THE MANGANIFEROUS SLATES OF THE CAMBRO-ORDOVICIAN MEGUMA GROUP AT LAKE CHARLOTTE, HALIFAX COUNTY, NOVA SCOTIA

submitted by

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Abstract

In recent years there has been considerable interest in manganiferous sediments of the oceans. This interest is due to the special environment required to form manganiferous sediments, the association with other metals, and their occurrence as geochemical halos around hydrothermal deposits. In the Meguma Group of Nova Scotia finely laminated manganiferous beds are present at many localities near the the Goldenville - Halifax Transition Zone (GHT) where deposits of Au, W, Pb, and Zn are known to occur (Zentilli et.al., 1984). These manganiferous beds may be interpreted as regionally metamorphosed equivalents of manganiferous sediments of marine origin.

The manganiferous bed at Lake Charlotte occurs in a 750m wide slate belt that forms the core of a tightly folded syncline and has been metamorphosed to chlorite and biotite grades. The manganiferous bed appears to occur across much of the width of the slate belt and is characterized by layers of carbonate that are commonly tightly folded or contorted. Its total thickness is uncertain but it could be up to 300m thick. The bed extends at least 11km along strike from the east shore of Ship Harbour to the village of Lake Charlotte in the west. Beyond these areas no mapping was done except along the east shore of Jeddore Harbour 7km west of Lake Charlotte. Samples taken in the 1950's from the north limb of the fold near the village of Lake Charlotte yielded 5.3% to 12.3% MnO_2 concentrations on core lengths of 160m to 1.5m, respectively.

This thesis describes the local geology and mineralogy of the manganiferous bed at Lake Charlotte. The Mn bed at Lake Charlotte is similar to other Mn beds in the Meguma Group and coticule beds found elsewhere in the world. Because of this similarity to coticule beds and the low degree of metamorphism the Mn bed at Lake Charlotte is considered a "proto - coticule". The Mn is concentrated in a Mn carbonate that is of diagenetic origin.

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CHAPTER 1

Introduction

1.1 General Statement

The purpose of this thesis is to describe and to explain the significance of the manganiferous slates found in the vicinity of Lake Charlotte, Nova Scotia. The manganiferous slates at Lake Charlotte are similar to coticules described by Schiller and Taylor (1965) and Kennan and Kennedy (1983). Coticules are defined as quartzites rich in spessartine and are typically found in pelitic rocks. Microscopically they contain many small euhedral garnets in a quartz matrix (Kennan and Kennedy,1983). Coticules occur world wide and may have long range stratigraphic significance (Kennan and Kennedy,1983). Similar manganiferous sediments have also been associated with many mineral deposits through out the world, most notably the Broken Hill deposit at New South Wales, Australia (Stanton,1976).

Locally within the Cambro-Ordovician Meguma Group of Nova Scotia manganiferous sediments similar to those found at Lake Charlotte exist near the contact between the Halifax and Goldenville Formations. Associated with these manganiferous sediments are a number of metallic mineral occurrences: W-Zn at Lazy Head, Guysborough County; Pb-Zn at Eastville, Colchester County; and Sn near the Wedgeport Pluton, Yarmouth County. Most of the gold deposits of the

Meguma Group are also found in this same stratigraphic horizon (Zentilli et.al.,1984). All these deposits occur with in the Goldenville-Halifax transition, indicating a stratigraphic significance for these manganiferous beds.

1.2 Location and Setting of the Study Area

The manganiferous slates are located near the village of Lake Charlotte along highway 7, 60 km east of Dartmouth (Fig. 1.1). They occur in a 27 km long slate belt that is 750m wide. This slate belt extends from Jeddore Harbour in the west to Tangier Lake in the east (Fig. 1.2).

The study area, approximately 31 sq. km, extends along the slate belt from Jeddore Harbour in the west to Newcombe Lake in the east, a distance of 17.5 km. Access to the slate belt can be obtained directly from highway 7 and by several secondary and logging roads that cross the slate belt (Fig. 1.2).

The relief of the area is low with the elevation of the area ranging from sea level to 76m above sea level. The area consists of low rolling hills, numerous lakes, several small streams, and several small swamps and bogs. Most of the area is covered with softwood and hardwood forests.

Good outcrops were found only along road cuts, coastlines, and along the brook flowing from Newcombe Lake (Fig. 1.2).

FIGURE 1.1 GEOLOGY OF THE MEGUMA ZONE

OTHER MANGANIFEROUS BEDS IN THE MEGUMA GROUP

1. EASTVILLE
2. SONORA
3. LAZY HEAD
4. ROCKY LAKE

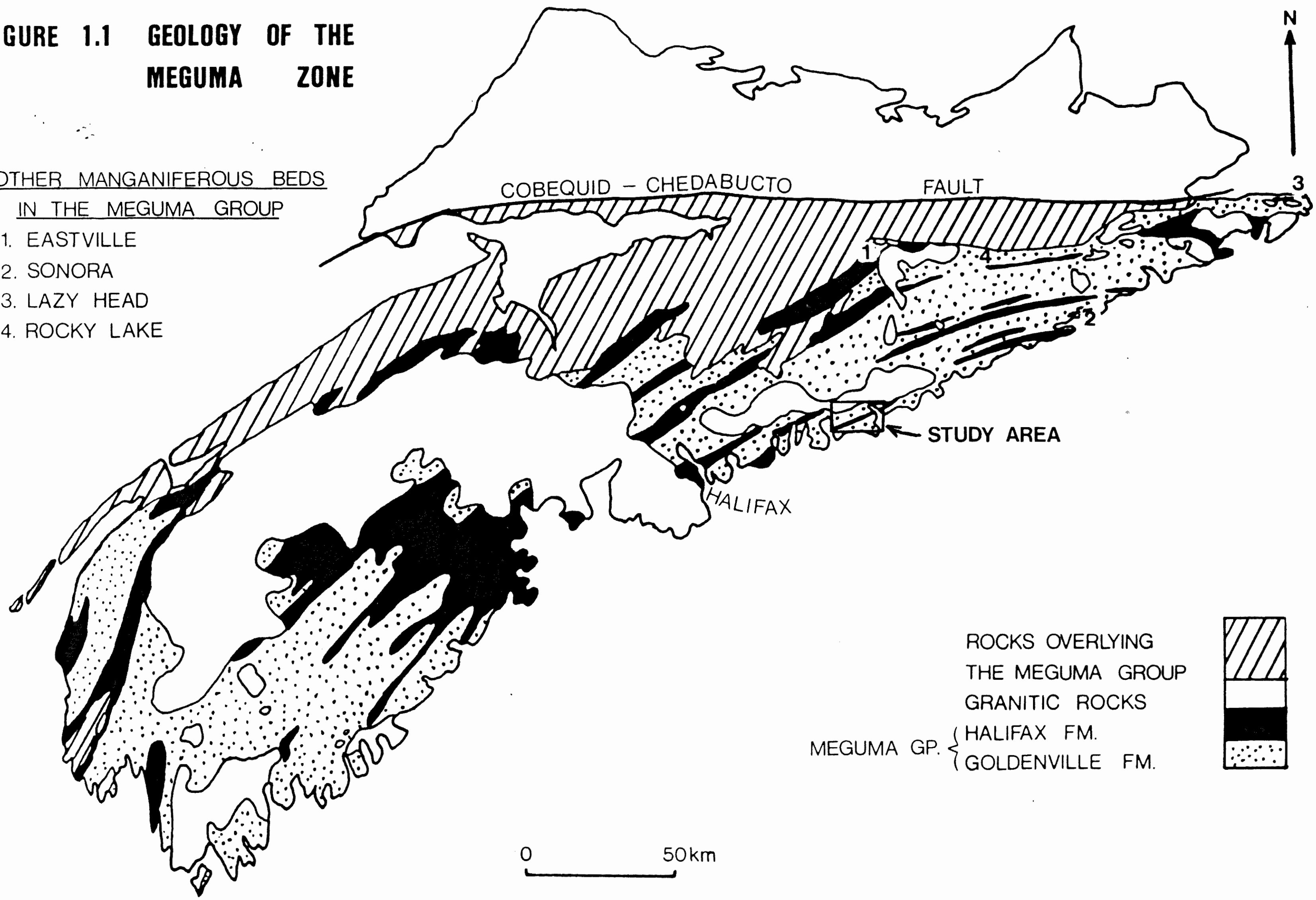
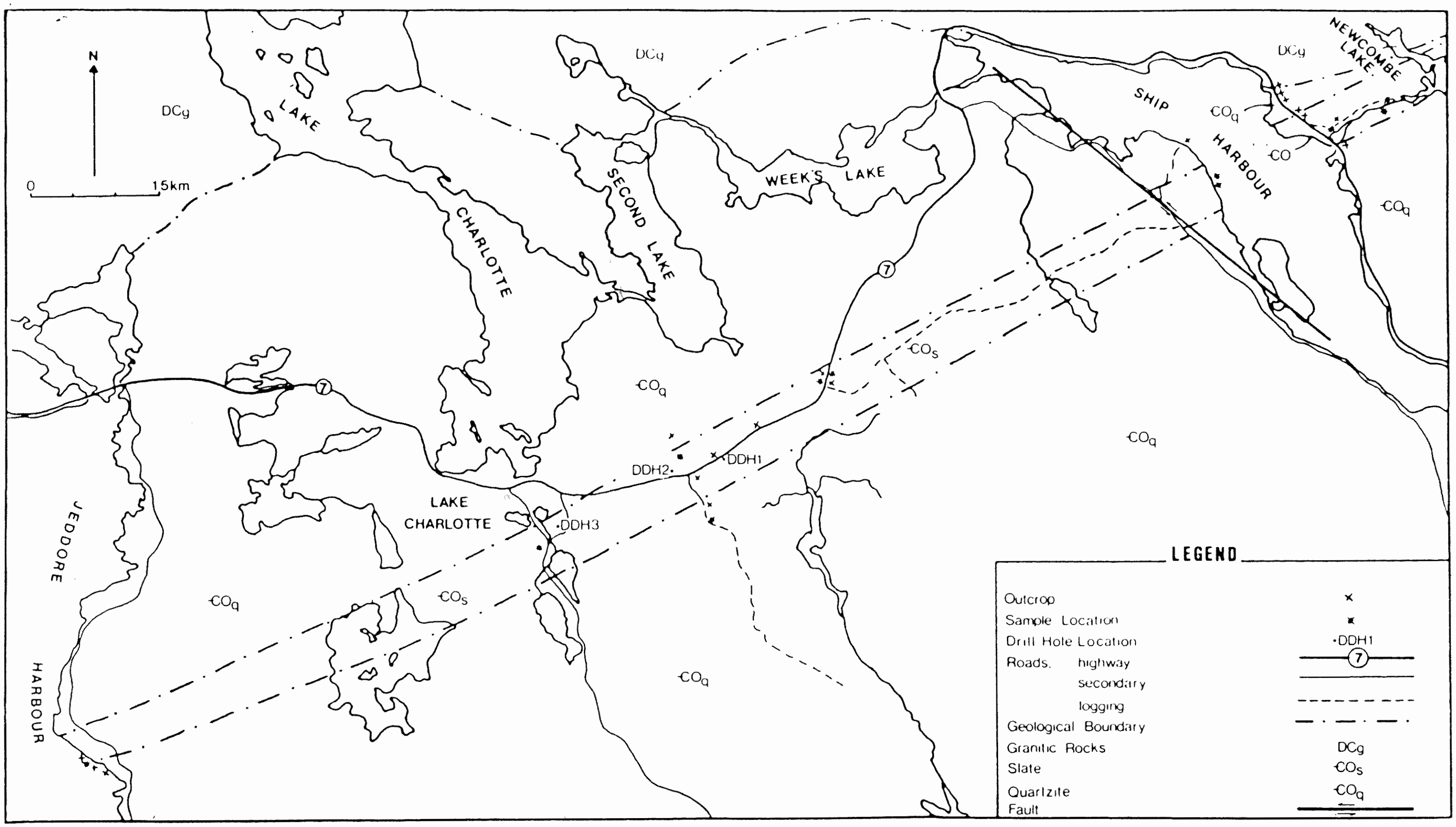


Figure 1.2: Sample locations and geology of the study area. Boundary of the granitic pluton and location of the fault is from Faribault (1897).



1.3 Previous Work

The first geologic map published of the Lake Charlotte area is that of E.R. Faribault (1897), who divided the area into a quartzite group, a graphitic and ferruginous slate group, and granite.

The first report of manganese bearing slates was in 1931 by R.A. Logan (Logan, 1956a). The first systematic exploration for manganese in the area was conducted in 1955 by Stratmat Ltd., who conducted a gravity survey and reported the occurrence of small quartz veins containing Pb and Mn minerals (Mowat, 1955). Between 1956 and 1957 Barymin Exploration Ltd. conducted a magnetometer survey and drilled 3 holes totalling 231m (Logan, 1956b).

During their investigation of manganese deposits of Nova Scotia D.G. Bishop and J.D. Wright (1970) collected dump samples and analysed them for major and minor elements.

In 1979 there was a renewed interest in the area when a government lake sediment survey showed a Cu, Ni, Zn, Co, and Mn anomaly in the area. A subsequent geochemical soil survey by St. Joseph's Exploration Ltd. showed a Pb, Zn, and Mn anomaly (Kryklywy, 1979).

1.4 Purpose and Scope of Study

The purpose of this thesis is to give a detailed description of the manganiferous bed at Lake Charlotte. This description includes the effects of metamorphism on the manganiferous bed and a detailed examination of the minerals that occur in the slates to determine the source of the manganese. To this end these slates are compared to other manganiferous beds in the Meguma Group and possible origins for these beds are suggested.

The main efforts of this thesis were concentrated on the slates. The batholith that outcrops in the area was not examined, and the quartzites were not examined in detail. No detailed mapping of the study area was undertaken because of time considerations and lack of outcrop. The outcrop that was present was generally badly weathered and most samples of the manganiferous slates had to be obtained from the drill core which was not intact, as described below.

1.5 Methods and Procedures

Surface samples of the slate and quartzite were collected by the author in the summer and fall of 1984. Figure 1.2 shows sample locations. Where there was sufficient exposure of outcrop the contact between the slates and quartzites were mapped. Drill core samples were also obtained with the assistance of Mr. J. Kidston and Mr. F. Webber, both of Lake Charlotte. The drill core from Barymin Explorations Ltd. was no longer intact, the core boxes had long since rotted and the drill core had become fill for a driveway. Locations of the drill holes are shown in figure 1.2, drill logs for these drill holes are given in appendix 1.

Thin sections were prepared and described for 12 surface samples and 8 drill core samples. Four polished thins of the drill core were also prepared, described, and examined using the electron microprobe. Several of the above samples were also selected for X-ray powder diffraction analyses.

1.6 Organization of the Thesis

Chapter 1 introduces the topic of the thesis. Chapter 2 provides a description of the geology of the Meguma Group and the study area. Included in this chapter is a description of the 3 lithologies observed at Lake Charlotte. Chapter 3 describes the mineralogy based on petrographic description and microprobe analysis. Chapter 4 discusses the origin of the carbonate, the relationship of the manganese bed at Lake Charlotte to other similar beds in the Meguma Group, and compares the characteristics of this manganese bed to the characteristics of coticule beds. Chapters 5 and 6 are the conclusion and recommendation chapters.

CHAPTER 2

General Geology

2.1 Regional Geology

Most of southern Nova Scotia (the area south of the Cobequid - Chedabucto Fault) including the Lake Charlotte area is underlain by the Cambro-Ordovician Meguma Group (Fig 1.1). The Meguma Group is a 10km thick flyschoid sequence consisting of alternating layers of quartz metawacke and slate (Schenk,1978; Harris and Schenk,1975). The Meguma Group has subsequently been folded and metamorphosed during the Acadian Orogeny (Reynolds et.al.,1973 and Taylor and Schiller,1966) followed by the intrusion of several granitic plutons during the Late Devonian and Early Carboniferous (Clarke and Halliday,1980 and Reynolds et.al.,1980).

The Meguma Group has been interpreted as a complex of deep sea coalescing fans on a steadily prograding continental rise. Current directions and sandstone compositions suggest a southeastern sedimentary source from a metasedimentary-metaigneous craton (Schenk, 1970, 1976, 1978).

2.1.1 Stratigraphy

The Meguma Group has been sub-divided into two conformable layers, the sandier basal Goldenville Formation and the shaly upper Halifax Formation (Harris and Schenk, 1975). Classification of these two formations is based on the sand to shale ratio (Harris and Schenk,1975; Schenk, 1970), a ratio of one marks the transition from the Goldenville to Halifax Formation (GHT) (Schenk,1970).

The Goldenville Formation consists primarily of lithic greywacke and feldspathic quartzite with only minor amounts of argillite, siltstone, slate, and rare pebble conglomerate (Taylor and Schiller,1966). The proportion of these finer sediments increases towards the top of the Goldenville Formation (Schenk,1970). The base has never been observed but the Goldenville Formation is at least 5600m thick (Faribault in Schenk,1975b). Primary sedimentary structures observed in this formation include sole marks, flute marks, graded bedding, cross lamination, convolute structures, load structures, sand volcanoes, ripple marks, pillar structures, trace fossils, and channels up to 3m in depth (Schenk,1975b,1970).

The Halifax Formation consists primarily of light grey to black thinly bedded slate, siltstone, argillite, and minor amounts of quartzite (Taylor and Schiller,1966). Locally the slate is better named schist, this schist typically occurs near granitic intrusions (Shaw,1983; Fyson,1966 and Faribault,1896). The total thickness of this formation varies from 4400m in the northwest to 500m in the south (Taylor in Schenk,1975b). Apart from bedding and trace fossils few sedimentary structures have been observed in this formation. Occurrences of the graptolite Dictyonema *flabelliforme* (Eichwald) have been found in the Halifax Formation, giving it a minimum age of early Ordovician (Schenk,1970).

The Goldenville-Halifax transition (hereforth the GHT), in addition to being defined by a sand to shale ratio of one may also be marked by the occurrence of manganiferous beds or "coticules". In addition to Lake Charlotte, manganiferous beds are known to occur in the GHT at both Eastville (Zentilli and MacInnes,1983) and Lazy Head (Shaw,1983). Other manganiferous beds at Rocky Lake and Sonora in Guysborough County may be similar to those mentioned above (Fig 1.1).

2.1.2 Granites

The granitic plutons that intrude the Meguma Zone are of Devonian to Early Carboniferous age and have been dated to 367Ma by Reynolds et.al. (1981). These plutons consist of granodiorite and monzogranites (adamellites) that were differentiated from the granodiorites by the fractionation of biotite and plagioclase (Muecke and Clarke,1981;McKenzie and Clarke,1975). $^{87}Sr/^{86}Sr$ ratios indicate that these plutons were not derived from the melting of Meguma Group rocks but from some sub-Meguma basement at depth (Clarke and Halliday,1980).

2.1.3 Metamorphism

Rocks of the Meguma Group have under gone two separate episodes of metamorphism. Regional metamorphism associated with the Acadian Orogeny 390Ma (Reynolds et.al.,1973) and contact metamorphism associated with the intrusion of the granitic plutons 367Ma (Reynolds et.al.,1981).

Taylor and Schiller (1966) recognized in the Meguma Group two regional metamorphic facies as defined by Turner and Verhoogen (1960). These facies are the greenschist and amphibolite facies. Conditions represented by these facies are temperatures of 300 to 500^{o}C and a P_{H_2O} of 3 to 8Kb for greenschist and temperatures of 550 to 750^{o}C and a P_{H_2O} of 4 to 8Kb for amphibolite facies (Turner and Verhoogen,1960). Both facies have since been sub-divided into metamorphic zones, these zones, listed in order of increasing metamorphic grade are; chlorite, biotite, garnet(almandine), andalusite-cordierite-staurolite, and sillimanite zone (Keppie and Muecke,1979). The garnet straddles the top of the greenschist and the bottom of the amphibolite facies. The transition from a lower metamorphic zone to a higher zone the other is marked by the first appearance of the mineral for which the zone is named (Turner and Verhoogen,1960).

The contact metamorphic aureoles around the plutons are observed only in areas that have been regionally metamorphosed to greenschist facies. These aureoles can extend from the contact of the pluton for 400 to 2400m into rocks of the Meguma Group. These metamorphic aureoles surrounding the plutons are recognized by the occurrence of cordierite, andalusite, sillimanite, and rare almandine garnets and staurolite (Taylor and Schiller,1966). These minerals are typical of Turner's and Verhoogen's (1960) hornblende-hornfels facies. Metamorphic conditions for this facies range from temperatures of 550 to 700°C and P_{H_2O} of 1 to 3Kb (Turner and Verhoogen,1960).

2.1.4 Structure

Associated with regional metamorphism of the Meguma Group are several tectonic structures (Fyson,1966 and Taylor and Schiller,1966). Most notable of these structures are the northeast trending, tight, isoclinal, low plunging folds (F_1) that often extend for 100's of kilometres along strike (Fyson,1966 and Muecke and Keppie,1979). Associated with these folds is an axial planar cleavage (S_1) that is particularly well developed in the slaty layers (Fyson,1966). Fyson (1966) also recognizes smaller cross folds (F_2) and kink bands (F_3) that are younger than the F_1 folds. The F_2 and F_3 folds are only observed on outcrop scale or smaller. Several northwesterly trending strike-slip faults cut the F_1 folds. These faults are between 10 and 40km in length and show left lateral displacement. Total offset along these faults varies from a few hundred metres to several kilometres. Nowhere is it seen that these faults cut the granitic plutons (Keppie,1979), therefore they must predate the granitic intrusions.

2.2 Geology of the Study Area

The manganiferous slates at Lake Charlotte outcrops in a 17.5km by 750m wide northeast striking slate belt. These slates occur at the top Goldenville Formation and form the core of a tightly folded syncline plunging 5^{o} to the northeast. Conformably underlying the slates are massive quartzites of the Goldenville Formation. Intruding the quartzites is the monzogranitic Musquodobit Batholith (Keppie,1979) which has an age of 362Ma (Reynolds et.al.,1980). The batholith intrudes the slate belt outside the study area, within the study area the closest occurence of the batholith to the slate is 100m. In the area of the batholith some of the slates are better described as schists.

2.2.1 Stratigraphy

Due to the poor exposure of bedrock in the area and the poor condition of the drill core no detailed stratigraphy could be described. However three lithologies were recognized in the area; a lower unit of massive quartzite of the Goldenville Formation, a middle unit of banded calcareous quartzite occuring at the base of the Halifax Formation (GHT Zone), and an upper unit of blue slate with occasional interbeds of quartz metawacke, this last unit is typical Halifax Formation. The calcareous unit is similar to the banded calcareous quartzite that occurs at the top of the Goldenville Formation at Eastville (Binney .et.al, in press). A unit of black slate similar to that at Eastville may occur between the calcareous unit and typical Halifax Formation, as it has been described in the drill logs (appendix 1). However no outcrop or drill core samples of black slate were found by the author.

The calcareous unit is not always present but is a significant unit as it outcrops for several kilometres along strike in the vicinity of Lake Charlotte and also outcrops near Newcombe Lake. The only observed continuous exposure between any two units occurs at Jeddore Harbour where there is an exposed contact between the massive quartzites of the Goldenville Formation and typical Halifax Formation.

2.2.2 Lithologies

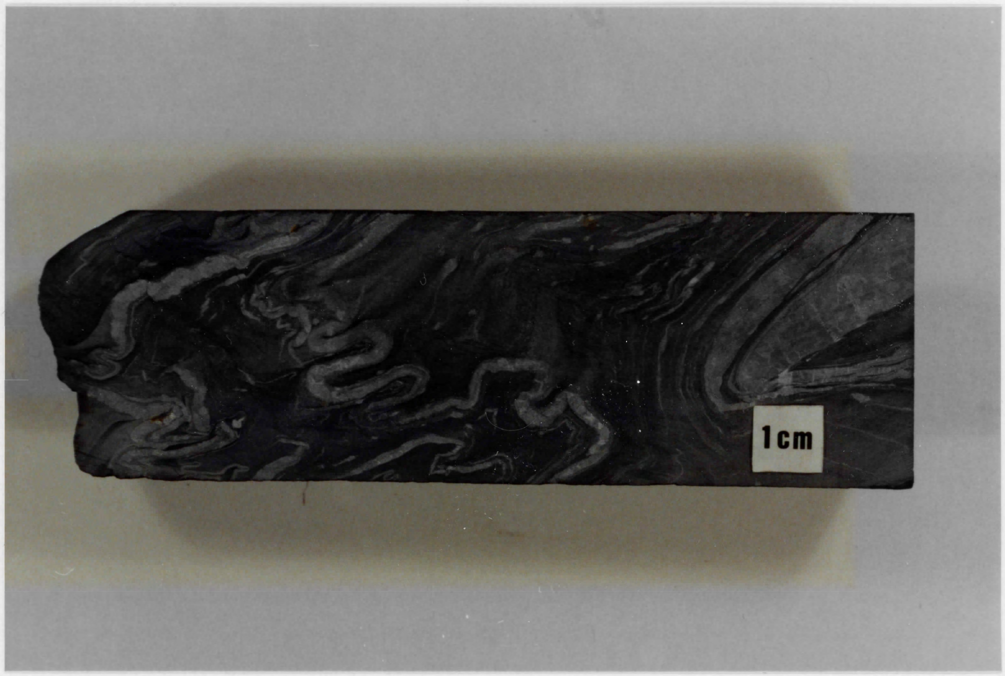
The massive quartzites (from here on this will be referred to as Lithology 1) are grey to pale green in colour and show no primary structures. Microscopically the quartzite consists primarily of quartz with minor amounts of plagioclase. Chlorite occurs interstitially between these grains and is responsible for the green colouring of the rock.

The banded calcareous quartzite (from here on this will be referred to as Lithology 2) contains thin (1 to 20mm)

Figure 2.1a: Carbonate Nodules

Figure 2.1b: Carbonate Nodule, note
the associated pressure shadow.

Figure 2.2a: Typical examples of lithology 2, note the ptygmatic and tight folds in the white carbonate layers. Also note the lighter grey host rock (quartzite) at the hinges of folds.



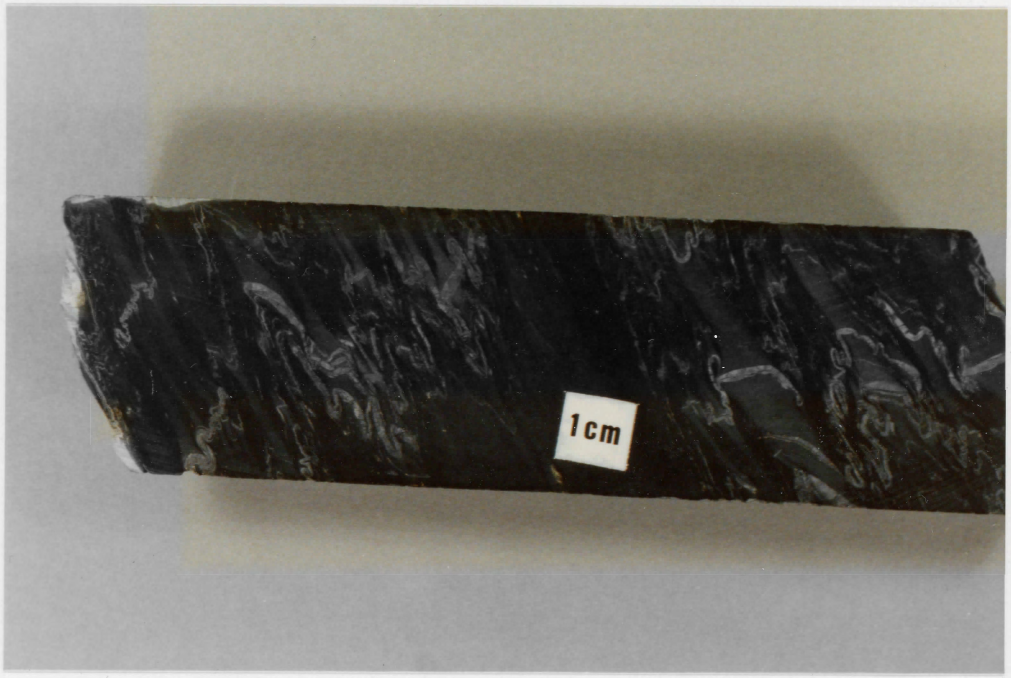
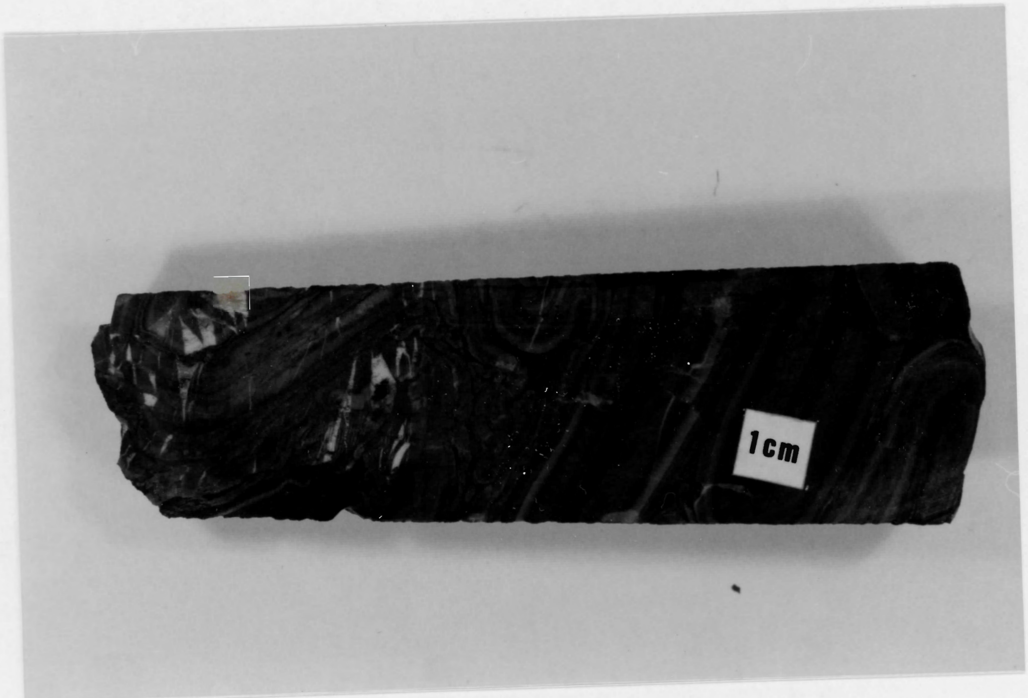


Figure 2.2b: Folded grey carbonate (lithology 2)



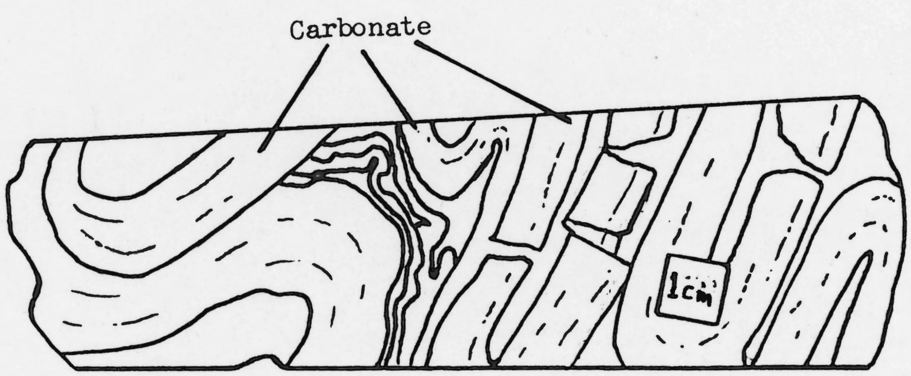


Figure 2.2c: Folded white carbonate.

layers of blue-grey slate, pale pink to pale grey carbonate, and minor amounts of pale grey quartzite. Figure 2.2 shows some typical examples of lithology 2. The carbonate also occurs as nodules, up to 10cm across (Fig. 2.1). In weathered surface samples the carbonate has been totally replaced by a soft brown material, presumably a manganese oxide. In areas with higher temperatures of metamorphism the carbonate has been replaced by quartz and biotite. In hand sample the carbonate layers are tightly folded, straight, or commonly ptygmatically folded (Fig 2.2). These folds appear to be of tectonic origin as there is a foliation parallel to the fold axis (Fig 2.3), some carbonate layers have been broken into blocks and are separated by elongate quartz grains (Fig 2.4), and in some cases the foliation has flowed in between these blocky beds. The quartzite layers occurs as pressure shadows at the hinges of the folds or as pressure shadows around the nodules (Fig. 2.1b, 2.2a, and 2.3). Microscopically the quartzite contains mostly anhedral quartz with minor amounts of opaques and spessartine. Slaty layers occur parallel to the limbs of the folded carbonate (Fig. 2.6).

This layer contains muscovite, chlorite, lesser amounts of quartz, spessartine, and minor amounts of prismatic opaques.

The typical Halifax Formation (from here on it will be referred to as Lithology 3) in this area is made up of blue slate with interbeds of pale brown quartz metawacke. The

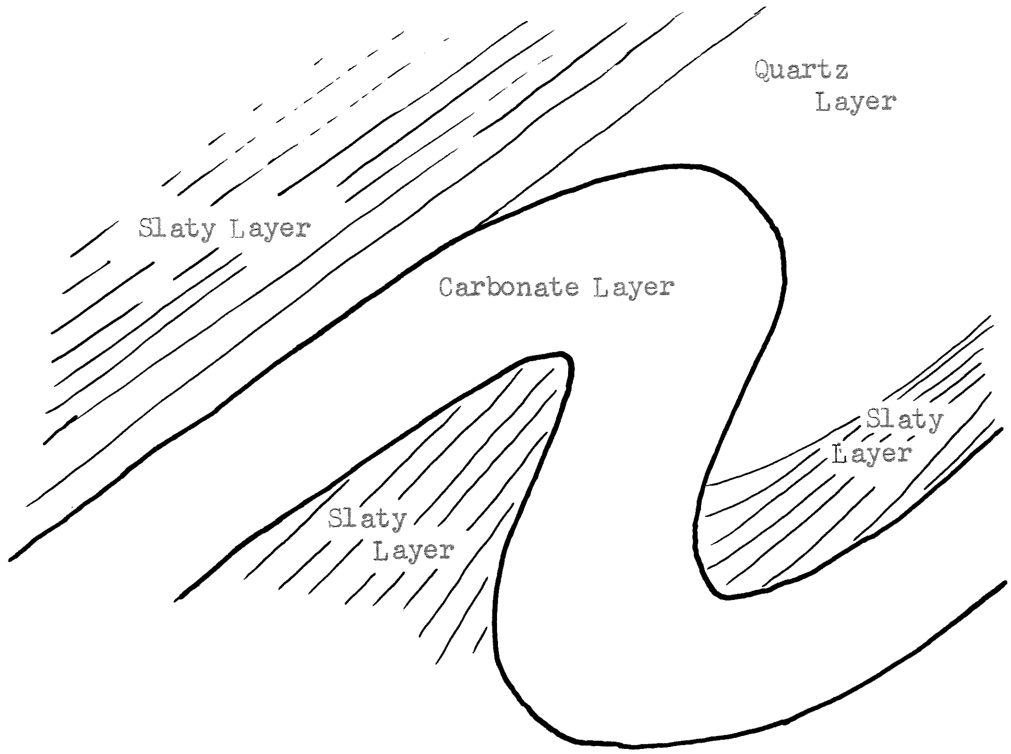
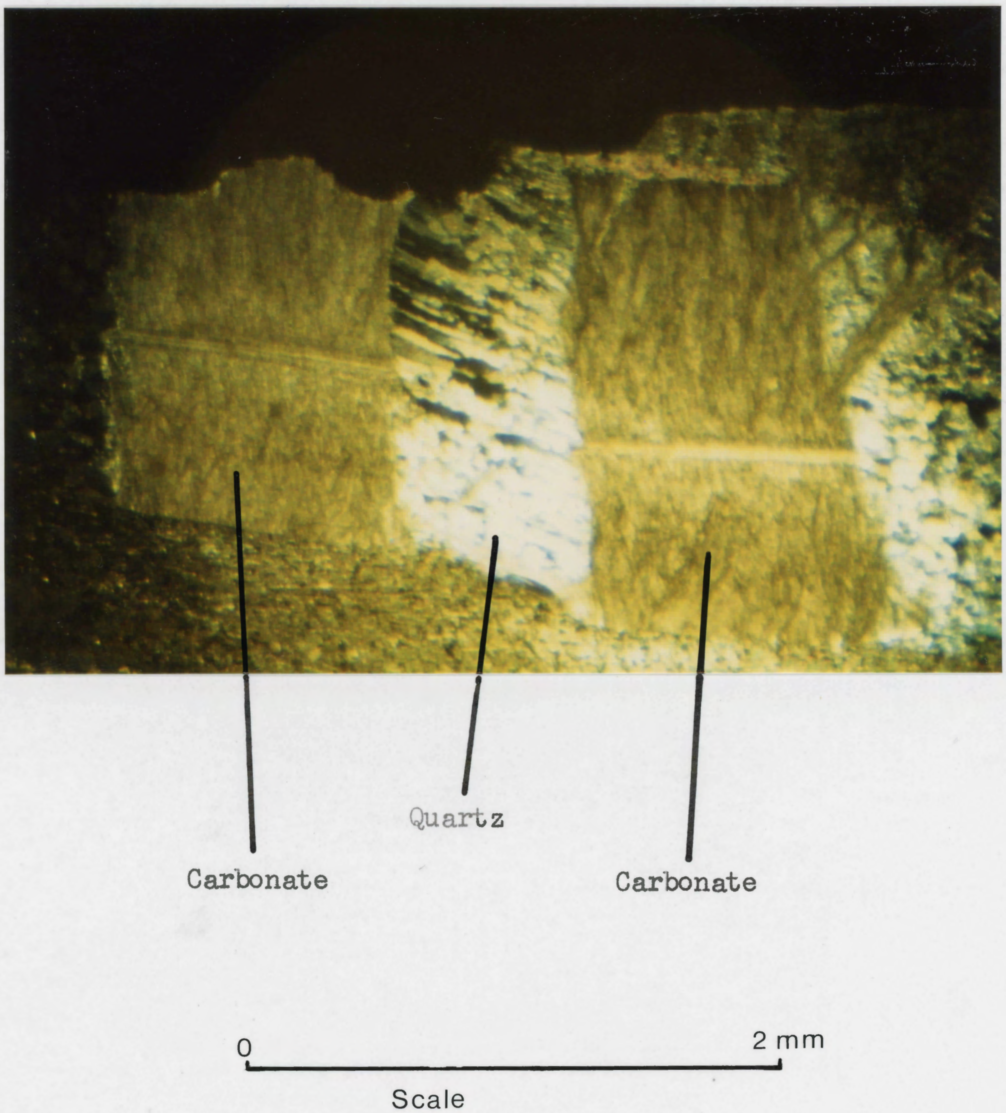


Figure 2.3: Sketch showing relationship between the foliation and folds in the carbonate as well as the relationship between the individual layers.

Figure 2.4: Photomicrograph of blocky beds of carbonate separated by elongated quartz. Note the "feathery" texture of the carbonate.



slate contains no sedimentary structures while the quartz metawacke sometimes contains small scale cross bedding. Microscopically the metawacke contains quartz while the slate consists of muscovite, chlorite, lesser amounts of quartz, minor amounts of opaques, and spessartine. The schist that occurs near the batholith has been placed in this lithology because of the large amounts of micas present and the absence of any carbonate bands or remanent carbonate bands.

2.2.3 Metamorphism

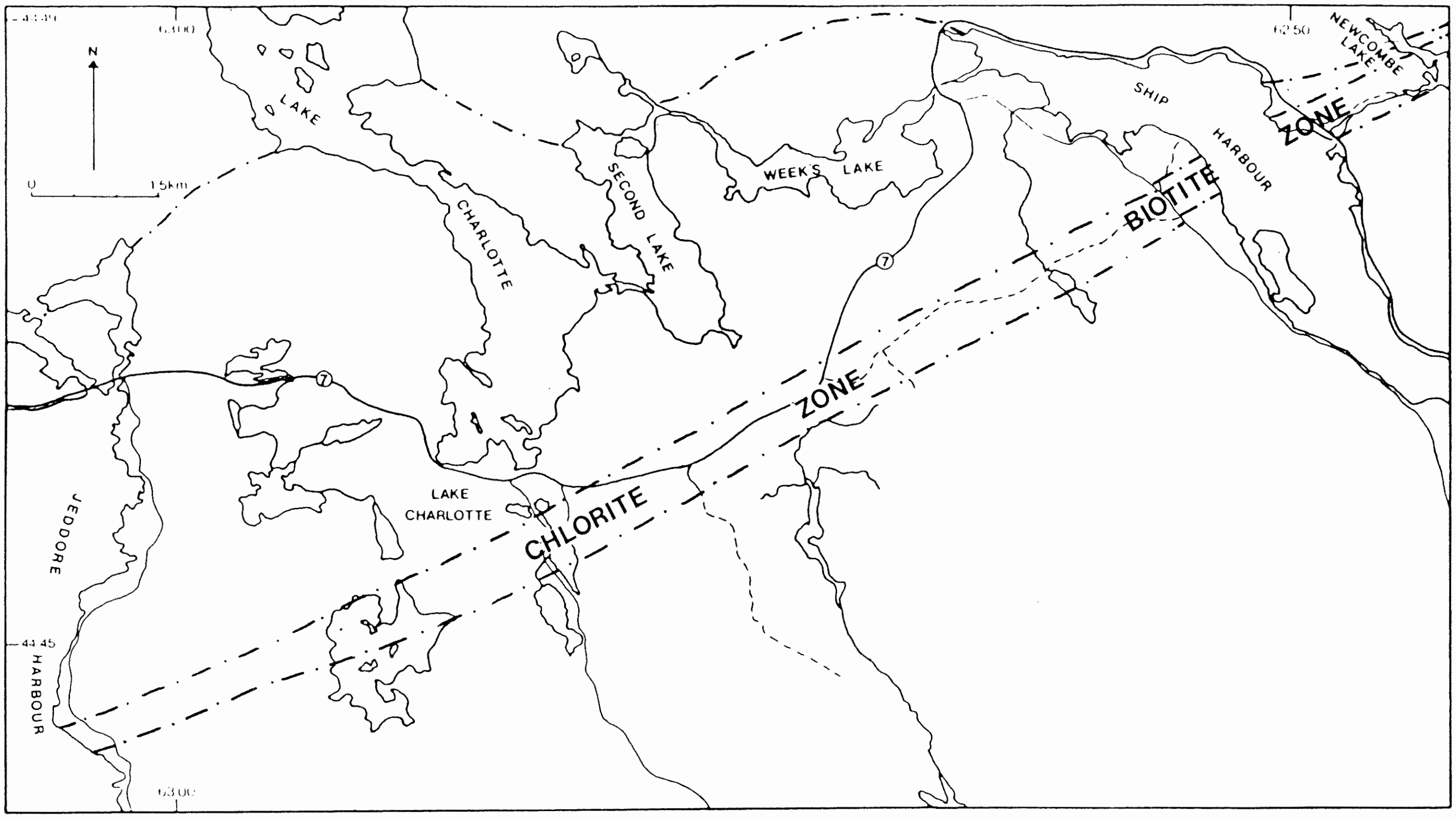
Rocks in the Lake Charlotte area have undergone both regional and contact metamorphism. The regional metamorphism is restricted to the lower greenschist facies while slates affected by contact metamorphism are restricted to the lower hornblende hornfels facies.

Greenschist facies contains two metamorphic zones in the study area, chlorite zone to the west and biotite zone in the vicinity of Ship Harbour(Fig. 2.5). Most of the study area lies in the lower grade chlorite zone, this zone is recognized by the occurrence of chlorite and spessartine. The biotite zone is recognized by the first appearance of biotite and contains the following mineral assemblage:

biotite + chlorite + epidote + spessartine + muscovite

There are also indications that carbonate has been partially or in some cases totally replaced by quartz and biotite in

Figure 2.5: Regional Metamorphic Zones



the biotite zone.

The effects of contact metamorphism are observed in the vicinity of Newcombe Lake and is recognized by the occurrence of large amounts of biotite and absence of carbonate. The mineral assemblage observed in these rocks is:

biotite + spessartine + chlorite + muscovite + phorpyroblast

This facies is very similar to that of the biotite zone but is considered separate on the following evidence. All the biotites over prints the foliation associated with regional metamorphism, the biotites and spessartines are considerably larger than in regionally metamorphosed rocks, the total replacement of carbonate to biotite and quartz, and the occurrence of large (1-2mm) porphyroblasts in the schist. These porphyroblasts could not be identified as they have been badly altered but it is believed to be either cordierite or andalusite because of its low birefringence and association with the pluton.

2.2.4 Structure

The rocks are folded (F_1) into a northeast trending syncline. Associated with this F_1 fold is an axial planar slaty cleavage (S_1). This cleavage is particularly well developed in the slaty layers, often totally obscuring the original bedding planes. Microscopicaly this slaty cleavage is defined by the alignment of muscovite, chlorite, and prismatic opaques. Folds in the banded calcareous quartzite are considered to be parasitic folds of the large scale F_1 folds because the S_1 foliation parallels the axial plane of the folds in the carbonate. Observed in outcrops through out the study area are counter clockwise kink bands (F_3) that offset the S_1 foliation by 2 to 5cm. Microscopically the S_1 foliation is slightly offset, this offset has been attributed to the same event that formed the kink bands. A left lateral transform fault that cuts the F_1 fold also occurs in the area. Total offset along this fault does not exceed 200m (Keppie,1979 and Faribault,1897). This fault was not observed by the author and no relationship between the fault and kink bands is known.

CHAPTER 3

Mineralogy and Petrography

3.1 Spessartine Garnets

Spessartine garnet is a minor mineral constituent (5-10%) but is indicative of lithology 2. They occur as colourless euhedral or subhedral crystals ranging in size from 0.5mm to 0.01mm but most are 0.05mm in size. Microprobe analysis of the garnets shows that they contain greater than 70% of the spessartine molecule and greater than 30 weight % MnO (Table 1). The garnets could not be analysed for zoning because of their small size. Good analysis could only be obtained on garnets located in the slaty layers. Good analysis of garnets that occur in the carbonate could not be obtained because of their small size and the presence of inclusions in these garnets. The best analysis for these garnets is given in table 1. Spessartine has been identified in other samples using X-ray diffraction methods.

Typically these garnets occur in the slaty portions of the rocks but are occasionally seen in both carbonate and quartzite layers. At least two generations of garnets occur in the study area, a pre-kinematic and a syn-kinematic to post-kinematic generation.

Table 1a Garnets (wt. %)

Oxide	Location of Garnet			
	Slate 1	Slate 2	Slate 3	Carbonate
MgO	0.08	--	--	0.18
Al2O3	20.44	20.61	20.86	19.59
SiO2	36.17	36.02	36.15	32.09
CaO	2.57	2.46	2.28	5.62
MnO	31.46	33.13	33.01	27.04
FeO	9.03	7.83	7.71	8.70
P2O5	--	--	0.09	--
TiO2	--	--	0.36	0.11
K2O	--	--	--	0.86
NiO	--	--	0.10	--
Total Wt. %	99.75	100.19	100.56	94.20

Table 1b Garnets

End Member	Location of Garnet			
	Slate 1	Slate 2	Slate 3	Carbonate
Andradite	3.70	5.01	1.66	14.9
Ca3Ti2Al2SiO12	--	--	1.11	0.40
Spessartine	73.68	77.90	76.77	71.19
Grossular	3.92	2.31	3.94	3.43
Pyrope	0.34	--	--	0.83
Almandine	18.38	14.78	16.52	9.26

The pre-kinematic generation is only observed in areas with biotite grade metamorphism. Garnets of this generation are large (0.5 to 0.1mm), subhedral and are found in contact with an anhedral opaque mineral. The S_1 foliation has formed wrap around structures around porphyroblasts of the garnets Occassionally pressure shadows are also associated with these porphyroblasts.

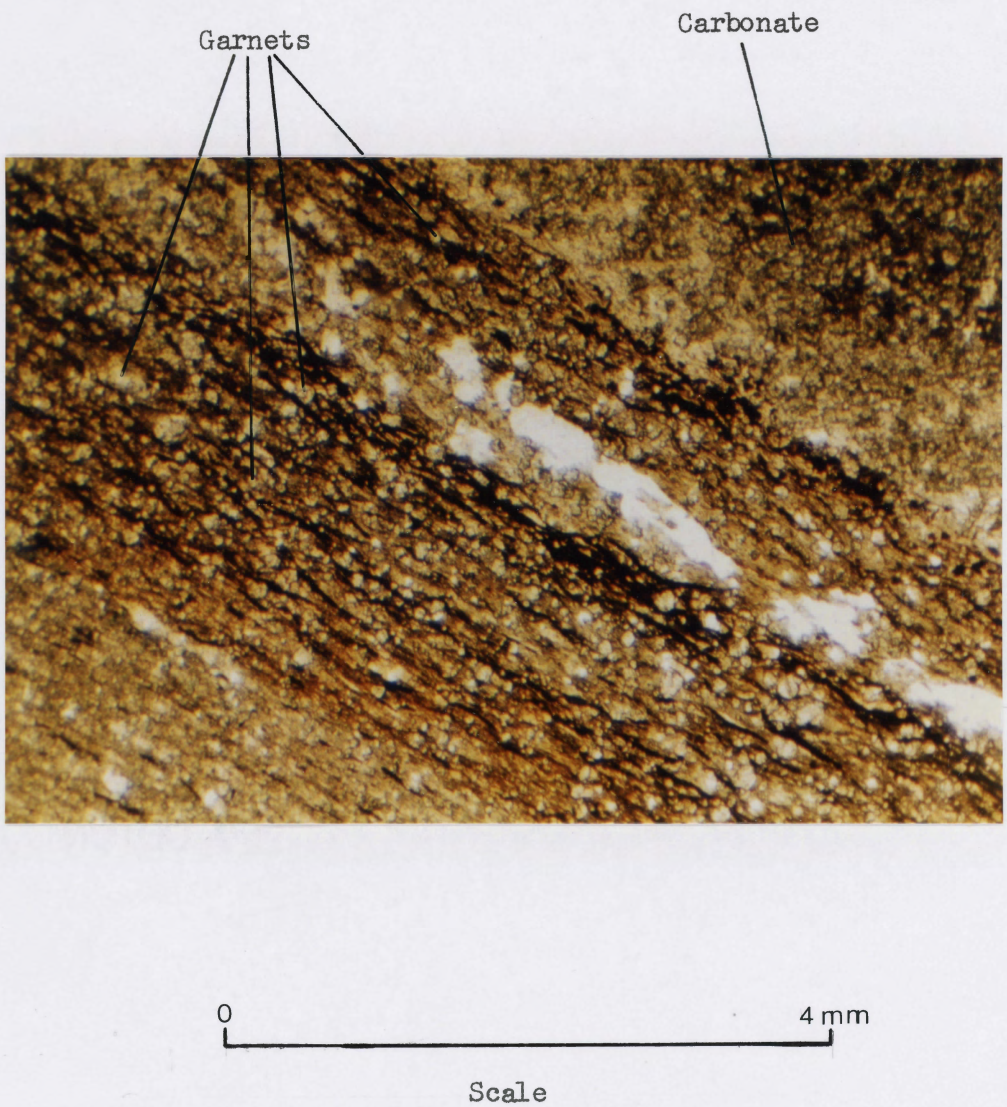
The syn-kinematic to post-kinematic generation occurs in all samples of lithology 2 and 3. Garnets of this generation tend to be smaller in size, generally 0.05mm in size, and are euhedral. These garnets cross cut the S_1

foliation and in some cases partially deflect the foliation, therefore suggesting both syn- and post-kinematic growth of these garnets. This second generation of garnets is also spatially related to the carbonate as they are more numerous closer to the carbonate (Fig. 3.1). In areas of biotite grade metamorphism there is a similar spatial relationship between quartz nodules, folded quartz layers, and spessartines.

3.2 Carbonates

The carbonate occurs only in lithology 2 in areas of chlorite grade metamorphism. The carbonate occurs as layers and nodules and is readily identified in unweathered samples by its reaction with dilute HCl. Various samples of lithology 2 show that the amount of carbonate in this lithology is variable, ranging from 10 to 80 % but most samples contain only 20% carbonate. The carbonate does show a large degree of variation both in colour and texture as well as in composition. The colour of the carbonate ranges from grey to white to pale pink in hand sample and colourless to pale pink in thin section. The carbonate rarely displays any cleavage but shows various textures; a feathery texture as seen in figure 2.4, massive texture (fig. 3.3a), and an altered or impure carbonate that contains metamorphic growths of chlorite, quartz, and muscovite occurring in between the carbonate grains . Samples of the carbonate analysed by the EMP showed wide a

Figure 3.1: Photomicrograph showing concentration of garnets decreasing away from the carbonate.



range of MnO concentrations, ranging from 29.55 to 58.25 weight % MnO, the latter being almost pure rhodochrosite. An overall manganese enrichment or depletion trend is observed in relation to MgO-FeO and CaO (Fig. 3.2). All the microprobe information for the carbonates is summarized in table 2.

Table 2a Pure Carbonate Analyses (wt. %)

Sample	MgO	CaO	MnO	FeO	Total
ZLC 0009					
1	1.40	20.79	30.79	4.68	57.66
2	0.54	16.65	36.65	5.18	59.00
ZLC 0011					
1	0.14	3.22	55.06	2.29	60.71

Table 2b Impure Carbonates* Analyses (wt. %)

Sample	MgO	CaO	MnO	FeO	Total
ZLC 0009					
1	0.91	10.06	41.66	6.96	59.37
2	0.89	8.91	44.39	6.68	60.87
3	0.99	14.49	37.34	7.22	60.03
4	2.24	21.64	29.52	4.76	58.16
5	0.54	10.31	45.02	5.70	61.64
6	0.90	16.55	34.88	6.51	58.84
ZLC 0011					
1	1.23	11.46	40.39	8.08	61.16
2	0.91	10.80	41.80	7.24	60.76
3	0.86	24.22	28.86	5.92	59.87
4	0.41	7.05	48.28	4.65	60.40
ZLC 0013					
1	0.37	3.51	56.09	2.47	62.43
2	0.59	1.91	53.17	3.84	60.85
ZLC 0010					
1	--	1.89	58.25	0.71	60.85
2	--	1.09	60.9	0.65	62.66

* Values for impure samples have been recalculated to the original total, assuming only the presence of MgO, CaO, MnO, and FeO. Original values are given in appendix 2.

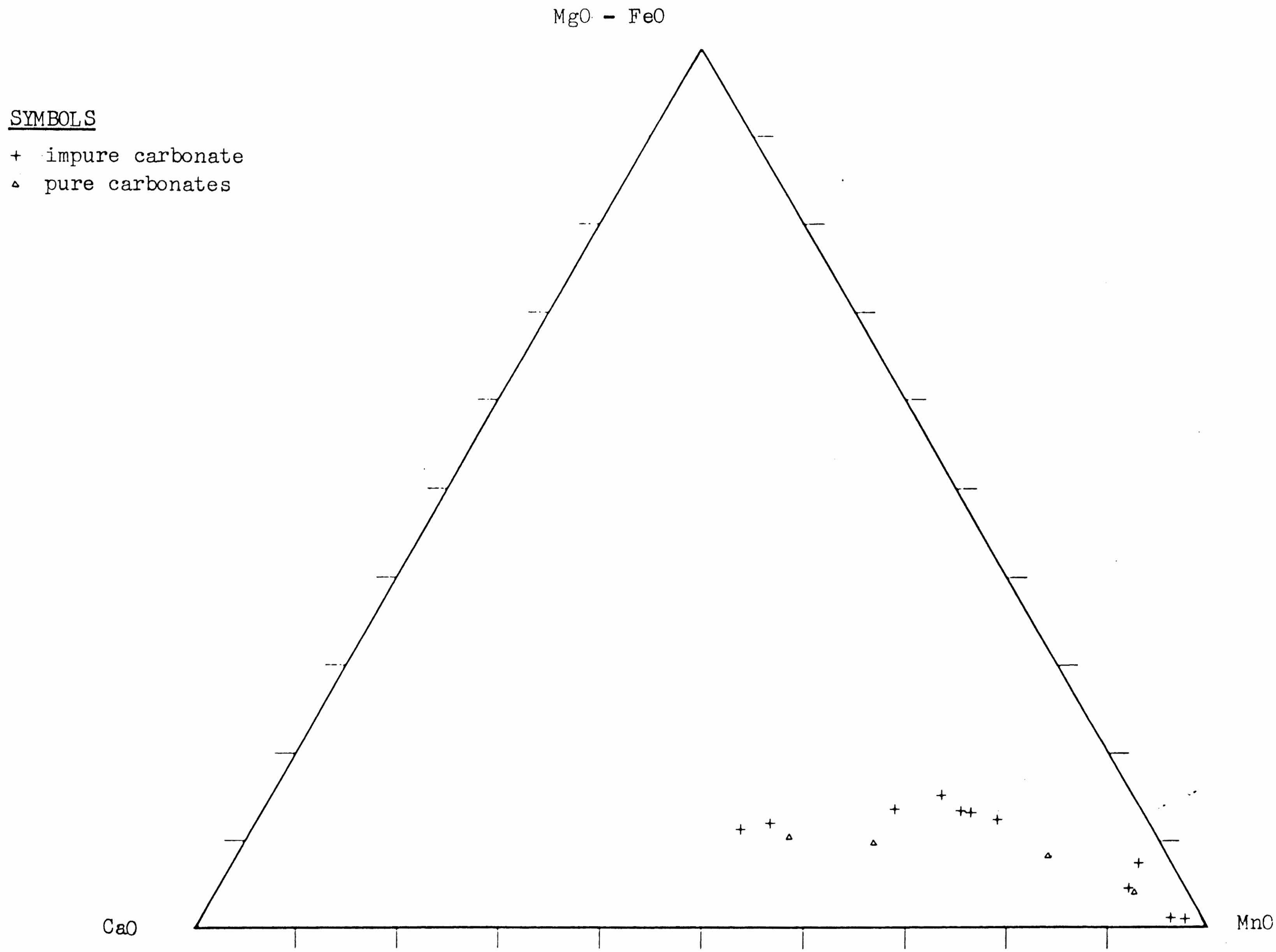


Figure 3.2: Plot of carbonate compositions

3.2.1 Carbonate Nodules

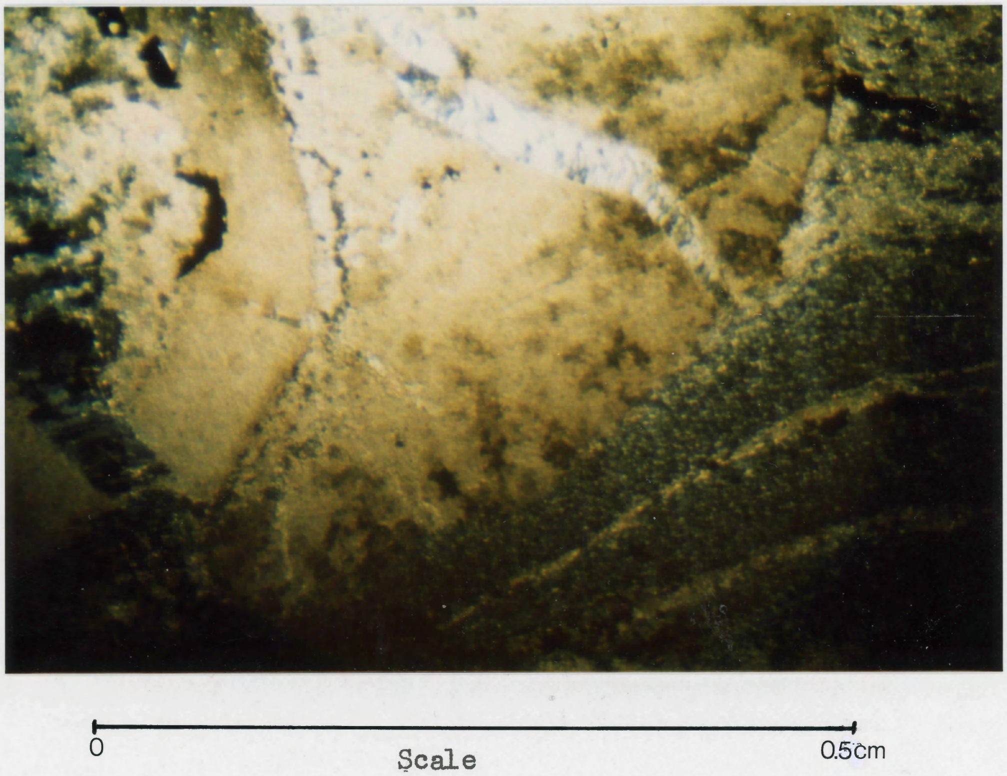
Three different types of carbonate nodules have been distinguished by their mineralogical texture. All nodules range in size from 0.5 to 2cm, however badly weathered nodules up to 10cm across have been seen in outcrop. These nodules are prekinematic as the S_1 foliation wraps around the nodules and the nodules tend to be elongated parallel to the S_1 foliation (Fig. 2.1 and 3.3).

The first type of nodule (Fig. 3.3a) shows distinct layering of the carbonate. These layers contain alternating layers made of aggregates of carbonate grains and layers of massive carbonate. The carbonate grains that make up the aggregate layers have very irregular grain boundaries and there is no uniform or symmetrical extinction between grains under XN. This layer also contains opaque minerals and quartz. The massive carbonate layer has no grain boundaries and shows a symmetrical extinction under XN, as one would find in a mineral that has grown out from a sphere.

A second type of nodule is made up completely of an aggregate of pale pink carbonate grains. These grains have very irregular grain boundaries and show random extinction under XN (Fig. 3.3b).

A third type of nodule is also made up of an aggregate of carbonate grains but what makes this nodule distinct from the other two types is the occurrence of irregularly cross hatched markings (Fig. 2.1a). These markings are about 0.5mm wide and are several millimetres long. In thin

Figure 3.3a: Photomicrograph of layered carbonate nodule.



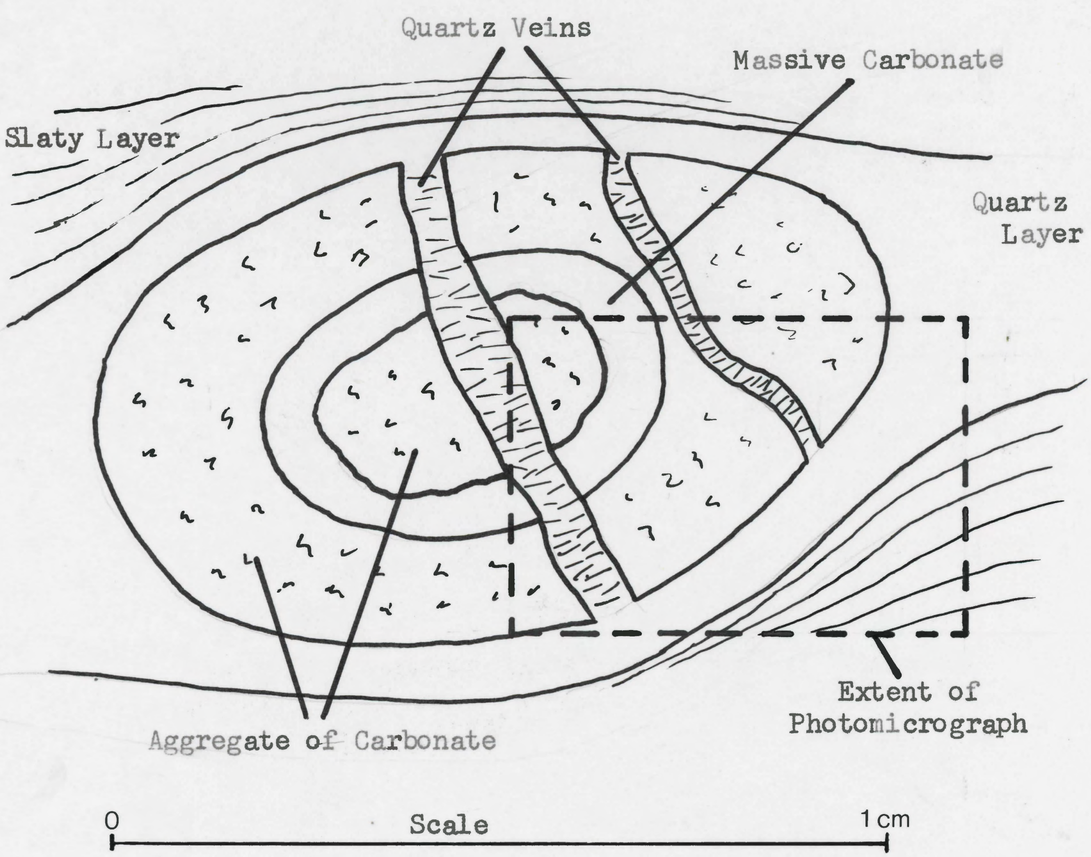
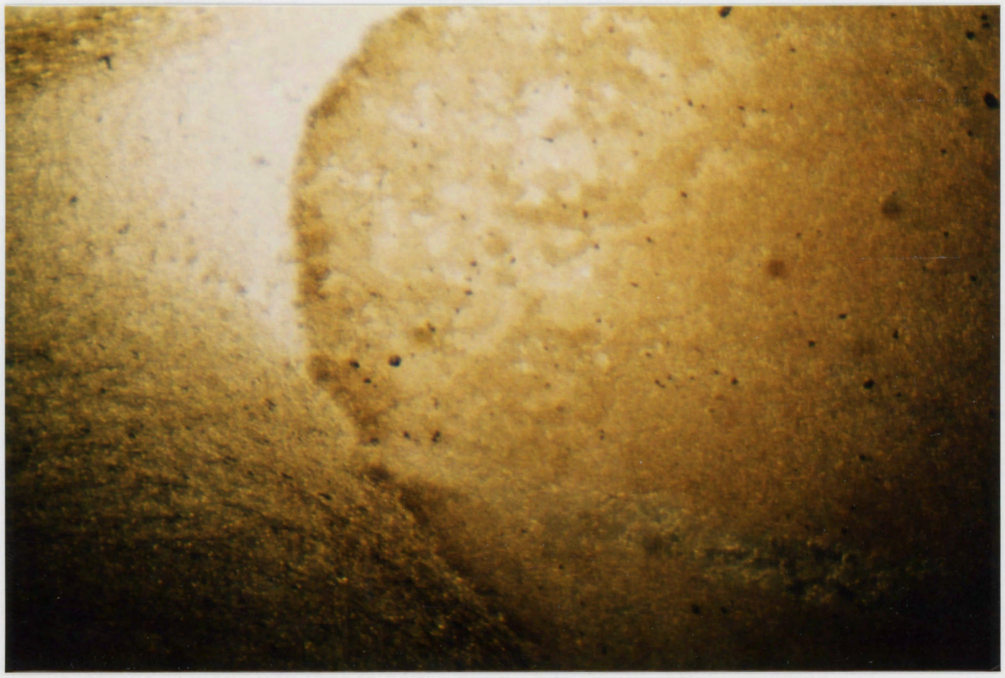
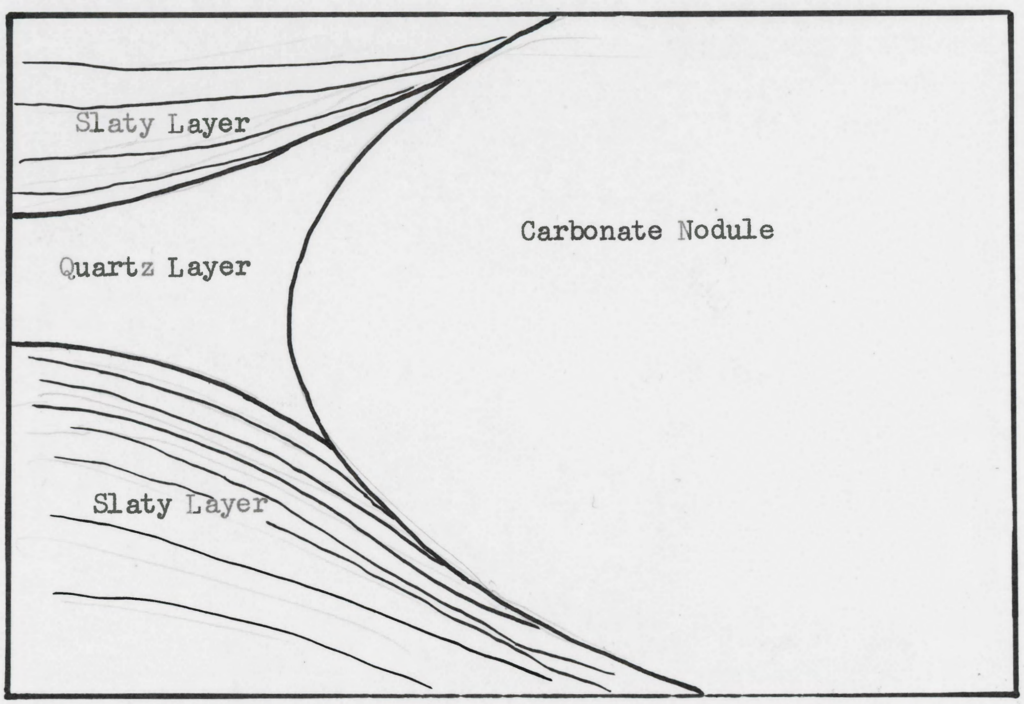


Figure 3.3b: Photomicrograph of aggregate carbonate nodule.



0 0.75cm

Scale



section these markings have a lighter colour than the carbonate and appear to be made up of a mixture of extremely fine grained carbonate, quartz, white mica, and opaques. None of these minerals were positively identified because of their extremely small size. Only one example of this third type of nodule is known to occur.

3.3 Ilmenites

Ilmenite is an accessory mineral (<1%) and is only seen in thin section. Typically they occur as prismatic opaque crystals (0.3mm x 0.05mm) and contain many small inclusions of quartz and mica. These ilmenites do not have the pure ilmenite formula ($FeTiO_3$) but instead about half of the Fe has been replaced by Mn as shown from the EMP data in table 3. The minor amounts of Al, Si, and K present (Appendix 2) are result of inclusions of quartz and muscovite.

Texturally the ilmenites are considered to be pre-kinematic as they are aligned parallel to the S_1 foliation. In some cases the ilmenites have only been partly rotated and pressure shadows have formed on either side of the ilmenite.

Table 3 Ilmenite Analyses* (wt. %)

Sample	TiO2	MnO	FeO	Total
1	54.59	21.62	21.25	97.06
2	52.20	23.75	22.74	98.69
3	51.48	23.39	22.47	97.34
4	51.27	24.11	22.45	97.82

* Due to the presence of small inclusions in the ilmenites the above values have been recalculated to the original total assuming the presence of only TiO_2, MnO, and FeO. The original data can be found in appendix 2.

3.4 Quartz

Quartz is found in all three lithologies. It typically occurs as anhedral grains with irregular grain boundaries and often showing undulatory extinction. Grain size is typically larger (0.5mm) in lithology 1 than the 0.05mm grain size in lithologies 2 and 3.

In lithology 1 quartz makes up approximately 60% of the rock. Lithology 3 contains about 20% quartz occurring between the laths of muscovite and chlorite. In lithology 2 quartz occurs in a variety of ways; as well as occurring in between laths of muscovite and chlorite in the slaty layers, quartz is also found in pressure shadows and filling breaks in the carbonate. Pressure shadows at the hinges of carbonate folds and around carbonate nodules are made up predominantly of fine grained anhedral quartz (Fig. 3.3a).

Quartz elongated parallel to the S_1 foliation fills cracks and breaks in the carbonate layers and nodules (Fig. 2.4), these cracks and breaks occur perpindicular to the S_1 foliation. Similarly elongated quartz also occurs between carbonate grains in impure layers of carbonate. Again the quartz is aligned parallel to the S_1 foliation. In areas of biotite grade metamorphism quartz and some biotite appears to have replaced the carbonate as these folded layers of quartz show the same relationship to the S_1 foliation and spessartine garnets as the carbonate layers.

3.5 Chlorites

Chlorites are found in all three lithologies and in all prograding metamorphic assemblages observed in the study area. In lithology 1 chlorite occurs interstitially between larger grains of quartz and plagioclase. In lithology 2 and 3 chlorite is a major component of the slaty layers and occurs as small laths (0.08 x 0.01mm) aligned with the S_1 foliation.

Chlorites from lithology 2 were analysed with the EMP and are shown to contain about 2.5 weight % MnO (Table 4). No analyses of chlorites from the other two lithologies was made.

Table 4 Chlorite (wt. %)

	MgO	Al2O3	SiO2	K2O	TiO2	MnO	FeO	NiO	Total
1	7.89	25.11	23.99	0.29	0.10	2.49	29.19	--	89.06
2	8.18	24.75	23.40	--	--	2.61	29.95	0.07	88.97

3.6 Muscovite

Muscovites are found in lithologies 2 and 3 and occur in all metamorphic assemblages. Muscovite has been identified both in thin section and by X-ray diffraction. They are most abundant in the slaty layers but occasionally are observed in the carbonate layers. The muscovite occurs as fine grained laths (0.08 x 0.01mm) and are aligned parallel to the S_1 foliation.

3.7 Biotites

Biotite occurs only in lithologies 2 and 3 and is restricted to rocks affected by contact metamorphism or rocks regionally metamorphosed to biotite grade. Contact metamorphic biotites are distinguished from regionally metamorphosed biotites because they overprint the S_1 foliation. The first appearance of regionally metamorphosed biotites appears to coincide with the disappearance of carbonate. These biotites occur in layers that are believed to have originally been carbonate but now contain both quartz and biotite (See Section 3.4).

3.8 Other Minerals

3.8.1 Plagioclase

Plagioclase is totally absent from lithologies 2 and 3 and is only as a minor (1%) constituent in lithology 1. The plagioclase is believed to be of detrital origin.

3.8.2 Opaque Minerals

The opaque minerals present are either pyrite or pyrrhotite. They are only minor constituents but they are ubiquitous to all lithologies but most abundant in lithologies 2 and 3. These minerals can usually be seen in hand sample and are observed occurring in quartz layers, slaty layers, and in both the carbonate layers and nodules.

3.9 Summary

Significant amounts of manganese occur in the carbonates, spessartines, chlorites, and ilmenites of lithology 2, however most of the manganese occurs in the carbonate. Carbonate is a major mineral constituent of lithology 2 and contain high concentrations of MnO, up to 58.25 weight %. Chlorite is also a major mineral constituent of lithology 2 but it contains relatively small amounts of MnO, an average of 2.55 weight %. Both ilmenite and spessartine are minor mineral constituents of lithology 2.

Ilmenites are pre-kinematic in origin and may also be of detrital origin. Spessartine has a syn-kinematic to post-kinematic origin and therefore are of metamorphic origin. Their spatial relationship with the carbonate suggests that they have formed at the expense of the manganese carbonate. Spessartine is known to form at low pressures with temperatures as low as 410°C in the presence of $MnCO_3$, Al_2O_3, and SiO_2 (Deer, Howie, and Zussman, 1972). Roy (1981) also suggests similar conditions for the formation of spessartine. Some spessartine may also have formed from the Mn-rich chlorites and quartz (Hsu in Roy, 1981). The Mn-rich chlorites may have originally been deposited as a Mn-rich sediment and subsequently metamorphosed or they may be totally metamorphic in origin and have become enriched in manganese at the exspense of either ilmenite or the manganese carbonate. In any case carbonate appears to have been the major source of manganese at the time of metamorphism.

CHAPTER 4

Discussion

4.1 Origin of the Carbonate

The carbonate can have three possible origins; epigenetic, syngenetic, or a diagenetic origin. Epigenetic origin would be indicated by the presence of veins or replacement textures. Syngenetic origin involves the precipitation of carbonate as the sediments are being laid down. Diagenetic origin involves the formation of the carbonate after the deposition of the sediments but before lithification.

An epigenetic origin for the carbonate is not considered possible. Any post tectonic origin is ruled out because of evidence showing that the carbonate has been tectonically deformed. The carbonates cannot be veins because of the occurrence of nodules. Replacement is also ruled out as a possible origin of the carbonate as no replacement textures, such as pseudomorphs were observed.

Syngenetic origin for the carbonate is not considered possible as environmental conditions interpreted for the Meguma Group are not favourable for the deposition of carbonate. The Meguma Group is interpreted as forming below the calcium compensation depth (Schenk, 1978) and therefore carbonate should not precipitate directly from the water. The association of black slates with the manganiferous beds indicates reducing conditions, in this condition manganese is in its soluble Mn^{2+} state.

Therefore only a diagenetic origin of the carbonate is left to be considered. Diagenetic manganese carbonate is known to occur in areas of today's oceans that have similar environmental conditions to those interpreted for the Meguma Group. Li, Bischoff, and Mathieu (1969) reported the presence of small amounts (<1%) $MnCO_3$ in a piston core taken in the Arctic Ocean at a depth of 3800m. They also were able to measure the pore water concentration of Mn^{2+} and CO_2 as well as the pH with respect to depth of sediment. With this information they were able to show that $MnCO_3$ becomes saturated at depths between 60 and 130cm below the sediment water interface, below this depth $MnCO_3$ is supersaturated and should therefore be present as a solid. Limited penetration into the sediment and low overall abundances in manganese could explain the presence of relatively small amounts of $MnCO_3$. Manheim (1982) reported the presence of manganese carbonate in sediments of the Baltic Sea. These carbonates occur in fine grained sediments in deep basins where reducing conditions prevail and where there is an abundant supply of organic material. Manheim (1982) claims the manganese carbonate is of diagenetic origin, forming below the water-sediment interface when the Mn:Ca reaches a level of 1:200 in the pore waters.

On the basis of the above discussion and other evidence presented in this thesis the following model is proposed which explains the origin of the carbonate at Lake Charlotte as a result of diagenesis. This model requires two essential conditions to be present; 1) reducing conditions at the site of Mn-carbonate deposition and 2) a means of supplying manganese in its oxidized form to the area where the Mn-carbonate is being deposited. Both of these conditions are interpreted as being present during the deposition of the Meguma Group, black slates being indicative of reducing conditions and turbidites being the mechanism for supplying oxidized manganese. Another possibility that must also be considered, in light of the fact that other manganiferous beds in the Meguma Group occur in the same stratigraphic horizon (GHT), is that conditions in the basin changed from an oxidizing to a reducing environment. If this is the case then these manganiferous beds represents the time at which these environmental changes occurred.

In reducing conditions and in the presence of organic material MnO will be reduced to Mn^{2+} because oxygen has a stronger affinity for the carbon in the organic material. The end result of this reaction is the production of CO_2 and Mn^{2+}, both of which go into solution. If the reaction takes place below the sediment-water interface CO_2 and Mn^{2+} will become concentrated in the pore water until concentrations are high enough to precipitate $MnCO_3$. Any other suitable cation (such as Fe, Ca, or Mg) present in the pore water would also combine with a carbonate anion and precipitate, thus explaining why the carbonate is not pure $MnCO_3$. Isotopic evidence at a similar manganiferous bed at Eastville (see section 4.2) suggests just such a situation where CO_2 in the carbonate is derived from the oxidation of organic material (MacInnis, 1984).

4.2 Relationship to Other Manganiferous Beds in the Meguma Group

There is stratigraphic, textural, and mineralogical evidence which indicates that the manganiferous bed at Lake Charlotte is related to other manganiferous beds in the Meguma Group (Fig. 1.1).

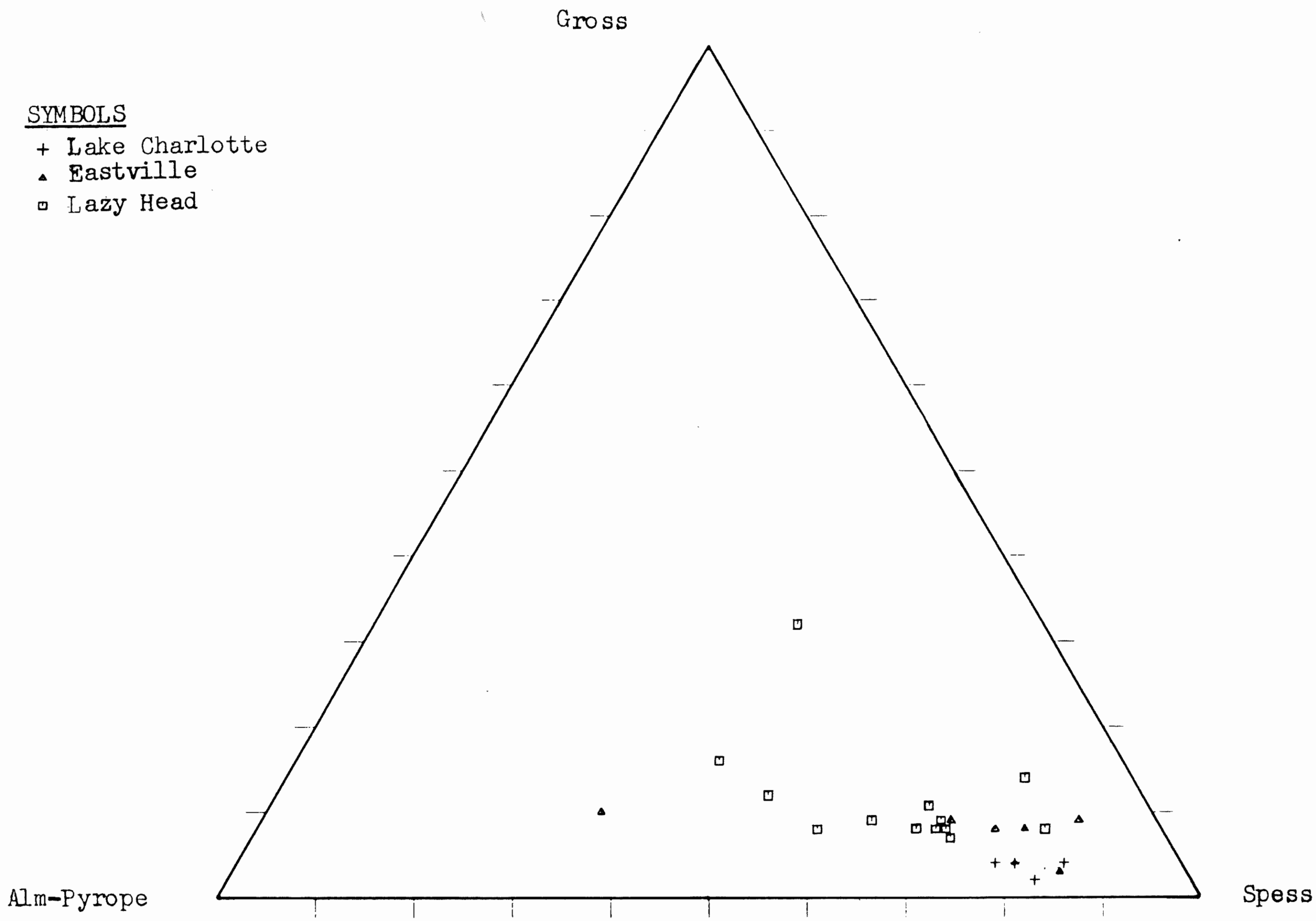
The manganiferous beds at Eastville, Lazy Head, Rocky Lake, Sonora, as well as at Lake Charlotte all occur in the same stratigraphic horizon, that is the GHT.

Texturally, the manganiferous beds at Lake Charlotte, Eastville (Binney et.al., in press), Lazy Head (Shaw,1983), and Rocky Lake (Bishop and Wright, 1974) are similar as they all contain thin (<2cm) contorted layers. With the exception of Lazy Head nodules up to 10cm across are also known to occur in the same horizon as the contorted layers. No textural description of the Sonora manganiferous bed was found by the author.

Mineralogically, the manganiferous beds at Eastville and Lazy Head are similar to the manganiferous bed at Lake

Charlotte. All three areas contain carbonate and spessartine (Binney et.al., in press; MacInnis,1983; Shaw,1983) but in different abundances. Differences in the abundances of particular minerals are attributed to varying degrees of metamorphism as the whole rock values for MnO are similar. Lazy Head has been metamorphosed to middle amphibolite facies (Shaw,1983) and at temperatures suggested by this metamorphic facies rhodochrosite would have broken down (Deer, Howie, and Zussman, 1972) and the Mn would be incorporated in the garnets (Roy, 1981; Deer, Howie, and Zussman, 1972). The manganiferous beds at both Eastville and Lake Charlotte have only been metamorphosed to greenschist facies. These beds also contain considerably more carbonate than Lazy Head. The manganiferous bed at Lake Charlotte contains more carbonate but a lesser amount of garnets than at Eastville (Ian MacInnis, personal communication). This difference between Eastville and Lake Charlotte may also be due to temperatures of metamorphism as manganese carbonate begins to break down and form spessartines in greenschist conditions (Roy, 1981; Deer, Howie, and Zussman, 1972). A plot of the garnets from these three areas (Fig. 4.2) shows that garnets from these three areas plot in the same field. However the garnets at Lazy Head show an enrichment trend in Fe, Mg, and Ca, this is attributed to the incorporation of these cations at temperatures of garnet grade metamorphism or higher (Edmunds and Atherton, 1971). The only manganese minerals reported

Figure 4.1: Plot comparing garnets at Lake Charlotte to those occurring at Eastville and Lazy Head.



from Rocky Lake are spessartine and pyrophanite, a manganese ilmenite (Bishop and Wright,1974). Ilmenites at Lake Charlotte also are enriched in manganese. No manganese carbonate is known to occur at Rocky Lake but sampling was limited to the top several centimetres of outcrop (Bishop and Wright,1974) where any manganese carbonate would been have weathered out, as is the case at Lake Charlotte. No description of the mineralogy of the manganiferous bed at Sonora was found by the author.

4.3 Lake Charlotte a "Proto - Coticule"?

Coticules are metamorphic rocks of sedimentary origin (Kennan and Kennedy, 1983; Kramm, 1976), however the nature of the original sedimentary rock has lead to widespread interpretations (Kramm, 1976). Interpretations of the sedimentary origin of coticules range from detrital methods, such as placer spessartine deposits aand the deposition of manganese rich sands, to non-detrital methods such as the precipitation of cherts (Kramm, 1976). DeDycker (in Kramm, 1976) believes to have found an unmetamorphosed equivalent to coticules (proto-coticules) that contains 50% manganese carbonate . It is not unreasonable to assume that different sedimentary processes are responsible for the formation of different coticules.

The manganiferous bed at Lake Charlotte may be considered a "proto-coticule" as metamorphism in areas of chlorite grade has been minimal, the manganese carbonate had only begun to breakdown. In other areas of the Meguma Group, coticules have been identified in areas of higher metamorphic grade, such as Eastville (MacInnis, 1983) and Lazy Head (Shaw, 1983; Schiller and Taylor, 1965). Schiller and Taylor (1965) have suggested that the coticules at Lazy Head have a non-detrital origin. In light of the above mentioned relationship between the manganiferous beds at Lake Charlotte and Lazy Head, it is logical to conclude that the bed at Lake Charlotte is a less metamorphosed equivalent of the coticule at Lazy Head.

The manganiferous bed at Lake Charlotte also has the 4 typical characteristics of a coticule as proposed by Kramm (1976). These characteristics include; (1) high manganese content in the divalent form, (2) the absence of MnO, (3) high Al content, and (4) the typical small scale folding and contortions of the coticule beds. The large amounts of manganese carbonate at Lake Charlotte indicates a high content of Mn in its divalent form. Mn oxides are absent in the area except as a product of weathering. Large amounts of Al are also present as the manganese carbonate is hosted in pelitic rocks. Kramm's fourth characteristic is also met as the carbonate layers are folded and contorted as seen in figure 2.2.

CHAPTER 5

Conclusions

1) Significant amounts of manganese are found in the carbonate, spessartines, ilmenites, and chlorites that occur in the manganiferous bed at Lake Charlotte. Most of the manganese occurs in the carbonate as it is the most abundant maganese bearing mineral and contains the highest concentrations of MnO, up to 58.25 weight percent.

2) The carbonate is of diagenetic origin and occurs as layers or nodules.

3) Manganese carbonate only occurs in areas of chlorite grade metamorphism. In these conditions spessartine garnets formed at the expense of the manganese carbonate. In areas of biotite grade metamorphism the carbonate layers and nodules have been replaced by quartz and biotite and spessartine garnets are more abundant.

4) At least some of the folding in the carbonate is the result of the same tectonic effect that created the large scale folds (F_1) and associated slaty cleavage (S_1) of the Meguma Group.

5) Stratigraphic, textural, and mineralogical evidence indicates that the manganiferous bed at Lake Charlotte is similar to other manganiferous beds in the Meguma Group, but

is less metamorphosed.

6) Due to the low degree of metamorphism of the manganiferous bed at Lake Charlotte and its similarities to other coticule beds, it is considered to be a "proto - coticule".

CHAPTER 6

Recommendations

1) Completion of whole rock geochemistry of the manganiferous bed so that geochemical comparisons of other manganiferous beds could be made.

2) Carbon and oxygen isotope study of the carbonate to determine if the formation of the carbonate is the result of oxidation of organic material.

3) A detailed microprobe study to determine the metamorphic reactions involving the manganese. Of particular interest is the disappearance of carbonate in areas of biotite grade metamorphism and its subsequent replacement by quartz and biotite.

4) A study to determine the original source of the the manganese that occurs in the carbonate.

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APPENDIX 1

Drill Logs

Diamond Drill Hole #1

In claim J, tract 16, Map 11D 15B. Location is shown in figure 1.2. Elevation above sea level is 49.1m. Dip is 45 degrees to magnetic north.

THICKNESS m	DEPTH m	COMMENTS
7.6	7.6	Overburden
0.6	8.2	Black slate with strongly magnetic sulphides
7.3	15.5	Dark grey slate with desseminated sulphides
7.0	22.5	Softer grey slate with manganese carbonate in wavy layers of varying shades of grey
8.5	31.0	Grey slate many narrow bands of light grey to white
10.4	41.4	Grey slate alternating with narrow bands of soft black material
6.7	48.1	Grey slate, some light grey nodules to 2.5cm in diameter, bands of soft light grey. Sludge very white when dry and fresh
9.1	47.2	Harder and darker slate, fewer bands of soft slate
12.8	70.0	Grey slate with bands of lighter grey, some magnetic sulphides, many small drag-folds and a few pinkish nodules
13.7	83.7	Grey slate, with many bands of light grey with small nodulespink to white, scattered non-magnetic sulphides
18.4	102.1	Contrasty grey bands, tiny fractures filled with sulphides and some quartz, some quartz veinlets to 12cm thick in last 4.6m

end of hole

Diamond Drill Hole #2

In claim G, Tract 16, Map 11D 15B. See figure 1.2 for location. Elevation is 54.3m above sea level. Dip is 30 degrees towards magnetic south

THICKNESS m	DEPTH m	COMMENTS
7.9	7.9	Overburden
1.2	9.1	Alternate bands of black and grey slate
24.5	33.5	Grey slate with bands of varying shades of lighter grey, some pinkish nodules to 2.5cm in diameter
1.5	35.0	Fractures filled with quartz and fine grained sulphides
18.3	53.3	Darker grey slate with some sections of fine disseminated magnetic sulphides
16.2	69.5	Grey slate with alternating bands of varying shades of light grey, soft layers and pinkish nodules
2.1	71.6	Hard black slate, dissemenated sulphides
4.6	76.2	Quartz veinlet, followed by bands of dark grey and lighter grey

end of hole

Diamond Drill Hole #3

In claim A, Tract 15, Map 11D 15B. See figure 1.2 for location. Elevation is 17.7m above sea level. Dip is 45 degrees towards magnetic south.

THICKNESS m	DEPTH m	COMMENTS
5.5	5.5	Overburden
3.6	9.1	Slate, dark grey
6.1	15.2	Grey slate with many wavy layers of lighter grey and layers to 2.5cm thick of pinkish grey carbonate
24.4	39.6	Light grey slate in varying shades in narrow wavy bands with many white-grey to pink nodules, nodules increase with depth
8.6	48.2	Grey slate in bands, with nodules

end of hole

APPENDIX 2

Original Microprobe Analysis of Carbonate

Oxide	ZLC 0009 1	2	3	4	5	6
MgO	0.89	0.86	0.98	2.15	0.51	0.90
CaO	9.83	8.62	14.27	20.77	9.79	16.49
MnO	40.72	42.94	36.78	28.33	42.73	34.76
FeO	6.80	6.46	7.11	4.57	5.41	6.49
Na2O	--	--	--	--	--	--
Al2O3	0.18	0.23	0.21	0.37	--	--
SiO2	0.86	1.50	0.63	1.33	3.13	0.16
K2O	0.07	0.07	0.05	0.15	--	0.04
TiO2	--	0.11	--	0.27	--	--
V2O5	--	--	--	--	--	--
NiO	--	--	--	--	0.08	--
Total	59.37	60.87	60.03	58.16	61.64	58.84

Oxide	ZLC 0010 1	2
MgO	--	--
CaO	1.84	1.00
MnO	56.8	55.71
FeO	0.69	0.59
Na2O	--	0.11
Al2O3	0.44	1.56
SiO2	1.04	3.48
K2O	0.10	0.21
TiO2	--	--
V2O5	0.06	--
NiO	--	--
Total	60.85	62.66

ZLC 0011				
Oxide	1	2	3	4
MgO	1.17	0.88	0.80	0.41
CaO	10.92	10.39	22.50	7.04
MnO	38.49	40.22	26.82	48.18
FeO	7.70	6.97	5.50	2.29
Na2O	--	--	--	--
Al2O3	0.32	0.33	0.62	--
SiO2	2.38	1.86	0.83	0.13
K2O	0.13	0.07	0.18	--
TiO2	--	--	2.61	--
V2O5	--	--	--	--
NiO	0.05	--	--	--
Total	61.16	60.76	59.87	60.40

ZLC 0013		
Oxide	1	2
MgO	0.35	0.58
CaO	3.31	3.23
MnO	52.90	52.65
FeO	2.33	3.80
Na2O	--	--
Al2O3	1.28	--
SiO2	2.01	0.59
K2O	0.26	--
TiO2	--	--
V2O5	--	--
NiO	--	--
Total	62.43	60.85

Original Microprobe Analysis of Ilmenite

	ZLC 0011			
Oxides	1	2	3	4
TiO_2	53.56	50.42	48.30	49.14
MnO	21.37	22.94	21.94	23.11
FeO	21.00	21.97	21.08	21.52
Al_2O_3	--	1.36	1.81	0.74
SiO_2	1.00	1.49	3.85	2.91
K_2O	0.07	0.41	0.36	0.13
CaO	0.06	--	--	0.12
V_2O_5	--	0.10	--	0.16
Total	97.06	98.69	97.34	97.82

APPENDIX 3

Whole Rock Analysis

Whole rock analysis of samples from the three lithologies have not been included in this thesis as they became available only after the deadline for the submitting of the thesis had passed. The results and the particulars of these analyses are now presented.

The samples were obtained from both drill core (samples numbered between 10 and 20) and surface samples (samples numbered over 300), locations shown in figure III-1. The samples were analysed for 14 trace elements and 10 major elements by X-ray flouresence (XRF) (Appendix 4). The results of the analyses are recorded below in tables III 1 and III 2.

Table III-la Whole Rock Analyses (wt. %)
Lithology 1 - Quartzite

Elements	ZLC-306	ZLC-319
SiO2	69.68	74.46
Al2O3	10.62	12.58
Fe2O3	3.20	3.21
MgO	0.92	1.01
CaO	0.37	0.78
Na2O	2.15	2.16
K2O	2.01	2.73
TiO2	0.39	0.71
MnO	0.05	0.06
P2O5	0.07	0.10
Total	89.46	97.8
L.O.I.*	1.46	0.85

Table III-1b Whole Rock Analyses (wt. %)
Lithology 2 - Grey Slate (GHT)

Element	ZLC-0014	ZLC-0015	ZLC-0016	ZLC-0017
SiO2	48.35	57.43	48.34	37.11
Al2O3	18.18	16.88	17.57	14.57
Fe2O3	15.14	10.16	11.93	7.61
MgO	3.45	2.62	3.12	1.64
CaO	1.32	0.50	1.48	4.98
Na2O	0.14	--	0.01	0.01
K2O	1.81	2.38	2.24	2.64
TiO2	0.98	1.04	1.04	0.88
MnO	2.66	2.90	4.87	13.63
P2O5	0.45	0.20	0.21	0.21
Total	92.48	94.04	90.73	83.28
L.O.I.*	5.31	4.15	6.77	13.38

Element	ZLC-301	ZLC-313	ZLC-318
SiO2	50.86	57.13	55.41
Al2O3	16.98	20.25	19.79
Fe2O3	11.08	8.14	7.77
MgO	2.65	2.47	2.45
CaO	2.54	2.15	6.31
Na2O	--	2.32	1.08
K2O	2.33	2.43	1.63
TiO2	0.88	0.95	0.86
MnO	4.16	1.26	2.11
P2O5	0.54	0.18	0.31
Total	91.90	97.28	97.72
L.O.I.*	5.69	2.62	0.69

Table III 1c Whole Rock Analyses (wt. %)
Lithology 3 - Blue Slate

Elements	ZLC-0012
SiO2	69.77
Al2O3	15.69
Fe2O3	3.82
MgO	1.35
CaO	--
Na2O	0.38
K2O	3.12
TiO2	0.84
MnO	0.33
P2O5	0.10
Total	95.37
L.O.I.*	4.31

* L.O.I. = lost on ignition

Table III 2a Trace Element Analyses (ppm)
Lithology 1 - Quartzite

Element	ZLC-306	ZLC-319
Ba	387	596
Rb	69	96
Sr	134	175
Y	16	27
Zr	139	348
Nb	9	14
Th	4	7
Pb	21	14
Ga	11	13
Zn	43	35
Cu	8	5
Ni	15	15
V	59	61
Cr	46	74

Table III 2b Trace Element Analyses (ppm)
Lithology 2 - Grey Slate (GHT)

Element	ZLC-0014	ZLC-0015	ZLC-0016	ZLC-0017
Ba	1071	1201	1160	1301
Rb	61	81	77	88
Sr	70	73	81	130
Y	40	23	34	29
Zr	165	173	168	150
Nb	16	17	16	15
Th	10	11	9	7
Pb	15	13	15	30
Ga	25	23	25	23
Zn	150	106	130	94
Cu	3	2	14	3
Ni	121	93	125	75
V	101	143	168	137
Cr	102	115	110	85

Element	ZLC-301	ZLC-313	ZLC-318
Ba	1167	621	332
Rb	80	151	99
Sr	106	659	628
Y	28	29	51
Zr	149	172	165
Nb	14	15	16
Th	13	10	10
Pb	17	32	39
Ga	22	26	26
Zn	142	118	111
Cu	53	25	81
Ni	125	58	60
V	145	147	118
Cr	89	121	93

Table III 2c Trace Element Analyses (ppm)
Lithology 3 - Blue Slate

Element	ZLC-0012
Ba	896
Rb	109
Sr	165
Y	32
Zr	129
Nb	14
Th	11
Pb	32
Ga	16
Zn	47
Cu	--
Ni	7
V	131
Cr	115

These analyses have not been examined in detail but they show an obvious trend that this lithology is indeed rich in manganese, even samples ZLC-313 and ZLC-318 which contained no carbonate. These samples occur near the batholith (Fig. III-1), however, they do contain contorted beds. The amount of manganese present in all of the samples is quite variable and is probably the result of the inhomogenity of the rocks, as the amount of manganese seems to be dependent on the amount of contorted beds present either carbonate or otherwise (see section 3.4).

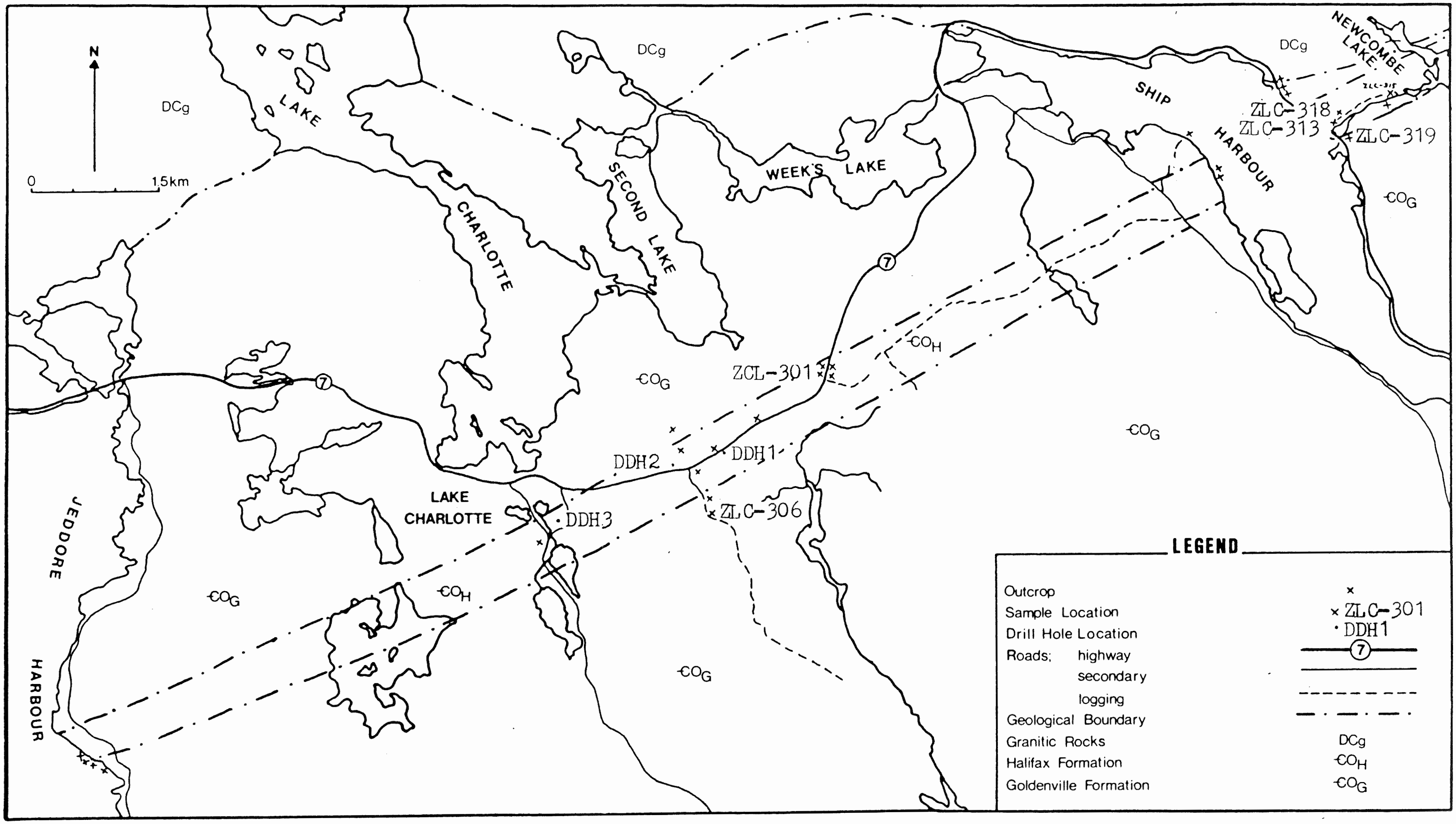

Figure III-1: Location of samples for geochemical analyses.

APPENDIX 4

X-Ray Fluoresence Procedure*

The samples were analysed for 14 trace elements on a Philips PW 1400 sequential x-ray fluoresence spectrometer using a Rh-anode X-ray tube and a LiF 220 analysing crystal. Analyses were done on pressed powder pellets. Within the trace element program employed, the sample counts were corrected for instrumental drift, background and line overlap effects. The resulting counts for all elements, except Cr and V, were corrected for mass absorption by ratio to the Rh Compton Scatter peak. The concentration of each element in the unknown samples was determined by reference to a calibration constructed from results on international rock standards. Precision and accuracy for most elements is generally between 5-10%.

* Description courtesy of Kevin Cameron of St. Mary's University.