L) were unconformably overlain by "Hastings Series" clastic metasedimentary rocks (unit M), which were in turn overlain by the "Belmont amygdaloidal basalt and tuff" (unit N).

In 1967, S.B. Lumbers completed a geological compilation of the Bancroft-Madoc area at 1:126 720 scale based on his own mapping as well as that of M.E. Wilson, D.F. Hewitt and others. He assigned most layered rocks in the map area of this thesis to the predominantly volcanic Hermon Group, and the rest to the overlying, sedimentary Mayo Group (Table 5). The Tudor metavolcanics are the oldest formation in the Hermon Group, according to Lumbers,

Table 4: Regional correlation of stratigraphy. The original sources of unit names are indicated in footnotes.

Prev. study Strat. units	Miller and Knight, 1914	Hewitt and Satterly, 1957	Lumbers, 1967	this study
Q				
P				
O	Belmont gabbro-diabase	Cordova gabbro		Cordova gabbro
N	Belmont basalt and tuff		Tudor meta-volcanics ^b	
M	Hastings Series		Vansickle formation ^h	possible Flinton Gp. ^t
L	Grenville Series ^l		Dungannon formation ^j	Grenville Supergroup ^r
K				
J			Vansickle formation ^h	
I		Belmont volcanics		
H			Tudor meta-volcanics ^b	
G				
F				
E				
D				
C				
B			Oak Lake formation ^h	
A				

h - Hewitt, 1961

j - Hewitt and James, 1956

b - Lumbers, 1967

r - Moore and Thompson, 1972; Wynne-Edwards, 1972

s - Hewitt and Satterly, 1957

l - Logan, 1847

m - Murray, 1854

t - Thompson, 1972

Table 5: Stratigraphic order according
to Lumbers (1967).

	Group	formation	units of this study
younger older	Mayo	Dungannon	L, J?
	Hermon	Turriff formation	---
		Vansickle formation	K, J, M
		Oak Lake formation	A, B, C
		Tudor meta- volcanics	G, H, I, N (D, E, F ?)

and include most mafic and intermediate volcanic rocks. Units G, H, I and N, and possibly D, E and F were assigned to the Tudor metavolcanics. Conformably overlying them, according to Lumbers, is the Oak Lake formation of felsic pyroclastic rocks (including units A, B and C), the type section of which was described by Hewitt (1961) on the south shore of Oak Lake. In Lumbers' stratigraphy, the Oak Lake formation is conformably overlain by the Vansickle formation (units K, J and M) of clastic metasedimentary rocks; the type section near Vansickle was described by Hewitt (1961). (Lumbers assigned mafic volcanic rocks overlying the Vansickle formation to the Turriff formation, but did not include any rocks of the present map area in the Turriff formation.) Unit L and probably marbles of unit J were assigned by Lumbers to the Dungannon formation of the Mayo Group.

Lumbers' (1967) assignment of relative ages is not consistent with the information presented earlier in this chapter. His stratigraphic order requires most of the section to be overturned. In one of the papers to which Lumbers referred, Hewitt (1956) had already concluded that metabasalt of unit N overlies the clastic rocks of unit M, indicating decreasing age to the east, with which conclusion the present author agrees. Lumbers appears to have neglected this information; his stratigraphy requires decreasing age to the west, and therefore overturned

stratigraphy, at this locality. His conclusion disagrees with clear top indicators near the contact (Figure 6). The relative ages of unit N and units below M cannot be determined, directly, as they are probably separated by a major fault. However, if one accepts that unit M is in the Vansickle formation, then unit N should be assigned to Lumbers' Turriff formation.

The results of the present study agree in general with the stratigraphic order proposed by Miller and Knight (1914), the only exception being the position of the siliceous marble layers found within unit M, as discussed in the Lithology section of this chapter. The term "Grenville Series" for units A through L has been replaced by the term "Grenville Supergroup" of Moore and Thompson (1972) and Wynne-Edwards (1972). The "Hastings Series" as mapped in Belmont Township by Miller and Knight has been tentatively assigned to the Grenville Supergroup, but may be correlative with the Bishop Corners Formation of the Flinton Group. (The stratigraphic position of unit M will be discussed further in Chapter 5.) Metabasalt of unit N was named "Belmont basalt and tuff" by Miller and Knight. If unit M predates the Flinton Group, then unit N very likely also predates the Flinton Group. However, if unit M is part of the Flinton Group, then unit N either is correlative with or post-dates the Flinton Group. (Only B.L. Smith (1969), working in the Ompah area to the northeast, has documented

possible post-Flinton Group volcanic rocks.) If unit N postdates the Flinton Group, it should be assigned its own stratigraphic unit name. The name "Belmont formation" would not be suitable because "Belmont" has been used as an informal name for unit I (Hewitt and Satterly, 1957), unit N (Miller and Knight, 1914) and unit M (Pilon, 1981).

III: STRUCTURE

III.1 Introduction

Centred at Oak Lake in southern Methuen Township is an oval dome structure. Rocks between Round Lake and Little Whitney Lake are in east dipping units which have been folded about steep east-northeast striking fold axial planes with steeply plunging fold axes. East of Round Lake, Lost Lake and Vansickle, the rocks form an east to southeast dipping homocline, probably interrupted by a major fault on the west side of Belmont Lake. The major structures of the map area are shown on vertical cross sections (Figure 7). The jagged lines represent facies changes. Note that the relative attitudes of bedding and the prominent schistosity are consistent, in most places, indicating that the map area is on one side of a major fold; this concurs with field observations.

Structure of the map area was studied in field observations and by compilation of data collected by the author as well as J.R. Bartlett and J.M. Moore. The map area was divided into seven structural domains. Measurements were plotted for each domain on stereograms.

Attitudes are written in the text as "strike/dip" for planes and "trend-plunge" for lines. Strike and trend directions are degrees clockwise from north. The dip of a

plane is to the right of the strike; the trend of a line is down plunge.

Folded fabrics and fold interference patterns indicate that there were two or three phases of deformation, D1, D2 and possibly D3. Stratigraphic units are truncated along a surface which is probably a fault. Minor faults are both dextral and sinistral. Fracture patterns do not appear to be related to the three deformation phases.

Comparison of the conclusions of several studies has resulted in the correlation of six deformation phases in the Bancroft-Madoc area.

III.2 Fabric, Folds and Phases of Deformation

A geometrical relationship between minor folds and metamorphic fabric suggests that the two formed at the same time. In this part of the thesis, the associated folds and fabrics are described, followed by an outline of the sequence of deformation phases. Fold interference patterns are classified according to Ramsay (1967).

Bedding is deformed into tight to isoclinal minor folds with mainly similar style (Figure 8). The fold axial plane is represented by a prominent mica or chlorite schistosity which is generally subparallel to bedding. The attitude varies throughout the map area. An intersection lineation (bedding/schistosity), biotite and hornblende

Figure 8:

D1 fold styles, viewed on horizontal surfaces. Bedding (S0) in tight to isoclinal folds.

8a.

Field sketch: tight folding of layering in calcareous chlorite schist of unit D (3696204936160) with axial planar S1 schistosity.

8b.

Field sketch: folding of layering in metasandstone of unit M with axial planar S1(?) fracture cleavage (3758804931180).

8c.

Sketch from photograph: isoclinal folding of layering forms irregular pattern; probably some boudinage and fold interference. Rock is metamorphosed felsic epiclastic or volcaniclastic rock of unit C near Long Lake (3664204940660).

8d.

Sketch from photograph: tight folding of layering in a calcareous, mica-bearing marble of unit L (3786604936300). Layers were boudined before the completion of folding. A discordant fracture cleavage is the result of a later deformation.

a

b

c

d

prisms, and the elongation of clasts and amygdules are parallel to the fold axis. Most fold axes plunge northeast, but some plunge southwest.

Schistosity with subparallel bedding is, in turn, deformed into moderately open minor folds (Figure 9) which have both similar and concentric styles. Some folds are V-shaped (Figure 9b). The axial plane is represented by a weak schistosity of biotite grains and aggregates. There is also closely-spaced fracture cleavage with no apparent mineral growth; its orientation suggests that it is axial planar to map scale folds (which fold the prominent schistosity) in central northern Belmont Township. Crenulations of the prominent schistosity form a lineation parallel to the fold axis. The folds are upright; the axial planes are vertical to steep and strike east-northeast, at a large angle to bedding. Fold axes plunge steeply to the northeast.

There are, in addition, very open folds of bedding and both schistosities (Figure 9f) in most of the map area, but which are moderately open at Oak Lake. No fabric is associated with the folds.

From the above information, fold styles and associated fabrics can be assigned to sequential deformation phases. The earliest phase, D₁, produced minor isoclinal folds of bedding (S₀), a prominent axial planar platy

Figure 9:

D2 and D3 fold styles, viewed on horizontal and vertical surfaces.

9a.

Sketch from photograph: siliceous layer in a laminated calcareous marble of unit J is boudined at the crest of an asymmetric fold, whereas laminations are unbroken, smeared out along a plane represented by the dashed line (3765904940840).

9b.

Sketch from field notes: layering (S0) and schistosity (S1) are asymmetrically folded in moderately open style in an intermediate, metamorphosed volcanoclastic rock of unit A (3684204942720). Granite veinlets (dotted) are also folded.

9c.

Sketch from photograph: layering (and schistosity?) of intermediate chlorite schist of unit D is folded in open style. Dotted rock is vein quartz (3714004941220).

9d.

Sketch from a photograph: metawacke of unit K is openly folded, with an axial planar fracture cleavage (3772004940300).

9e.

Sketch from field notes: tight fold of layering (S0) with an axial planar schistosity is in calcareous chlorite schist of unit M (3679804931870).

9f.

Sketch from field notes: very open folding of fracture cleavage (S2) in unit E is the only illustration in this figure of possible D3 folding (3710004937270).

a

b

c

d

e

f

mineral schistosity (S1), and a fold axial intersection, stretching and mineral lineation (L1). The next phase, D2, produced moderately open folds in S0 and S1 with a weak axial planar schistosity (S2), and possibly axial planar fracture cleavage, and a fold axial crenulation (L2). The D2 phase also resulted in the northeast striking antiform at Oak Lake. Very open folds may have been the result of inhomogeneous D2 phase folding or a third deformation phase, D3. The folding of lineations and fold axes, especially apparent at Oak Lake and immediately north of Round Lake, is assigned to the last (D3 or late D2) phase.

III.3 Fold Interference

The sequence of deformation phases resulted in the superposition of folds and therefore fold interference patterns. The patterns depend on relative attitudes of the fold elements (axial planes and fold axes). In most of the map area, the fold axes of D1 and D2 are parallel, but the axial planes are at a large angle to each other. The attitudes of D3 fold elements are less well documented due to the very open nature of folds and a lack of fabric associated with the phase.

Interference patterns of D1 and D2 folds are Type III in Ramsay's classification (Ramsay, 1967). Two examples (Figure 10a and b) show D1 folds folded by D2.

Figure 10:

Fold interference patterns. 10a and b are Ramsay Type III patterns, and 10c is Ramsay Type I. Views are of one vertical and two horizontal surfaces.

10a.

Sketch from field notes: bedding (S0) in a rusty metasiltstone of unit K is isoclinally folded (D1). The trace of the D1 axial plane is shown as a dashed line. The fold is refolded (D2) to an open fold. A fracture cleavage (S2) may be related to the second phase of folding, or may have formed later. Fold axes of D1 and D2 are both approximately perpendicular to the rock face and parallel to each other; the axial plane of D1 is folded by D2 (3761504937280).

10b.

Sketch from a photograph: calcitic marble (unpatterned) and biotite schist (dotted) of unit E (3708704938000) both contain isoclinal fold hinges (D1) refolded by tight folds (D2). The trace of the D1 axial plane is indicated by a dashed line. The schist has a strong biotite schistosity which is parallel to the D1 axial plane. It also has a crenulation which is parallel to the D2 fold axis. The axes of both generations of folds are approximately perpendicular to the rock surface and subparallel to each other; the D1 axial plane is folded by D2.

10c.

Sketch from a photograph: granitoid gneiss of unit A (3695904942600) forms a dome structure. Gneissic layering (S1) forms a moderately open D2 fold, which is openly refolded (D3) to make a dome. The D2 fold axis plunges shallowly to the east on the right side of the sketch, and shallowly to the west on the left side. The D3 fold axis is approximately horizontal, trending northward. The D2 fold axial plane is approximately vertical, striking eastward, whereas the D3 axial plane is approximately vertical, striking northward.

a

b

c

Figure 11 is a sketch of an oriented deformed felsic muscovite-biotite schist folded in a D2 fold. S0 is subparallel to a prominent biotite schistosity, S1. On the S1 surface is the intersection of bedding, which is the lineation L1. The schistosity has been deformed during D2 into a moderately open fold; L1 is also folded. A weak S2 schistosity consists of oblate biotite aggregates with the same attitude as the D2 axial plane. No D2 lineation can be seen in the sample. The D2 fold axial surface is warped, suggesting inhomogeneous D2 folding.

The other type of interference pattern is seen in the Oak Lake dome, where an S1 schistosity was folded during D2 and then D3 to reflect the map scale structure. Dome and basin patterns (Figure 10c) are Ramsay's Type I interference pattern. Fold axes and axial planes of D2 and D3 are both non-parallel; as well, the fold axis of D3 does not lie in the D2 axial plane.

III.4 Geometric Analysis of Fold Elements and Fabrics

Attitudes of fabrics and fold elements were plotted on overlays to the geological map. Examination of the overlays led to a division of the map area into seven structural domains in which attitudes of most features are constant. The structural data were then plotted on Lambert equal area nets. Domain locations, stereograms and generalized structural data are given in Figure 12. The

Figure 11: Sketch of a sawn, oriented sample of metawacke (sample 67, Appendix II), and diagram of the attitudes of fabrics in the sample. Both drawings show a plan view, and are in the same orientation. Subparallel S_0 and S_1 intersect to form L_1 . Both S_0 and S_1 are folded in a moderately open, similar style D2 fold which has a weak biotite schistosity (S_2). The S_2 surface is very openly folded, probably the result of inhomogeneous D2 strain.

four stereograms for each domain show:

poles to primary layering(S0);
 poles to planar fabric (marble
 lamination, fracture cleavage,
 schistosity and gneissic layering);
 linear fabric;
 fold elements.

Points accompanied by a number (1, 2 or 3) refer to data for which the associated deformation phase is known (D1, D2 or D3).

Data of planar fabrics in most domains are spread along a great circle of the net. Linear data in some domains also are spread along a great circle, or possibly a small circle; the small amount of data does not exhibit conclusive patterns. In the case of planar fabrics, the poles to fabric plot on a great circle if the fabric has been cylindrically folded about the pole of the great circle. Lineations plot on a great circle if the surface on which the lineations lie has been cylindrically folded about the pole to the great circle, or if the lineations have been rotated by deformation. The poles, or π axes (Ramsay, 1967), are shown on the stereograms of Figure 12, where they can be compared to measured fold axes. Some domains have one concentration of poles within a great circle distribution, suggesting that most of the measurements were made on the limbs of isoclinal folds, or asymmetric tight

folds with one limb much longer than the other.

Table 6 presents generalized information from stereograms including π axes and concentrations of data. Table 7 gives stereogram information specific to each deformation phase. The numbers of the table have been obtained by inspection of the stereograms; statistical methods were not applied due to the small amount of data. The stereograms of each domain are distinctive and illustrate the differences of deformation style and attitude from one domain to another. The domain margins lie between areas with different fabric attitudes, but the margins do not represent sharp breaks in attitudes.

Below is a description of stereogram data followed by an interpretation of the data, for each domain. A paragraph at the end summarizes the structure of the whole map area, as interpreted from stereograms.

III.4.1 Oak Lake Domain

Attitudes of primary and metamorphic fabrics as well as fold elements are distributed evenly along great circles, illustrating the strong influence of D2 and D3 cylindrical folding in this domain. Poles to bedding, schistosity (S1 and S2), gneissic layering (Sl), fracture cleavage, and marble lamination all lie in a band following a great circle. The π axis to schistosity is 065-00. Fracture

Table 6: Generalized π axes and concentrations of data from stereograms.

	Oak Lake	Round Lake	Little Whitney Lake	Cordova Lake	Lost Lake	Belmont-Cordova	Crowe Lake
Planar fabric π axis	$065 \rightarrow 00$	$075 \rightarrow 25$	$080 \rightarrow 35$	$110 \rightarrow 55$	$050 \rightarrow 30$	$180 \rightarrow 55$	$085 \rightarrow 65$
Planar fabric concentration		$\frac{075}{20}$	$\frac{035}{50}$	$\frac{075}{55}$	$\frac{075}{60}$	$\frac{035}{65}$	$\frac{075}{10}$
Lineation π axis						$30 \leftarrow 290$	
Lineation concentration		$070 \rightarrow 25$	$080 \rightarrow 35$	$\frac{090}{075} \rightarrow \begin{matrix} 60 \\ 50 \end{matrix}$	$080 \rightarrow 50$		
π axis to fold axes				$25 \leftarrow 290$	$25 \leftarrow 300$	$15 \leftarrow 220$	
Fold axial plane concentration		$\frac{075}{10}$	$\frac{065}{65}$	$\frac{1}{\text{mod-steep}}$	$\frac{1}{\text{mod}}$	$\frac{1}{\text{mod}}$	

Table 7: Information about each deformation phase
derived from stereograms.

Domain Feature	Oak Lake	Round Lake	L. Wh. Lake	Cor- dova Lake	Lost Lake	Bel.- Cord.	Crowe Lake
<u>Planar</u> S0 π axis	205-25	080-30	080-35	100-55	080-40	100-55	085-65
<u>Fabric</u> S0 conc.	--	335/30	--	--	000-25	--	--
S1 π axis	065-00	070-20	--	115-55	075-30	--	060-65
S1 conc.	070/55	070/90	055/50	015/55	015/60	025/65	--
S1 conc.	--	345/30	--	--	--	--	--
S2 π axis	075-20	070-20	--	--	075-30	--	170-30
S2 conc.	--	--	--	--	025/50	020/70	005/70
Axial D1 conc.	--	--	--	030/65	--	--	--
Plane D2 conc.	--	075/90	065/65	015/60	--	--	--
<u>Line-</u> L1 π axis	--	--	--	--	--	290-30	--
<u>ation</u> L1 conc.	080-10	070-25	070-35	080-60	080-50	080-60	--
L2 conc.	--	075-35	095-60	--	--	--	--
Fold D1 π axis	--	--	--	325-20	300-25	320-15	--
Axis D1 conc.	260-45	070-30	070-35	--	060-40	--	--
D2 conc.	085-15	070-30	--	--	--	075-60	--

cleavage attitudes are more shallow than schistositities; the fracture cleavage π axis is 075-20. Intersection lineations (L1) are shallow and trend east, west or northwest. Mineral lineations are mainly shallow, trending east. Some hornblende lineations (L1) in gneiss of unit A trend southeast and northwest with shallow and moderate plunges; they appear to have grown during D1 as they wrap around minor dome structures and lie in the S1 schistosity surface. The four tight fold axes trend east-southeast with a moderate plunge. Open fold axes trend northeast, west-southwest and northwest with moderate plunges.

The structure of the domain therefore is subparallel bedding, schistosity, gneissic layering and fracture cleavage with minor fold axes (intersection and mineral lineations), which were deformed to a northeast-trending, shallowly plunging antiform during the D2 phase. The π axis at 065-00 is the fold axis of the antiform. A later deformation phase (D3) caused the rotation of lineations and fold axes about an approximately north-trending horizontal axis, and caused the great circle of planar features to be broadened to a band. As noted earlier in this chapter, the D3 phase may not have been a distinctive phase but rather part of the D2 phase.

III. 4.2 Round Lake Domain

This domain has more in common with the Oak Lake

Domain than do the others. Bedding, schistosity and fracture cleavage poles are arranged in a band which follows a steep great circle; the π axis of the great circle is about 075-25. There is a concentration of bedding and schistosity at 345/30; schistosity is also concentrated about 070/90. Lineations are mainly formed by mineral prisms, but there are also intersection lineations and crenulations. Although a few mineral lineations and crenulations plunge southwest, most lie close to 070-25, near the π axis. Fold element attitudes are scattered. Axes of tight folds are mainly east-northeast trending with a shallow plunge. Open fold axes trend northeast and southwest, horizontal to vertical in plunge. Poles to open fold axial planes indicate mainly steep planes with an approximately northeast strike.

The stereograms indicate the following structure. Bedding, schistosity and fracture cleavage have been cylindrically folded about a moderately plunging east-northeast fold axis during the D2 folding phase. The concentrations of bedding and schistosity have the same attitudes as on the hinges (345/30) and limbs (070/90) of major D2 folds suggesting that the major folds comprise many asymmetric minor folds, allowing for measurement of elongate limbs and fold noses but few measurements of attitudes transitional between the two. The marked concentration of all types of lineations near the π axis suggests that the D2

fold axis formed parallel to L1, or that L1 was rotated into the L2 orientation. Crenulations formed probably during the D2 phase. The few southwest-trending lineations are close to the concentration of lineations and therefore do not necessarily represent later folding of the L2 lineations. The axial planes of open folds are steep to vertical, generally east striking; the scatter of open (D2) fold axes is probably the result of different attitudes of planes before D2 folding.

III.4.3 Little Whitney Lake Domain

The Little Whitney Lake Domain encompasses part of one limb of a large D2 fold; the only D3 effect is the warping of schistosity. Bedding and schistosity poles lie on a great circle band, mainly on half of it. The π axis of the great circle is 080-35. Schistosity and fracture, cleavage concentrate about 055/50. Intersection, mineral and crenulation lineations are well grouped around 070-35, as are open and tight fold axes. Open fold axial planes are grouped around 065/65, although a few dip moderately northeast.

The structure of the domain is as follows. Bedding and schistosity are folded cylindrically by a major D2 phase fold; measurements are along one limb of the fold. All lineations and fold axes are parallel to the D2 fold axis indicating either initially parallel attitudes or rotation

into parallelism. Crenulations (L2) probably formed during D2. Fracture cleavage attitudes are spread in the same configuration as schistosity (S1) attitudes. The scatter of axial planes of open folds is due to inhomogeneous D2 strain, or different original attitudes of planes before folding. The D3 phase had no effect on the domain.

III.4.4 Cordova Lake Domain

The predominantly metasedimentary rocks in the domain have fold interference patterns outlined by bedding surfaces, especially noticeable in the rusty siliceous semi-schist of unit K. Bedding, marble lamination, schistosity and fracture cleavage poles lie on a great circle band which is shallow; the π axis is 110-55. Planar features concentrate near 015/55. Lineations are mainly the intersection of bedding with schistosity (L1) and with fracture cleavage (L2?). There are also a few mineral and crenulation lineations. The intersection lineations weakly concentrate about 070-35, while crenulations (L2) and mineral lineations (L1) concentrate about 095-60. Axes of open and tight folds lie vaguely along a great circle the π axis of which is 325-20. Axial planes of open and tight folds strike approximately northeast with a steep to moderate southeast dip.

In this domain, therefore, D1 folds are isoclinal, making bedding and schistosity subparallel. D2 folds have

an east-southeast trending, moderately plunging fold axis and crenulation lineation, and a fracture cleavage along the fold axial plane. Lineations weakly concentrate about the fold axis. The scatter of fold axes and fold axial planes (as well as S2 fracture cleavage) is probably due to inhomogeneous D2 strain. Open folding of schistosity and cleavage is also probably due to inhomogeneous D2 strain.

III.4.5 Lost Lake Domain

Metavolcanic rocks and marble are the predominant rock types of the domain. Stereograms may indicate cylindrical folding of bedding and fold axes, and concentration of foliations and lineations. Bedding poles form a great circle band the π axis of which is 080-40. Bedding concentrates at 000-25; marble lamination, schistosity and fracture cleavage concentrate about 015/60. There are mainly intersection lineations, but also mineral and crenulation lineations; all three types concentrate about 080-50. Fold axial planes, mainly of open folds, strike north-northeast and dip moderately southeast. Axes of both closed and open folds form a band on a great circle the π axis of which is 300-25.

The preceding paragraph indicates that Lost Lake Domain is very similar to Cordova Lake Domain in attitudes and configuration of data; Lost Lake Domain is different, though, in its concentration of planar fabrics (only bedding

is cylindrically folded), in its better defined concentration of linear data, and in the attitude of the π axis of bedding poles. The differences are due probably to the difference of rock types in the two domains. The competent, siliceous metasedimentary rocks of the Cordova Lake Domain resist deformation, and may therefore be the cause of inhomogeneous strain, indicated by scattered lineations and S2 fracture cleavage, while the mafic and carbonate rocks of Lost Lake Domain are less resistant to deformation.

III.4.6 Belmont Lake-Cordova Mines Domain

Bedding, marble lamination, schistosity and fracture cleavage form a band about a great circle the π axis of which is 100-55. Schistosity and fracture cleavage cluster about 025/65. Lineations are all formed by intersection of bedding with schistosity (L1) and with fracture cleavage (L2?), except for a few mineral lineations; the scarcity of mineral lineations is probably on account of the lower metamorphic grade reached in this domain compared with domains further west, where a biotite lineation is prominent in rocks of similar composition. No crenulations were measured, although some were observed. The lineations form a vague great circle band; its π axis is 290-30. Axes to tight and open folds also form a great circle band; its π axis is 320-15. Axial planes of tight and open folds strike

north-northeast and dip moderately southeast.

The configuration and attitudes of stereogram data of this domain are similar to Cordova Lake Domain. Distinctive in this domain is the greater scatter of lineations. The west boundary of the domain is the locus for a probable fault, which will be discussed later in this chapter.

III.4.7 Crowe Lake Domain

The Crowe Lake Domain comprises mafic metavolcanic rocks and the Cordova gabbro. Poles to the small number of primary layering measurements outline a great circle; its π axis is 085-65. Poles to schistosity vaguely outline a horizontal great circle, suggesting rotation about a vertical π axis. Fracture cleavage poles lie on a wide great circle band the π axis of which is 170-30. There are a few intersection, mineral and crenulation lineations, which have various trends and shallow plunges. No fold elements were noted in the domain.

The scarcity of structural data in the domain results in less certainty about the attitude of π axes than in other domains. It is, however, the only domain in which schistosity and fracture cleavage plot at clearly different attitudes. Although the schistosity has similar attitude to that in adjacent domains, the fracture cleavage is distinct: the latter dips moderately southwest to southeast, and may

be related to the gold-ankerite-bearing east striking shear zones from which ore has been produced by the Cordova Mine.

In summary, planar features throughout the map area strike north to northeast, and dip east to southeast. Dips are steeper toward the southeast part of the map area, making the structure a homocline steepening from Oak Lake to Crowe Lake. D1 folding appears to be isoclinal. The D2 phase resulted in cylindrical folding of planar features about an east trending axis which steepens to the southeast. D3 phase folding had a major effect on the Oak Lake Domain, a minor effect on the Round Lake Domain, and possibly no effect on the rest of the map area in which the stereogram configurations of data are similar to each other. Only the Crowe Lake Domain has very different attitudes of fracture cleavages.

III.5 Boudinage, fractures and faults

There are several examples of boudinage of layers and veins in the map area; all indicate local extension in rocks with alternate layers of different strengths. Figure 8d shows boudined siliceous layers in a calcitic marble; boudinage here took place before or during folding, and contributed to the fold styles of adjacent layers.

Non-folded rocks also have undergone boudinage.

Joints in the map area have steep to moderate dips.

There are many which strike about 135, and a smaller group which strike 035 (Figure 13). The two most common strikes are therefore almost perpendicular. There is no evidence to link the joints with a Precambrian folding phase. They may be associated with Phanerozoic crustal extension. Attitudes of veins and dykes are random (Figure 14).

Faults with centimetre scale offset commonly strike about 015; dips are steep to moderate easterly. Equal numbers of minor faults have left- and right-hand offset. One fault with at least a few metres of displacement was identified (3766004931390); it juxtaposes siliceous dolomitic marble (of unit L?) with metaconglomerate of unit M. The fault surface is marked by closely spaced, parallel fractures. Its attitude is 005/68; sense of displacement could not be determined.

No fault zones were identified in outcrop in the map area; there are no apparent shear or mylonite zones. A breccia on the east shore of Cordova Lake (375820493816) may have been formed by faulting. It has angular, fine to medium grained, hornblende-plagioclase clasts, up to 1 m in diameter, with a calcite rim, in a brown-weathering calcitic marble. The clasts have a foliation, and some have been folded.

The map scale truncation of stratigraphic units along one side of a surface is indirect evidence for one major

Figure 13: Histogram of the strikes of joints and minor faults.

Figure 14: Histogram of the strikes of veins and dykes. The pattern of short lines indicates mafic dykes, x's indicate granite dykes, no pattern indicates quartz-bearing veins, and inclined lines indicate calcite veins.

fault; its trace is indicated on figures 2 and 4. Along the west side of Belmont Lake, the trace of the inferred fault follows the contact of units I and L. To the north, it separates units I and K. Its northern extent is less certain. The most likely position for it is along the east shore of Cordova Lake, incorporating the possible fault breccia described in the last paragraph, and separating unit J marbles from mafic schist and dykes (found along the shoreline and on nearshore islands and included in unit J). The trace is possibly continuous with the trace of a major north striking fault in Lake Township (J.M. Moore, personal communication, 1982). To the south, the fault trace is buried beneath Paleozoic rocks. Along the trace are outcrops of rusty, aluminous schists, as though the fault has followed almost parallel to the schist layer. On the west side of Belmont Lake, there are lenses of marble in chlorite schist and carbonate-rich chlorite schists near the inferred fault, suggesting a network of small faults.

Timing of fault motion is not known. The fault trace may be tightly folded 400 metres north of Munn Bay (Belmont Lake) (3753804933040), but the outcrop distribution there could likewise indicate a series of minor faults. There is no other evidence for tight folding of the fault; its trace is almost straight. Table 3 shows that diabase, quartz, feldspar and calcite veins are found on both sides of the fault, whereas small metagabbro bodies and granite are only

on one side of the fault, and rhyolite porphyry dykes only on the other. The diabase dykes probably arose from separate sources, and therefore may predate the fault. However, quartz and later veins may well have intruded the area after fault motion. The timing of fault motion will be discussed further in Chapter 5.

III.6 Structural Correlation

Geological reports of nearby areas (Figure 2) give varying histories of deformation, and describe different structures and fabrics. From the types of structures and fabrics produced and, to a lesser extent, their attitudes, deformation phases were regionally correlated (Table 8). Table 9 provides information from the reports, which was used to make the correlation. The names given to deformation phases by each author appear next to Roman numerals which were assigned to regionally correlative phases by the present author. The term "correlative" in this instance means an association of the results of deformation phases in separate areas; it does not suggest that each phase took place at the same time in separate areas.

There is a sequence of six regional deformation phases, I through VI. All six phases were mentioned by Thompson (1972); other studies report fewer.

Table 8: Regional correlation of deformation phases. Reports indicated by numbers in table are keyed to footnote. Phase I is the oldest and phase VI the youngest.

Report Region. Correl. Phase.	this one	2	3	4	5	6	7	8	9	11	15	16
I					pre- D1						pre- Fli- nton	
	int- rus- ion											
II	D1	F1	B1	F1	D1 & thr- usts	D1		Bdg. foln			D1	first phase
	int- rus- ion; fltg	thr- usts & int- rus- ion										
III	D2	F2	B2	F2 & int- rus- ion	D2	D2	main defm ?	maj- or fldg	maj- or fldg	maj- or fldg	D2	sec- ond phase
IV											D3	
V	D3			F3	D3	D3		cro- ss fldg		cro- ss fldg	D4	
VI					lat- er sli- cken side	D4 she- ar ing	lat- er pha- se?				myl- oni- tiz- ati- on	

2. Beavon, 1970
3. Best, 1966
4. Carmichael, 1967
5. Chappell, 1978
6. Evans, 1964
7. Heidecker, 1963

8. Hewitt, 1961
9. Hewitt and James, 1956
11. Lumbers, 1967
15. Thompson, 1972
16. Venkitasubramanyan, 1969

Table 8 (continued)

Key to abbreviations

bdg foln - bedding foliation

defm - deformation

fldg - folding

fltg - faulting

Table 9: Structural data from previous reports.

Report		this one	2	3	4	5	6	7	8	9	11	15	16
Pha-se	Fea- ture												
I	FAP					sch						min lent	
	att.
II	fold styl	iscl	iscl	sim recm	iscl	iscl recm, recl						tght flx- flow	iscl recm or recl
	FAP	sch	clv	sil sch	clst fltt	sch	sch					clv	
	att						llbdg
	FA	int	int		int, elg							elg	
	att
	met. grd	grsc ?			low	mid amph						grsc mid amph	
III	fold styl	open flx- flow	sym, mod open	sym, tght	open	tght	tght	many	tght	tght	tght	flx- flow mod open	tght ?
	FAP	sch	clv	sch	sch	crn, fct clv ?-			foln			clv	
	att		var
	FA	crn	int	min seg	int	crn	min	elg or crmp	strg			int	
	att
	met grd	grsc up- amph			grsc ep- amph	low amph						mid amph	

Report (cont.)		this one	2	3	4	5	6	7	8	9	11	15	16
Pha- se	Fea- ture												
IV	fold styl											flx- slp, flow mod- open	
	FAP att											clv	
	FAatt												
	met grd											grsc low- amph ?	
V	fold styl	warp				warp	warp		warp		open	open flx- slip ?	
	FAP				str- slp clv								
	att											var, g.	
	FA att	g			crn				g				
	met grd	post met			grsc ep- amph	post met						post met	
VI	shr							off- set, und. exn, jnts					
	att						vert						

Table 9 (continued)

Key to abbreviations

amph	-	amphibolite facies
att	-	attitude
clst fltt	-	clast flattening
clv	-	cleavage
crmp	-	crumpling
crn	-	crenulation
elg	-	elongation lineation
ep	-	epidote
FA	-	fold axis
FAP	-	fold axial plane
fct clv	-	fracture cleavage
flx-flow	-	flexural-flow
flx-slip	-	flexural-slip
foln	-	foliation
g	-	gentle
grsc	-	greenschist facies
int	-	intersection lineation
iscl	-	isoclinal
jnts	-	joints
lent	-	lenticles
low	-	lower
met. grd	-	metamorphic grade
mid	-	middle
min	-	mineral lineation
mod	-	moderately open
post met	-	post metamorphic
recl	-	reclined
recm	-	recumbent
sch	-	schistosity
shr	-	shearing
sil	-	silica
sim	-	similar
str-slip	-	strain-slip
tgth	-	tight
und. exn	-	undulatory extinction in quartz
up	-	upper
vert	-	vertical

The earliest phase (I) created folds as well as a foliation in rocks older than the Flinton Group. The second phase (II) produced tight folds and an axial planar foliation in rocks of the Flinton Group as well as older rocks. It is equivalent to phase D1 of this thesis. During and after phase II there was thrust faulting according to Beavon (1970) and Chappell (1978).

Phase III produced the "major folds" reported in some studies. The majority of map scale folds as well as predominant schistosity and lineations of most studies are associated with this phase, which correlates to phase D2 of this study. Heidecker's "main deformation" is probably correlative with III; he related many styles of folds as well as two mutually perpendicular lineations (a stretching elongation and a crumpling lineation) to the "main deformation" phase.

Only Thompson (1972) found evidence for deformation IV; he reported moderate flexural-slip and flexural-flow folding with an axial planar cleavage.

Phase V is the "cross-folding" of some reports. In the present study area, as phase D3, it produced open folds.

Chappell (1978), Evans (1964) and Thompson (1972) reported minor fault motion to be the final deformation, phase VI, generating slickensides, shearing and mylonitization, respectively. Heidecker referred to a

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"later phase" responsible for minor offsets, quartz grain undulatory extinction and joints; it may be correlative with phase VI.

Table 8 indicates timing of both intrusion and faulting as reported in studies by Beavon and Chappell as well as this one. The timing is discussed in Chapter 5 of this study.

Table 9 shows that attitudes vary from place to place, but fold style and types of fabric of each phase are consistent from one study to the next.

Carmichael (1967), Chappell (1978), Thompson (1972) and this study report the timing of highest metamorphic grade relative to deformation. According to Chappell, the highest grade was during phase I; this study found the highest grade to be between phases II and III (see Chapter 4), and Thompson and Carmichael reported the highest grade coincident with phase III.

IV: METAMORPHISM

IV.1 Introduction

Mafic, quartzofeldspathic, siliceous carbonate and aluminous rocks occur throughout the map area. Each rock type is characterized by a set of mineral assemblages varying according to metamorphic grade. The mineral assemblages indicate that metamorphic grade increases toward the northwest. The chlorite-out "isograd" has a complex pattern; considering only the mafic rocks, the pattern is relatively simple. Grain size of granoblastic matrix increases to the northwest. Textural relationships convey information about the time sequence of metamorphism and deformation. The sets of mineral assemblages suggest metamorphic reactions; a probable pressure-temperature path on the present erosion surface is deduced from the sequence of reactions.

IV.2 Metamorphic Mineral Assemblages

The equilibrium mineral assemblages of thin sections examined are entered in Appendix 2 and their localities are given in Appendix 1.

IV.2.1 Mafic Rocks

The lowest grade rock in the map area is metagabbro containing recrystallized plagioclase (An16 to about An35), relict plagioclase (An40 to An52), chlorite, clinozoisite and pale green to colourless clinoamphibole after pyroxene. The clinoamphibole is probably tremolite-actinolite. Other metagabbro in the same area contains stable hornblende as well. Metamorphic grade increases to the northwest. The assemblages in mafic intrusive and extrusive rocks indicate the following progressive changes to higher grade:

both hornblende and pale amphibole are present (in many cases, the hornblende forming a rim around the pale amphibole) as well as chlorite;

hornblende and chlorite are present without pale amphibole;

hornblende is present without chlorite;

hornblende and clinopyroxene coexist.

Many relict plagioclase grains in the east half of the map area have a narrow zone of slightly more calcic plagioclase around the core.

The highest grade metagabbro has biotite with vermicular quartz; there is myrmekite in the microcline. Minor quartz and microcline are also found in a few other mafic rocks, and a trace of garnet in one. Small grains of carbonate and of epidote (or clinozoisite) are retrograde minerals in most mafic rocks. Very fine grained minerals,

probably sericite, scapolite, calcite and chlorite, are found within grains of relict plagioclase. Magnetite and skeletal leucoxene are common in metagabbro.

IV.2.2 Aluminous Rocks

Mica-rich rocks are not plentiful in the map area; they vary in composition, which influences the mineral assemblage. In general, the mineralogy changes in the following manner, toward higher grade:

chlorite, muscovite and biotite are stable together;

muscovite and biotite coexist without chlorite;

muscovite, biotite and microcline are stable together.

Quartz is ubiquitous. Garnet is found in rocks in the eastern two-thirds of the map area, and is probably missing from the western rocks only because of their composition. The only aluminosilicate found was an occurrence of kyanite in a muscovite-biotite schist (sample 39, Appendix II). Cummingtonite occurs in iron rich schist at several places. Either plagioclase (oligoclase to andesine) or microcline is found in most aluminous rocks. Hematite and pyrite are common accessory minerals, and traces of carbonate and tourmaline are present locally.

IV.2.3 Felsic and Intermediate Rocks

Felsic and intermediate rocks are widespread. Most contain micas; the change in mica assemblages reflects metamorphic grade change, as in the case of the more aluminous rocks. With increasing grade, rocks change progressively as follows:

chlorite and muscovite coexist;

chlorite, biotite and muscovite coexist;

biotite and muscovite coexist without chlorite;

biotite, muscovite and microcline coexist;

biotite and microcline coexist without muscovite.

Many intermediate rocks contain amphibole, generally hornblende; in some samples from the southeast of the map area, hornblende is accompanied by pale clinoamphibole probably tremolite-actinolite. Plagioclase (An10 to An20) is present in most rocks; a grain of relict An32 plagioclase, probably originally a sand grain, was found in one metamorphosed mudstone. Microcline or untwinned potassic feldspar occurs in many samples. Carbonate, epidote or clinozoisite, magnetite, hematite, apatite, and pyrite are accessory.

Near Oak Lake and Long Lake, the felsic and intermediate rocks contain discontinuous quartz-feldspar

veinlets which vary in width. The origin of the veinlets is important in determining metamorphic grade of the host rocks. The veinlets could be related to the intrusion of nearby granite bodies, or they could have resulted from hydrothermal activity, or from anatexis of the host rocks. Muscovite is less abundant in the veinlet-bearing rocks than in lower grade rocks, but appears to be stable; this suggests that the rocks have not undergone anatexis. The coarse grain size and lack of biotite in the veinlets indicates that they are not simply stray portions of the biotite granite magma. Their location seems to be dependent on metamorphic grade and not on proximity to granite bodies. The veinlets are therefore probably the result of hydrothermal activity or incipient anatexis.

IV.2.4 Carbonate-bearing Rocks

The presence or absence of chlorite in mica-bearing carbonate rocks indicates higher or lower grade, respectively. There are other metamorphic reactions, as well, useful to the establishment of metamorphic grade in this area. Dolomite plus quartz react up grade to form calcite plus tremolite; dolomite and quartz coexist on Belmont Lake, whereas tremolite occurs between them west of Little Whitney Lake. The isograd which marks their reaction therefore lies within chlorite-bearing rocks between Little Whitney and Belmont Lakes; sparsity of data precludes its

accurate location.

The other interesting calc-silicate mineral assemblage in the map area is calcite + plagioclase (An₂₀) + clinozoisite + grossularite + augite + quartz which forms a gneiss in the Oak Lake dome (sample 90, Appendix II).

Winkler (1976) states that the assemblage zoisite/clinozoisite + grossularite + quartz + anorthite + calcite has a univariant P-T relationship. It is the product of two simultaneous dehydration reactions:

The two reactions take place at increasing temperature with increasing pressure. Their reaction curve crosses the limit of wet anatexis at about 5.3 kbar and 630 degrees Celsius (Winkler, 1976). Felsic rocks surrounding the calc-silicate gneiss contain a few granite veinlets. If the veinlets are the result of incipient anatexis, then the calc-silicate assemblage was stable when anatexis began. If the veinlets are hydrothermal, then temperatures of anatexis were not reached, and the pressure remained less than 5.3 kbar. The pressure must have reached little higher than 5.3 kbars (the equivalent of about 19 kilometres depth of burial) when the maximum grade of metamorphism was reached in the Oak Lake dome. This information will be applied to a discussion of the pressure and temperature of metamorphism later in this

chapter,

IV.3 Chlorite-out "Isograd"

One metamorphic change which most rock types have in common is that they lose chlorite with increasing metamorphic grade, a reaction in the lower to middle amphibolite facies. The presence or absence of chlorite is indicated on Figure 15 by closed and open circles respectively. The chlorite-out isograd is the dotted line drawn between areas of stable chlorite and no chlorite. The dashed line shows the chlorite-out isograd taking into account only mafic rocks of basaltic or gabbroic composition.

The lowest grade rocks are near Crowe Lake, and the highest grade rocks are near Long Lake; the area in between has a complex isograd pattern which separates it into linear chlorite-in and chlorite-out zones. The gabbroic or basaltic mafic rocks have a simple metamorphic distribution; their chlorite-out isograd bisects the map area. The significance of the isograd pattern will be discussed in Chapter 5.

Figure 15: Map of the chlorite-out isograd. Circles, triangles, squares and hexagons represent respectively mafic, aluminous, felsic (or intermediate) and carbonate-bearing rocks. Closed symbols indicate stable chlorite. The dashed line separates chloritic (striped) and non-chloritic metagabbro and metabasalt. The dotted line separates chloritic (shaded) and non-chloritic rocks, taking account of all rock types.

IV.4 Grain Size Variation

In general, metamorphic recrystallization of fine grained rocks causes an increase in matrix grain size. The average granoblastic grain size is an indication of the amount of grain growth during metamorphism, not the metamorphic grade of the rock. Quartz and feldspar matrix grains of mafic, intermediate and felsic granoblastic rocks were measured. Their localities are plotted on Figure 16, with contour lines separating grain size intervals. The contours form a complex pattern, but indicate a general increase of grain size to the northwest, the same direction as the general increase of metamorphic grade. The detail of grain size contours is quite different from the detail of the chlorite isograd pattern, suggesting that metamorphic grain growth depends on a set of variables different from that of the chlorite-out reactions.

IV.5 Metamorphic textures

In the lowest grade mafic rocks, east of Belmont Lake, primary textures are preserved, and metamorphic recrystallization is visible only in the granoblastic nature of matrix grains, and the zonation of plagioclase and amphibole grains. Mafic rocks to the west, however, show more metamorphic mineral growth (mica and chlorite schistosity and hornblende lineation).

Figure 16: Map of average matrix grain size, in hundredths of a millimetre, of fine grained rocks. Circles, x's and squares represent mafic, intermediate and felsic compositions, respectively. The dashed lines are contours of constant grain size.

The finest example of overprinting of textures found by the author in the map area is in an intermediate cummingtonite-biotite-garnet-chlorite schist (sample 46, Appendix II); a photomicrograph (Plate 1a) shows two generations of platy minerals preserved in subhedral, equant garnet porphyroblasts. The highest metamorphic grade, represented by garnet growth, was achieved after the growth of a schistosity (S1) and subsequent, non-oriented mica porphyroblasts. In the example, garnet appears to have nucleated on mica grains; the apparent radial zonation of the garnets is not understood, but is probably related to the position of the replaced mica grain with respect to the garnet.

In aluminous rocks, coarser clastic grains (generally quartz) retain a rounded, clastic appearance, whereas fine grains are recrystallized. The prominent schistosity (S1) in most rocks is defined by parallel chlorite, biotite or muscovite grains. In some rocks, the schistosity was crenulated (Plate 2a) by a second deformation (D2). S1 schistosity is preserved as inclusion trails in euhedral porphyroblasts of garnet, magnetite or cummingtonite (Plates 1b, c, d). The relative ages of crenulation and garnet growth cannot be determined, as garnets are not found in crenulated rocks. Blades of kyanite lie in an S1 muscovite schistosity but are aligned with linear biotite grains (L1?) (Plate 2b). A thin section of a garnet-chlorite schist

Plate 1:

Plane light photomicrographs of garnet porphyroblasts in which metamorphic textures are preserved.

1a.

Sample 74, Appendix II. Subhedral garnet occupies three-quarters of the photograph. A fine grained schistosity (S1) was overgrown by a large mica porphyroblast. Garnet appears to have nucleated on the mica porphyroblast, and exactly replaced it. Growth of the mica porphyroblast followed by the garnet porphyroblast may have taken place during a single prograde metamorphism.

1b.

Sample 41, Appendix II. Weakly aligned laths of chlorite are completely replaced by garnet at the margin of the subhedral garnet porphyroblast. The chlorite may be an S1 schistosity.

1c.

Sample 46, Appendix II. Subhedral garnet contains folded inclusion trails of quartz which are continuous with chlorite schistosity (S1) outside the garnet. The garnet has been rotated so that its trails are almost perpendicular to S1.

1d.

Sample 37, Appendix II. Anhedral garnet contains sigmoidally folded inclusion trails continuous with S1 chlorite schistosity. Garnet probably grew during D2, when S1 was being folded, but may have grown after D2.

Plate 1

Plate 2:

Photomicrographs of metamorphic textures in plane light.

2a.

Sample 48, Appendix II. Muscovite schistosity (S1) is crenulated to tight microfolds which are outlined by folded muscovite grains as well as opaque minerals.

2b.

Sample 39, Appendix II. Muscovite schistosity (S1) is overgrown by subparallel linear biotite and kyanite grains (L1?).

2c.

Sample 68, Appendix II. The clear area in the middle of the photograph is a poikiloblastic muscovite grain which truncated biotite grains of the schistosity (S1). Such muscovite grains are randomly oriented, and are thus thought to be products of a post-D2 retrograde metamorphism.

2d.

Sample 67, Appendix II. The surface shown is the south-facing sawn surface of the rock sample in figure 11. The prominent biotite schistosity (S1) is subparallel to the layering (S0), parallel to the length of the photograph. The weak S2 biotite schistosity is represented by small biotite grains parallel to the width of the photograph.

Plate 2

demonstrates a folded S1 schistosity preserved as inclusion trails within a slightly elongate garnet porphyroblast (Plate 1d); there was therefore garnet growth during or following D2.

Quartzofeldspathic rocks generally have a strong S1 schistosity of parallel chlorite, biotite or muscovite. There are examples of a weak S2 schistosity of small biotite aggregates which grew across the prominent S1 schistosity (Plate 2d, Figure 11). There are many examples of a prominent S1 schistosity overgrown by randomly oriented, large, poikiloblastic muscovite grains (Plate 2c) which must have grown in a static period after the highest grade of metamorphism, and after D2.

Discontinuous granitic veinlets are found in quartzofeldspathic rocks in the centre of the Oak Lake dome (unit A) and at Long Lake; the veinlets are tightly folded and therefore predated or accompanied at least one phase of folding. The folding of veinlets indicates, therefore, that incipient anatexis, hydrothermal activity or granite intrusion predated or accompanied at least one folding event, probably D2, at Oak and Long Lakes.

Textural timing evidence in calc-silicate rocks comes from clinozoisite-grossularite-augite gneiss in unit A at Oak Lake (sample 90, Appendix II). Clinozoisite-coated garnet spheroids are surrounded by sigmoidally folded

gneissic layering; the folded gneiss is truncated by both folded and straight granite and pegmatite veinlets. Gneissic layering, and probably the spheroids, formed during D1. Veinlets intruded the host rock probably between D1 and D2. The nearby granite body was emplaced before D2. Spheroid rotation (sense of rotation not known, because rock sample is not oriented) and folding of the gneissic layering happened during D2, and the veinlets were folded at the same time; some veinlets may have intruded after D2. The nearby granite body acquired a foliation during D2. Gneissic layering was refolded during D3 to form dome and basin patterns.

Throughout the map area, there is evidence of retrograde reactions, pyroxene to hornblende and pale amphibole, hornblende to pale amphibole, biotite to chlorite, and plagioclase to very fine grained minerals.

In summary, most porphyroblasts in the map area grew during a static period between D1 and D2 when metamorphic grade reached its apex. As well, there are cases of porphyroblast growth during and after D2 folding. Poikiloblastic muscovite grew during a retrograde metamorphism after D2. Retrograde reactions of pyroxene, amphibole, biotite and chlorite may have occurred at the same time.

IV.6 Pressure-Temperature Path on the Erosion Surface

With increasing metamorphic grade, plagioclase increased in anorthite content (from An₁₀₋₁₆ to An₃₅₋₅₂), and colourless to pale green amphibole yielded darkly pleochroic hornblende. Chlorite and muscovite became less abundant, and biotite more abundant. At highest grade, hornblende and clinopyroxene coexisted. Dolomite and quartz became incompatible.

On a P-T diagram (Figure 17), curves were drawn to show the sets of conditions at which reactions take place during metamorphism of different rock types (Winkler 1976). From evidence of the above mineralogical changes, an approximate pressure-temperature path on the erosion surface of the map area was drawn. Mafic rocks near Crowe Lake contain hornblende and plagioclase (with a composition of An₁₅ or more), which indicates a maximum metamorphic temperature of about 500 degrees Centigrade; the mineral assemblage can not be used to determine limits of pressure. The An₁₇ curve separates upper greenschist from lower amphibolite facies. The intersection of the limit of wet anatexis and the calc-silicate reaction curve (see section IV.2.4 of this thesis) provides a maximum temperature (630 degrees Centigrade) and pressure (5.3 kbar) for rocks in the Oak Lake dome. The wet anatexis curve separates middle from upper amphibolite facies. There is some doubt whether the rocks at Oak Lake achieved anatexis; the maximum pressure

Figure 17: Pressure-temperature diagram. Reaction curves are from Winkler (1976); aluminosilicate triple point is after D.M. Carmichael (Met. Petr. course notes, Carleton University, 1981). The dashed line represents pressure-temperature conditions at the highest grade of metamorphism in the map area, exposed on the present erosion surface.

may therefore have been less than 5.3 kbar. The P-T path is shown to enter the field of sillimanite, although no sillimanite was found. The path satisfies evidence of the other reaction curves; the one aluminosilicate occurrence (kyanite) does not contradict the position of the P-T path as drawn.

Metagabbro in the Oak Lake dome (sample 31, Appendix II) contains hornblende but not pyroxene, indicating middle amphibolite facies. North of Long Lake, the metagabbro contains stable hornblende and clinopyroxene, indicating grade higher than that at Oak Lake. The maximum temperature at Oak Lake (630 degrees Centigrade) is therefore lower than the highest temperature reached near Long Lake. It is not certain if there has been anatexis in the rocks at Long Lake, so metamorphic grade there may be either middle or upper amphibolite facies. The grade could not have reached granulite facies as the rocks do not bear orthopyroxene.

In summary, metamorphic grade increases northwestward from Crowe Lake to Long Lake. It ranges from upper greenschist to middle to upper amphibolite facies.

V. DISCUSSION

This chapter presents conclusions drawn from the preceding data, and summarizes the geological history of the study area.

V.1 Unit M: Position in Regional Stratigraphy

Miller and Knight (1914) assigned rocks of unit M to the Hastings Series (sic), to which they also assigned metaconglomerate near Flinton. The latter is assigned to the Flinton Group (Thompson, 1972). Both localities have well preserved pebble and cobble metaconglomerates.

Miller and Knight may have been correct in correlating the two metaconglomerates. Unit M might be part of the Flinton Group, as shown in the following paragraph.

In many ways, the metaconglomerate at Belmont Lake resembles metaconglomerate of the Bishop Corners Formation in the Flinton Group. Both are polymictic, framework-supported in part, with well-rounded pebbles, cobbles and boulders. Both have matrix rich in hematite and magnetite, signifying a dominantly terrestrial source of detritus. Both vary in both clast type and lithology over short distances. Both are cross-cut by very few veins and dykes, including lamprophyre dykes.

In other ways, unit M is dissimilar to the Flinton Group. Unlike the Flinton Group, unit M does not appear to rest on a major unconformity, nor to postdate any deformation phases which affected nearby Grenville Supergroup rocks (i.e. unit L). (One interesting point to note is that a dyke of rhyolite porphyry, probably correlative with rhyolite porphyry of unit M, truncates folded laminations of unit L. This suggests that the porphyry of unit M was deposited after deformation of unit L. On the other hand, the marble and the rhyolite dyke may have been initially deformed at the same time; the marble would show much more strain than the rhyolite because of the differences in competence of the two rock types.) Whereas the Flinton Group appears to postdate all volcanism in the Grenville Province (with a possible exception near Ompah (Smith, 1969)), unit M was deposited concurrently with felsic and probably mafic volcanism. As well, there are mafic dykes cutting through unit M, and the unit is overlain by a thick layer of metabasalt (unit N). A large gabbro body (the Cordova gabbro) is younger than unit N, and also therefore younger than unit M; there is presently no knowledge of intrusive bodies younger than the Flinton Group.

In summary, unit M is a coarse clastic unit derived mainly from a local, weathered, terrestrial source. It therefore may well have been deposited long after the

submarine volcanism and sedimentation which made most units in the map area. In this sense, unit M may be correlative with the Flinton Group, though not necessarily time-equivalent. Syn- and post-unit M igneous activity are presently a problem to its correlation with the Flinton Group, but future mapping of the Flinton Group and age-dating of igneous bodies in the C.M.B. may reveal more post-Flinton Group intrusions and volcanic units.

V.2 Significance of the Chlorite-out Isograd Pattern

The chlorite-out "isograd" was discussed in Chapter 4, and its pattern is shown on Figure 15. The pattern is complex and deserves an explanation.

The "isograd" coincides with lithologic contacts in many places; mafic and carbonate-rich rocks bear chlorite in places where adjacent felsic and aluminous rocks do not. In these places, therefore, the "isograd" position indicates a change in lithology rather than a change in metamorphic grade. The contact area between units I and M on the west side of Belmont Lake is an example. Mafic, metavolcanic rocks of unit I have stable chlorite, whereas nearby felsic, metasedimentary rocks of unit M do not. In fact, intermediate composition volcanoclastic rocks of unit I, in this area, do not have chlorite either. Therefore, there is evidence for a major fault in this area (the contact between units I and L), but there is no evidence that the fault

formed during or after metamorphism. The inferred fault probably formed before the highest metamorphic grade was reached.

Between Round and Cordova Lakes is a linear zone of chlorite-free rocks. The zone cuts across stratigraphic units, and therefore includes several rock types. Mafic rocks which bear hornblende, but neither pale amphibole nor pyroxene, suggest that the zone is in the middle amphibolite metamorphic facies. Within the zone are almost all small metagabbro bodies and dykes of the map area. The density of mafic intrusive bodies plus the lack of chlorite in host rocks suggests that the intrusion of gabbro in this area rendered the host rocks incapable of producing chlorite. The mechanism may have been a dehydration of the host rocks, or a zone-wide elevation in temperature at the time of maximum metamorphic grade.

V.3 Timing of Intrusions and Fault Motion

Relative ages of the gabbroic and granitoid intrusive bodies cannot be determined directly, because they are not in contact. Their relative ages can only be deduced from structural and metamorphic evidence, and from evidence of cross-cutting veins and dykes, which may be correlative with the intrusive bodies.

The small metagabbro bodies between Round and Cordova

Lakes intrude rocks as young as unit I. The spatial association of the bodies with a zone free of chlorite suggests that they were emplaced before or during the achievement of the highest metamorphic grade (between D1 and D2). The bodies have a strong hornblende lineation parallel to the L1 hornblende and biotite lineations in surrounding rocks, suggesting that they were in place before D1. If the small gabbro bodies were feeders for overlying mafic volcanic rocks (probably unit I, possibly unit N), then they intruded at the time of volcanism, well before D1, and predate all other intrusions.

The Cordova gabbro intruded and therefore postdates unit N metavolcanic rocks. Schistosity in the metagabbro body suggests that it intruded before the deformation (D1 and D2) of units L, M and N.

Quartz monzonite was foliated before granite intrusion. One granite body has a regional S2 foliation. The two main schistositities of the map area formed during D1 and D2; therefore the quartz monzonite probably intruded before D1, and granite between D1 and D2.

The sequence of intrusions is therefore as follows. Small gabbro bodies were possibly emplaced during the extrusion of unit I basalt and andesite. Quartz monzonite was later intruded at Oak Lake and Long Lake and the Cordova gabbro was emplaced. Both gabbro and quartz monzonite were

deformed during D1. After D1, the maximum metamorphic grade was reached and granite bodies were intruded. The granite was then deformed during D2.

In Chapter 3, there is evidence for motion of the inferred major fault following intrusion of gabbro bodies and granite veins, and therefore possibly following intrusion of the granite. This would require fault motion following D1. Similar metamorphic grade on both sides of the fault suggests fault motion before the highest grade of metamorphism, which implies that granite, and therefore all large intrusive bodies, were in place before the highest grade of metamorphism.

V.4 Evidence for More than one Orogeny

Most layered rock units in the map area have deformation patterns which could be achieved by the two or three deformation phases described in Chapter Three. The three phases were probably the result of a single cycle of burial, deformation, and uplift.

However, there is subtle evidence for a previous orogeny. In Chapter 2 are three descriptions of clasts which have a foliation, in units D, J and M. In each example, the clasts may have had a metamorphic layering before they were deposited, and therefore may have come from a metamorphic terrain. Few foliated clasts were found,

indicating that metamorphic terrain was not a principal source of detritus. The foliated clasts suggest, however, that nearby outcrops had already undergone one orogeny before most of the rocks of the present map area were deposited.

V.5 Summary of Geologic History

The chronology of geological events in the map area is given in Table 10. Evidence is accompanied by speculation to create a credible prehistory for the area mapped.

Table 10: Summary of geologic history.

Time	Environment	Depos'n (strat. unit)	Intrusion	Deformation	Metamorphism
present	unconformity		calcite veins	↑	↑
early to middle Ordo- vician	erosion shallow inland sea	lime- stone			
Hadrynian ?	unconformity			jointing D3?	post-metan. mu prbl; retrograde
Helikian	↑		felsite veins	D2	bl schisto- sity
	uplift and erosion		quartz/ epidote/ ankerite veins		
			pegmatite veins		
	maximum pressure and temperature			major fault?	highest grade (ga, mt, ky, cu prbl)
	↑		granite bodies and dykes		
	burial		g2 monz; happ dyke	D1	mica and chlorite schisto- sity
	↑		Cordova gabbro and syenite		
	subaerial uncon- formity?	N M	dibs dyke rylt prpy dyke		
	↑	J - L			
	shallow marine uncon- formity?	I	small gab- bros and dibs dyke		
erosion?	↑	A - H			
				basement deformation?→	basement meta- morphism?

Table 10 (continued)

Key to abbreviations

bi	-	biotite
cu	-	cummingtonite
dibs	-	diabase
ga	-	garnet
lmpp	-	lamprophyre
mt	-	magnetite
mu	-	muscovite
prbl	-	porphyroblast
prpy	-	porphyry
rylt	-	rhyolite

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APPENDIX I

Figure 18: Localities of thin sections. Numbers refer to locality of numbers of Table 11, Appendix II.

APPENDIX II

Table 11: Metamorphic mineral assemblages. Plagioclase compositions are and average of relict grains. Minerals are listed in order of increasing abundance.

Locality	Sample No.	Proto-lith	Strat. Unit	UTM Coordinates	Mineral Assemblage
Mafic Rocks					
1	007B1	bslt	I	3741604934850	op-cb-pc-czo-hb
2	012B1	bslt	I	3756004935200	cb-ch-czo-An30-pale am
3	015B1	bslt	I	3752204936560	cb-pc-ep-pale am
4	074B1	dyke?	I	3739404938220	op-ep-pc-hb
5	093B2	bslt	I	3730104934340	op-cb-ep-ch-hb-pc
6	135B1	bslt	G	3718004936890	cb-czo-An58-hb
7	216B2	bslt	I	3752804938780	bi-op-cb-czo-pc-pale am
8	237B2	bslt	N	3758604924760	py-mt-ch-ep-pc-pale am
9	038E2	bslt	I	3747704930920	ch-czo-bi-hb-An40
10	089E6	gbbr	O	3698204940860	cb-py-hb-pc
11	090E2	bslt	C	3701404941140	czo-cc-bi-hb-An40
12	104E7	gbbr	O	3747204930720	cc-czo-ch-hb-act-pc
13	109E1	bslt?	I	3750604933180	cc-ch-qz-pc-hb-ep-grun?
14	110E1	tuff	I	3747004933260	ep-op-ch-cb-trem-pc
15	138E2	gbbr	O	3710204931980	cc-ch-hb-pc
16	144E1	sed?	F	3724404941360	cum?-ga-hb-qz
17	148E2	bslt	D	3715804941300	scap?-bi-hb-pc
18	186E1	bslt	N	3783204931600	ch-hb-hm-bi-czo-pc
19	217E2	gbbr	O	3754804942120	mt-bi-act-hb-pc
20	240E1	sed	I	3750004939500	ga-bi-act-hb-pc
21	246E2	gbbr	O	3730104940150	op-czo-ser-pc-pale am
22	256E1	gbbr	O	3804504927570	ch-czo-bi-act-pale am-An50
23	277E1	gbbr	O	3808204929020	op-bi-pale am-ch-An42-czo-act
24	278E1	gbbr	O	3798204929860	op-pale am-An41-cb-ch-czo-act
25	280E2	gbbr	O	3802204930780	bi-ap-czo-hb-An38
26	283E1	gbbr	O	3796004930340	cb-ch-czo-hb-qz-act-An52
27	285E1	dibs	O	3791004930740	cb-py-ch-An43
28	301E2	gbbr	O	3790104930100	op-bi-pc-ap-ch-hb
29	301E6	dibs	O	3790104930100	cb-op-ch-qz-hb-ks-An34
30	306E1	brcc	N	3765204929240	ep-cb-qz-mc-pale am-bi-An32
31	332E1	gbbr	O	3692504943130	scap?-cb-bi-op-An42-hb
32	354E1	brcc	N	3765004929170	act?-bi-mc?-pc
33	359E1	gbbr	O	3782004935100	op-cb-pale am-bi-czo-ch-An17
34	022M1	bslt	N	3779004932660	bi-cb-ch-czo-pc-pale am
35	034M1	gbbr	O	3631204940420	ap-sf-cpx-bi-mc-hb-An27

Aluminous Rocks

36	003B2	mdst	G	3721804933920	ch-ga-qz-grun?
37	070B1	mdst	I	3739804934060	qz-cu-ga
38	091B1	mdst	G	3726604934860	An32-ap-hm-op-bi-mu-qz
39	107B2	clst	D	3702604939710	to-pc-sf-ky-mu-bi-qz
40	193B2	mdst	H	3742404940340	ga-mu-qz-fs
41	117E1	Fmdst	K	3759204934880	ch-mt-ga-qz
42	118E2	Fmdst	L	3763404934660	op-cb-mu-ch-bi-qz-An20
43	158E1	mdst	F	3746604943500	ga-ks-bi-ch-qz
44	169E1	mdst	C	3694404941060	ap-cb-op-bi-mu-mc-qz
45	202E1	mdst	K	3771404939200	hm-mu-pc-qz
46	247E1	mdst	I	3751204939120	cb-ga-ch-bi-qz
47	351E4	Fmdst	B	3681404941820	op-hm-cu-ep-mc-qz

Felsic and Intermediate Rocks

48	001B1	mdst	G	3713104933500	cb-mu-bi-qz
49	083B1	tuff	E	3712204934690	op-cb-mc-bi-An12-qz
50	095B1	tuff	E	3702404934910	op-cb-ch-bi-qz-ks
51	156B1	tuff	H	3725004936870	mu-bi-ks-qz
52	159B1	tuff	K	3781604938440	op-pc-mu?-cb-bi-qz
53	002E1	tuff	M	3763604930740	cb-bi-mu-qz-An17(phen)
54	025E1	bomb	K	3765504936740	bi-ch-cb-qz-An10(phen)
55	029E1	vlct	K	3772204937410	op-bi-cb-ep-ch-hb-qz-pc
56	039E1	sed	I	3750404931090	ep-op-mu-cb-bi-qz-ch
57	049E5	sdst	M	3755304930080	cb-mt-mu-bi-ab-mc-qz
58	052E1	sed	I	3750204931310	mt-bi-cb-ks-pc-qz
59	052E2	sed	I	3750204931310	op-cb-ep-ch-bi-mu-qz
60	053E1	sed	I	3751004931180	cb-py-ch-bi-An20-qz
61	055E2	sed	I	3751004930890	py-ep-ch-cb-bi-pc-qz
62	056E1	ands	I	3749804930800	op-ep-bi-ch-cb-qz-An12
63	060E1	slst	M	3771904931750	op-cb-czo-pc-qz-bi
64	064E1	mdst	M	3769804931870	hm-ch-bi-qz-cc
65	109E2	vlct	I	3750604933180	hm-bi-ch-qz
66	122E1	sed	M	3780804935160	cb-op-bi-hb-pale am-qz-ep-mc
67	133E1	wcke?	E	3703204932880	op-hm-bi-cb-qz
68	137E1	dact?	E	3711404932260	cb-An20-mu-bi-qz
69	147E1	arks	C	3714004941220	op-bi-mu-pc-mc-qz
70	170E5	tuff	C	3692604940920	mu-bi-An15-qz
71	172E1	arks	C	3686004941300	ep-bi-mu-qz-mc
72	194E5	sdst	E	3707804936080	An10-cb-bi-qz
73	281E1	vlct	N?	3801604931440	ep-cb-mu-qz-ch-pc
74	296E1	sed	I	3733904938390	hb-grun?-ch?-ga-qz-pc
75	301E5	qmonz	P	3790104930100	ch-qz-An25-mc
76	302E1	syen	O	3789004930840	op-hm-ch-cb-hb-An16-grun?
77	339E1	rykt	M?	3777404936030	cb-mu-qz-ab / ab-qz phens
78	347E1	qdior	O	3688304942980	zr-op-ep-bi-qz-mc-An16
79	358E1	qdior	O	3784304932180	op-cb-czo-ch-bi-qz-An15
80	002M1	tuff?	D	3686704933180	ep-ab-ks-mu-bi-cb-qz
81	008M1	qmdst	H	3728904933740	mu-bi-mc-qz

Carbonate-bearing Rocks

82	106B3	brcc	F	3705304339390	op-Fecc-ch-bi-mu-mc-qz
83	018E2	qlmst	K	3761504937280	bi-mu?-qz-cc
84	027E3	lmst	L	3768504936940	op-qz-cc
85	046E1	wcke	M	3752704929830	mu-Fedo-An35-qz
86	055E1	lmst	L	3751004930890	qz-cc
87	205E3	vein	E	3704404936800	hm-op-ch-ep-cc-qz
88	211E3	marl	H	3743204941260	hm-mc-ep-qz-cc
89	256E4	lmst	N?	3804504927570	ch-tr-cc
90	336E1	qlmst	A	3695904942600	cc-An20-czo-gros-ag-qz
91	340E1	brcc	L	3774204935600	hm-mu-tr-cc-qz
92	352E1	qlmst	B	3683104941750	py-hm-to-An31-ph?-qz-cc

Table 11 (continued)

Key to abbreviations

Protoliths

ands	-	andesite	qdior	-	quartz diorite
arks	-	arkose	qlmst	-	siliceous limestone
brcc	-	breccia	qmdst	-	siliceous mudstone
bslt	-	basalt	qmonz	-	quartz monzonite
clst	-	claystone	rylt	-	rhyolite
dact	-	dacite	sdst	-	sandstone
dibs	-	diabase	sed	-	sediment
Fmdst	-	iron-rich mudstone	slst	-	siltstone
gbbrr	-	gabbro	syen	-	syenite
lmst	-	limestone	vlct	-	volcaniclastic
mdst	-	mudstone	wcke	-	wacke

Minerals

ab	-	albite	grun	-	grunerite
act	-	actinolite	hb	-	hornblende
ag	-	augite	hm	-	hematite
am	-	amphibole	ks	-	potassium feldspar
An	-	anorthite	ky	-	kyanite
	-	content	mc	-	microcline
ap	-	apatite	mt	-	magnetite
bi	-	biotite	mu	-	muscovite
cb	-	carbonate	op	-	opaques
cc	-	calcite	pc	-	plagioclase
ch	-	chlorite	ph	-	phlogopite
cpx	-	clinopyroxene	phen	-	phenocrysts
cu	-	cummingtonite	py	-	pyrite
czo	-	clinozoisite	qz	-	quartz
ep	-	epidote	scap	-	scapolite
fs	-	feldspar	ser	-	sericite
Fecc	-	ferrocalcite	sf	-	sulphide
Fedo	-	ferrodolomite	to	-	tourmaline
ga	-	garnet	tr	-	tremolite
gros	-	grossularite	zr	-	zircon

Horse L.

RIVER

Black Lake

OAK LAKE

South Lake

D

2

13a

Ontario

Ministry of
Natural
Resources

Hon. Alan W. Pope
Minister

W. T. Foster
Deputy Minister

Figure 2

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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LOCATION MAP

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

LEGEND

PHANEROZOIC
CENOZOIC
QUATERNARY

PHANEROZOIC

CENOZOIC

QUATERNARY

RECENT

Stream, lake and swamp deposits

PLEISTOCENE

Glacial, glacioluvial and glaciolacustrine deposits

UNCONFORMITY

PALEOZOIC

ORDOVICIAN

14

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

UNCONFORMITY

PRECAMBRIAN

LATE PRECAMBRIAN

METAMORPHOSSED INTRUSIVE ROCKS

FELSIC INTRUSIVE ROCKS

13

- 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

- 12 Biotite granodiorite, quartz monzonite

INTERMEDIATE TO MAFIC INTRUSIVE ROCKS

11

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

INTRUSIVE CONTACT

10

- 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

9

- 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

8

- 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 METASED.

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

4
st

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
- 1i 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

MARGIN

BELMONT AND METHUEN

LOCATION AND ACCESS

The map-area includes all of Belmont and five lots of Methuen Township. The Mines are situated in the southwest of Belmont Township Highway 7 traversing Township County Roads 44-46 and the western north-central and south. Numerous township concession roads provide excellent access to and Long Lakes in Methuen Township and Crowe Lakes in Belmont Township. Four lakes are only partially navigable.

MINING AND EXPLORATION

Magnetite iron ore was exploited and iron and gold have been mined in the area for over a century (Belmont Cordova Ledy). The area has been explored for base and precious metals. The only present metal production and dumps at the Cordova Mine. The area operates a quarry for the production of aggregate. The properties in the area are described by Carter (1980).

GENERAL GEOLOGY

Approximately one-half of Belmont Township is composed of Precambrian rocks, predominantly limestone and dolomite. The Paleozoic geology was mapped in 1979 as part of a Terrain Geology Section of the Ontario Geological Survey. Thus the attention given the Paleozoic was minimal, save between Precambrian and Paleozoic.

The Precambrian stratified rocks, are mostly volcanic flows in composition from basalt to dacite. The area is underlain by rock clearly with less abundant clastics (the clastic units is difficult in much of the area and siliceous chemical products).

17 of

GINAL NOTES AND SOUTHERN IN TOWNSHIPS

CESS

Belmont Township and the southernmost part of the towns of Havelock and Cordova. The west and northeast parts, respectively, of 7 traverses the southern part of the Belmont 46 and 48 provide access to, respectively, the southeast and south sections of the map-area. The fire access, farm and private cottage access to most of the areas, as do Oak South Township and Round Cordova Belmont Township. The rivers connecting the latter are navigable.

ORATION ACTIVITY

mined as early as 1820 at the Blairton Mine. The town of Belmont and Cordova have been mined at various times since the turn of the century. The Ledyard Deposits. More recently the area has been mined for gold and industrial minerals. The recovery of gold from tailings has been the production of roofing granules. Mineral resources are described in more detail below, and also by the Ontario Geological Survey (Carson 1979).

Y

Belmont Township is underlain by Paleozoic rocks with minor basal sandstone and conglomerate. The geology of Belmont and Methuen Townships is described in a regional survey by the Engineering and Geology of Ontario Geological Survey (Carson 1979). Paleozoic rocks in the map area during the Paleozoic rocks in the map area during the Paleozoic rocks.

rocks, which belong to the Grenville Supergroup, are composed of igneous and metamorphic rocks, which belong to the Grenville Supergroup. The rocks are composed of igneous and metamorphic rocks, which belong to the Grenville Supergroup. The rocks are composed of igneous and metamorphic rocks, which belong to the Grenville Supergroup.

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 sub-angular 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 flame-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 phryic flows of basaltic composition. About 2 km east of Belmont Lake, highly amygdaloidal

ECONOMIC GEOLOGY

Metallic Minerals

Four types of occurrences have been identified:

a) *Stratiform Sulphide* Mineralization in volcanogenic parts of Cycles I, II and III. Fine-grained pyrrhotite with sphalerite and grained lithic wackes and/or tuff of pyrite. Examples include the rusty schists within Cycle II, schists immediately below and above the Young-Cumming (Deer Lake) fold hinge, a fold of 300 m in a D₁ fold hinge, a values are 0.5% Zn, 0.05% Cu. Young personal communication, assay 3.0% Zn. At this metacumingtonite schists also metal values.

b) *Stratiform Iron Oxides* Intercalated with mafic flows, breccias within 0.5 km of the top (east of Belmont Lake) (20), the rock is gray about 10% magnetite by volume. The chert can be traced along strike for 400 m. Similar types are locally present in the vicinity of the foot of Corq Belmont Lake, where drill holes bearing cherts below Paleozoic rocks.

Both sulphide and oxide mineralization is associated with exhalative activity associated with the volcanism.

c) *Skarn Deposits* Occur along the western margin of the Belmont Lake Mine (3). The Blairton Mine (5) is a gabbro body south of the fine-grained rocks comprising magnetite, pyrite, pyrrhotite, and

Round
655
Lake

GEOLOGY¹

als

Occurrences have been recognized in Belmont Township

Sulphide Mineralization Concentrations of sulphide in volcanogenic metasediments occur within the upper II and III. Fine-grained, rusty-weathering siliceous gravel from siltstone, contains up to 25% pyrite and/or sphalerite and chalcocopyrite. Associated strata are fine-grained and/or tufts with cherty layers and lesser amounts of pyrite. These include the Round Lake sulphide occurrence (15), in Cycle II south of Little Whitney Lake, and pyritic chert below and above the felsic-tuff unit (3e) of Cycle II at the (Deer Lake) property (18) east of Cordova Lake occurrence. There the sulphidic schists attain a thickness of 100 m, and are continuously mineralized, average 0.05% Cu, and 0.2 ounce/ton Ag (Carter, 1980, C.R. communication). A surface grab sample from the property (18) shows 0.05% Zn. At this property and within Cycle III basalt, garnet schists also exhibit anomalous base and precious metal concentrations.

Iron Oxides Magnetite-bearing cherts are found in the felsic flows, breccias, and epiclastic sediments in Cycle II at the top (east side) of the unit. At the Young-Purdy Occurrence the rock is granular, centimeter-layered and averages 15% magnetite by visual estimation. The unit is 15 m thick and can strike for 400 m. The immediately enclosing rock is a fine-grained schist, with or without garnet. Magnetite-silica rocks are locally present at the same stratigraphic level, from the foot of Cordova Lake, south to Breckenridge Bay on the west. Here drill holes penetrated magnetite- and hematite-bearing Paleozoic cover.

These and oxide-rich stratiform deposits appear to result from hydrothermal activity associated with volcanism.

Skarns: Contact skarns were formed in calcite marble at the margin of the Cordova gabbro, at the Belmont Iron Mine (5) is similar, but may be related to a separate intrusion south of the Cordova intrusion. The skarns are dense, composed of garnet, pyroxene, amphibole, epidote,

Freeman
Corners

- 1) ~~Hyaloclastite pyroclastic dykes, amp. small intrusions~~
- 1k Chlorite schist, chlorite amphibole schist, amphibole of probable volcanic origin
- 1m Flows of basaltic composition, typically plagioclase phyrn, 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

	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

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

Thus the attention given the 1980 season was minimal between Precambrian and Palaeozoic.

The Precambrian stratigraphic group, are mostly volcanic in composition from basaltic area is underlain by rock with less abundant clastics. The clastic units is difficult in nature and siliceous chemical products formed during at least two intruded by plutons that range from intrusive rocks in the area. The non-metamorphic (protolith) can be assigned with confidence.

The volcanic rocks can be felsic, volcanic cycles, two within the map-area. Cycle I, northern boundary of Belmont, is because of complex folding massive plagioclase-phyrn, contain hyaloclastites and two horizons with a maximum of 100 m. The felsic parts of the and probably reworked pyroclastic. Felsic tuff is the dominant felsic pyroclastic rocks ranging from 100 m to 1 km. Both lithic fragments and tuff may represent ash-flow deposits in the tuffs toward the top of the township in the vicinity of Lost Lake. Both calcitic and dolomitic cap Cycle I. About 1 km north of the tuffs is marked by a thick epiblastic metasediments of 100 m thick.

The maximum thickness of the base of the cycle consists of hyaloclastites with minor and tuff-breccias. Within the Creek lies a distinctive rust-tonite, with or without garnet. In places is a calcitic and dolomitic. 1 km north of the northeast end, north are thin mafic to intermediate felsic portion of Cycle II. Mafic flows, which typically in northern Belmont and southern, intercalated with intermediate overlying unit, which is common. The unit is a distinctive wacke and mudstone, and the thickness of Cycle II. Typical lithic tuff coarsens to the north, the beds are pyritic. Cycle II is a pyritic siltstone, which is and is intercalated with mudstone.

Cycle III is much thicker than the basal part of the cycle, 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 diatom-grained, locally plagioclase volcanics. These dykes grade into magnetite ironstone up to close to the top of the mafic. It has been observed along the local reports may extend further.

Immediately overlying Breckenridge Bay area of intermediate biotite-hornblende, probably represents clastic sediment. It contains dispersed. These rocks separate the mafic pillowed volcanic flows and

...bearing cherts. The contact between the Paleozoic rocks and the map area during the was minimal, save for the delineation of the contact between the Cambrian and Paleozoic rocks.

...Cambrian stratified rocks, which belong to the Grenville facies. The rocks are mostly volcanic flows and fragmental deposits that range from basalt to dacite and rhyolite. Twenty percent of the map area is covered by rock clearly of sedimentary origin, mainly marbles and clastics (the distinction between pyroclastic and epiclastic is difficult in much of the quartzofeldspathic successions and chemical precipitates). The layered rocks have been dated at least two episodes, regionally metamorphosed and in places that range in composition from gabbro to granite. All rocks in the area have been metamorphosed. In these notes, protolith (protolith) terms are used where they are concise and used with confidence.

...The rocks can be assigned to at least three distinct mafic cycles. Two additional cycles are present but incomplete in the area. Cycle I is located between Round Lake and the Ledyard of Belmont Township. Its extent is currently speculative because of complex folding. The base of Cycle I is represented by plagioclase phyrn and amygdaloidal mafic flows which locally contain clastites and structures resembling pillows. These occupy a thickness of 300 to 350 m each. Intermediate parts of the cycle are expressed solely as pyroclastic brecciated pyroclastic rocks which typically are intercalated with the dominant mafic flows, although both intermediate and mafic rocks range from tuffs through lapilli tuffs to tuff breccias and pyroclastic breccias. The felsic tuffs commonly contain fragments and locally suffused with fragments of mafic flows. Magmatic breccias are more common toward the top of the cycle. In the north-central part of the map area, the Little Whitney Lake area, a marble unit consisting of and dolomitic members and bearing tremolite appears to be about 1 km north of Round Lake. The contact between Cycle I and Cycle II is marked by a 50 m thickness of rusty weathering cherty metasediments containing a massive pyritic chert horizon 1-2

...m thick. The thickness of the Cycle II meta-volcanics is 1000 m. The cycle consists of mafic pillowed and massive flows and flows with minor amygdaloidal and plagioclase phyrn flows. Within the mafic base of Cycle II west of Whitney Lake, a distinctive rusty mudstone unit characterized by cumming without garnet and magnetite. Directly overlying this unit is a calcic and dolomitic marble unit which pinches out about 4 km northeast end of Round Lake. Overlying this marble is the mafic to intermediate massive flows north of the marble. Cycle II is directly underlain by massive and pillowed flows which typically contain large porphyroblasts of hornblende. Belmont and southern Methuen Townships the flows are in places intermediate, largely fragmental, meta-volcanics. The unit which is continuous from Seright Bay northward into Methuen is a distinctive felsic tuff which probably includes lithic mudstone, and constitutes one third to one half of the total Cycle II. Typically fine grained and cherty in the south, this unit passes to the north. Toward the stratigraphic top of this unit, pyritic Cycle II is capped by a thin zone of rusty weathering mudstone which is continuous south of Lost Lake. It thickens and is overlain with mudstone east of Seright Bay.

...The unit is much thicker than Cycle I. The mafic unit which constitutes the top of the cycle is about 3.5 km thick and comprises massive flows and hyaloclastites in flow units 20 m to 70 m thick. Flow breccias are developed locally. This unit is best exposed at Crowe Lake and on Cordova Lake. Cherty space fillings are locally present in the flows. Magnetitic intermediate and more rarely felsic flows as well as sparse magnetite, magnetite garnet, and magnetite bearing mudstones are intercalated with the mafic flows. The middle portion of the mafic unit. In the upper part, fine to medium grained locally plagioclase phyrn mafic dikes cut the mafic flows. These dykes grade in places into gabbroic rocks. A quartzite mudstone up to 20 m thick is present within chlorite schist at the top of the mafic unit near the north end of Belmont Lake. It is exposed along a strike length of 2 km and on the basis of the mapping may extend further north.

...The unit is locally overlying the mafic volcanic rocks of Cycle III in the Crowe River area of Belmont Lake is a stratum up to 200 m thick of biotite-hornblende-plagioclase schist. This stratum probably represents clastic sediments derived from a volcanic source, as evidenced by dispersed intermediate and felsic volcanic clasts. The schist separates the mafic volcanic rocks from intermediate, locally mafic flows and from predominantly dolomitic marble which is present at Belmont Lake and north along the Crowe River.

...data with the same 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 phyrn 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 1961), these meta-volcanics 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, but 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

...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-order open folding. D₁ D₂ cleavage intersections and D₂ minor fold axes form a prominent lineation, generally east-trending, which has a major reversal only in the doubly-plunging D₂ 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 D₂ folds) and thus lie mainly on a single limb of a D₁ 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 meta-volcanics.

...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-D₂ thrust fault. Post-D₂ 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

...bearing cherts. Both sulphur from exhalative c) Skarn along the west Mine (3). The B rate gabbro bor fine-grained ro magnetite, pyri Blairton the sk River iron depo marlite has bee Young, persona Blairton Mine contains magn cover

d) Veni D silver mineraliz gabbro 0.4 to erly. These hav posits. At Cordo ings extended covered from d ported by Cart samples of qua in metabasal Mine Bay. It is lating metamor rocks themselves

Galena occ then Township dale, minor cha currences were

Non-Metallic

Three rock type

a) Metab incorporated n Cordova gabb found suitable

b) Granit mont Granite 2 medium-graine ite has been d Township

c) Marbl plored by drilli ment uses. The and Vansickle Cycle II. Paleo drilled as a pot

RECOMM

Base and prec warrants further to be encounte involved in D₁ Lake. Further possibly adjac analogous dep The proximity v duction favour as high purity

'Unless otherw the Assessment communication this property an anomalous base

Skarn Deposits Contact skarns were formed in calcite marble the western margin of the Cordova gabbro, at the Belmont Iron (3). The Blairton Mine (5) is similar, but may be related to a separate gabbro body south of the Cordova intrusion. The skarns are dense, grained rocks comprising garnet, pyroxene, amphibole, epidote, magnetite, pyrite, pyrrhotite, and carbonate, with minor chalcocite. At Belmont the skarn is 70 m wide and at least 400 m long. At the Crowe Iron deposit (7) massive hematite occurs within the gabbro, and magnetite has been discovered in the river and field immediately west (C.R.G. 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

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

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

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

and precious metal potential of the volcanogenic metasediments warrants further exploration. Suitable grade and tonnage are most likely encountered where beds at the top of a volcanic cycle have been dated in D_1/D_2 interference patterns, as has occurred east of Cordova. Further vein gold mineralization may be encountered within, and immediately adjacent to, the Cordova metagabbro, and the possibility of precious deposits within mafic metavolcanics should not be ignored. Proximity of the area to urban centres makes industrial mineral prospects favourable, particularly the relatively high-value specialities such as high-purity carbonates for chemical production.

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 the property and within Cycle III basalt, garnet-cummingtonite schists also exhibit low base and precious metal values.

METAL

Freeman
Corners

Chase
Corners

V
Creek

IV

III

24 of

Auto
Wreckers

Blairton Sta

9
mag

LAND
ERAL

7a.

7b.

the east end of Round Lake. Overlying this marble in the north to intermediate massive flows, north of the marble of Cycle II is directly underlain by massive and pillowed flows, which typically contain large porphyroblasts of hornblende and plagioclase. In the north and southern Methuen Townships the flows are in the north, largely fragmental metavolcanics. The contact is continuous from Seright Bay northward into Belmont Lake, and constitutes one-third to one-half of the total thickness of Cycle II. Typically fine grained and cherty in the south, this unit is to the north. Toward the stratigraphic top of this unit of Cycle II is capped by a thin zone of rusty weathering, which is continuous south of Lost Lake, it thickens and grades into mudstone east of Seright Bay.

much thicker than I or II. The mafic unit which constitutes the cycle is about 3.5 km thick and comprises massive flows and hyaloclastites in flow units 20 m to 70 m thick. Breccias are developed locally. This unit is best exposed on Cordova Lake. Cherty space fillings are locally developed. Magnetite intermediate and, more rarely, felsic as well as sparse magnetite, magnetite-garnet, and magnetite bearing mudstones are intercalated with the mafic portion of the mafic unit. In the upper part, fine- to medium-grained plagioclase phryic mafic dikes cut the mafic meta-dykes grade in places into gabbroic rocks. A quartzite up to 20 m thick is present within chlorite schist of the mafic unit, near the north end of Belmont Lake. It extends along a strike length of 2 km, and on the basis of the evidence extend further north.

Overlying the mafic volcanic rocks of Cycle III in the Belmont Lake area is a stratum up to 200 m thick of chlorite-hornblende-plagioclase schist. This stratum probably represents sediments derived from a volcanic source, as it is dispersed intermediate and felsic volcanic clasts. It separates the mafic volcanic rocks from intermediate, locally massive flows and from predominantly dolomitic marble which, in the north of Belmont Lake and north along the Crowe River, separates the mafic volcanic rocks. The north-trending contact separating the mafic volcanic rocks from the marble north and west of Belmont Lake, from the intermediate and mafic volcanic rocks, and dominantly calcitic marble east and south of Belmont Lake, may be tectonic. This deduction is based largely on the discordance between the latter rock units and the mafic unit to the south and west of Cordova Lake. The mafic unit, according to the southeast of Cordova Lake resemble greatly those of Cycle III. They are apparently intermediate metavolcanics, wacke, and fine-grained mica schists, which are pyritic. These rusty-weathering mudstones, garnet-cummingtonite schist, are believed to be epiclastic through volcanic exhalative processes probably contributing to their formation. Felsic lithic pyroclastic rocks, ranging from coarse lapilli-tuff, occur at or near the top of the siliceous

unit overlying the intermediate volcanic rocks southeast of Belmont Lake are intercalated, relatively pure, calcitic and dolomitic marble with cherty lenses and layers. These rocks are probably to the marble on the northwest shore of Belmont Lake. Belmont Lake, the maximum apparent thickness is approximately 100 m, however internal deformation may have considerably

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.

medium-grained tuffite has been drilled in Township.

c) **Marble**
explored by drilling for cement uses. The property is owned by Vansickle (177) and Belmont Lake. Cycle II. Paleozoic. Drilled as a potential

RECOMMENDATIONS

Base and precious metal warrants further exploration to be encountered in Belmont Lake. Further vein possibly adjacent to the analogues deposits. The proximity of the ducture favourable as high-purity carbon

'Unless otherwise stated, the Assessment File is for communication. A this property and with anomalous base and

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en drilled in the Horse Lake area (10), southwest of Methuen
Marble Both calcitic and dolomitic marble have been ex-
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RECOMMENDATIONS

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Geology 1920-1925

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

METAL AND MINERAL ABBREVIATIONS

cp
Cu
gn
Au
hem
ky
mag
mb
py
po
Ag
sp
st
Zn

13
mag

Auto Wreckers

Auto Wreckers

Blairton Sta

TAL AND
MINERAL
EVIATIONS

- Chalcopyrite
- Copper
- Galena
- Gold
- Hematite
- Kyanite
- Magnetite
- Marble
- Pyrite
- Pyrrhotite
- Silver
- Sphalerite
- Stone
- Zinc

29 ft

BELMONT TP
SEYMOUR TP

Highway

9
mag

HASTINGS COUNTY
PETERBOROUGH COUNTY

BM 640
CANADIAN

| 30 of 30 |

77° 44' 44" 26'

7a.

7b.

0 200 400 600 800 1000
Horizontal Scale (m)

Figure 7:

Vertical cross sections. Rock units same as Fig. 2. stratigraphic units at base of sections. Apparent dip of bedding (—) and S1 schistosity (↔), from field measurements, above section as well as top indicators and minor folds.

a. Section A-A'-A'' from Oak Lake to near Cordova Mines, showing part of Oak Lake dome and homocline. Major fault interpreted immediate east of Crowe River.

b. Section B-B'-B'' across Round and Belmont Lakes, showing homocline. Major fault interpreted on west side of Belmont Lake.

1 of 1

OAK LAKE DOMAIN

12 of 1

METHUEN TOWNSHIP

LIT

Figure 12:

Structure map
stereograms.

Selected fabric
ments are plotted
map. Equal-area
grams in blocks
data from each
seven structur

13 of

LITTLE WHITNEY LAKE DOMAIN

Figure 12:

Structure map with
stereograms.

Selected fabric measure-
ments are plotted on the
map. Equal-area stereo-
grams in blocks present
data from each of
seven structural domains.

4 of 1

DOMA

ROUND LAKE DOMAIN

5 of 1

CORDOVA LAKE DOMAIN

1891

LOST LAKE OCEANOGRAPHY

1961

TSL 52

BELMONT TOWNSHIP

● Havelock

CROWE LAKE DOMAIN

Map Symbols

- bedd
- bedd
- schis
- fract
- lineat
- cren
- doma

Stereogram Sym

bedding, la

lineatio

- x intersect
- mineral,
- crenulatio

11 of 1

EROWE LAKE DOMAIN

Figure 12

12 of 12

LEGEND

Map Symbols

- bedding; bedding with upright top; facing of pillow.
- bedding overturned with top in arrowhead direction.
- ↔ schistosity - inclined, vertical.
- fracture cleavage - inclined, vertical
- → → → lineation - intersection, elongation, mineral, crenulation
- domain boundary

Stereogram Symbols

bedding, layering

planar fabric

- x marble lamination
- schistosity, gneissic layering
- fracture cleavage

lineation

fold elements

- x intersection
- mineral, elongation
- crenulation

- ○ fold axis - closed, open fold
- ▲△ axial plane - closed, open fold

END

104109H84

FIN