A STUDY OF SULFIDE MINERALIZATION IN THE MEGUMA GROUP SEDIMENTS GOLD BROOK, COLCHESTER COUNTY NOVA SCOTIA

by

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ABSTRACT

A preliminary study of representative drill core from the Gold Brook property (of Sulpetro Minerals Limited), Colchester County, Nova Scotia was undertaken, to describe the styles of strata-bound and vein-type mineralization hosted in metasediments of the Meguma Group.

Mineralization is distributed mainly within a calcareous quartz metawacke unit at the top of the Goldenville Formation and within immediately overlying graphitic slates of the Halifax Formation.

Sulfides occur as three styles of aggregates: stratiform, vein-fracture filling and fabric controlled. The mineralogy consists predominantly of pyrrhotite and pyrite with associated sphalerite and galena and traces of chalcopyrite and arsenopyrite.

High lead-zinc values within the calcareous quartz metawackes are associated with manganese. This enrichment is accounted for in calcite and spessartite garnets. Iron is concentrated within the black graphitic slates.

The data are compatible with a model suggesting an enrichment of metals during sedimentation, followed by remobilization of these metals during regional metamorphism and later precipitation into fractures and veinlets.

ACKNOWLEDGEMENTS

I would like to extend special thanks to Dr. Marcos Zentilli for suggesting this thesis topic and for his guidance and encouragement as my supervisor. I also extend my appreciation to Sulpetro Minerals Limited for the use of their core and to Paul Binney for his interest and stimulating discussions.

Thanks go to Bob MacKay for his instruction on the use of the microprobe and to Dr. P.E. Schenk for the use of his camera/microscope equipment. Discussions with Sam Akande and Dr. G. Muecke were much appreciated.

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CHAPTER 1

INTRODUCTION

1.1 General Statement

Between 1977 and 1981 Sulpetro Minerals Limited (formerly St. Joseph Explorations Limited) undertook a diamond drilling project at Gold Brook, Nova Scotia to confirm possible economic concentrations of sulfide mineralization within the Meguma Group. The highest percentages of sulfides were found within the Goldenville quartz metawackes and the, basal, black slate units of the overlying Halifax Formation. Extensive mineralization was not observed in surface outcrop. No previous concentrated work on lithology or mineralization from this area has been undertaken. This thesis provides an overview of the geology of these previously unreported sulfide occurrences within the Meguma sediments of Gold Brook.

1.2 Location

The Gold Brook property, latitude 45°16'N, longitude 62°54'W to latitude 45°17'N, longitude 62°44'W is located immediately east of Eastville, Colchester County in an area controlled by Scott Maritime Paper Company. Access is by means of two roads; Route 102 from Halifax to Brookfield, thence via Route 289 east to Eastville. A paved secondary road (6.5 km) to the right off of route 289 east, connects on to the gravel roads leading into the property. All routes are suitable for automobiles. The drillhole selected for detailed study (DH 224-15) lies in the western part of the property (Fig. 1.1).

1.3 Physiography

The topography at Gold Brook changes from an erratic, hummocky terrain in the west, with relief ranging from 15 to 45 metres to a more gently rolling terrain in the east. Drainage is poor with the exception of those areas in the western part of the property surrounding Cox Brook and Little Brook. The region is densely forested with a mixture of hardwood and softwood trees and is currently being exploited by Scott Maritime Paper Company.

1.4 Previous Geological Work

H. Fletcher and E. R. Fairbault (1891) mapped the study area on a scale of 1 inch = 1 mile. Their results were published by Fairbault in an accompanying geological report of Colchester and Pictou Counties, N.S. Although somewhat modified, their observations are still in common use. Further geological mapping in the area was carried out by Benson (1958).

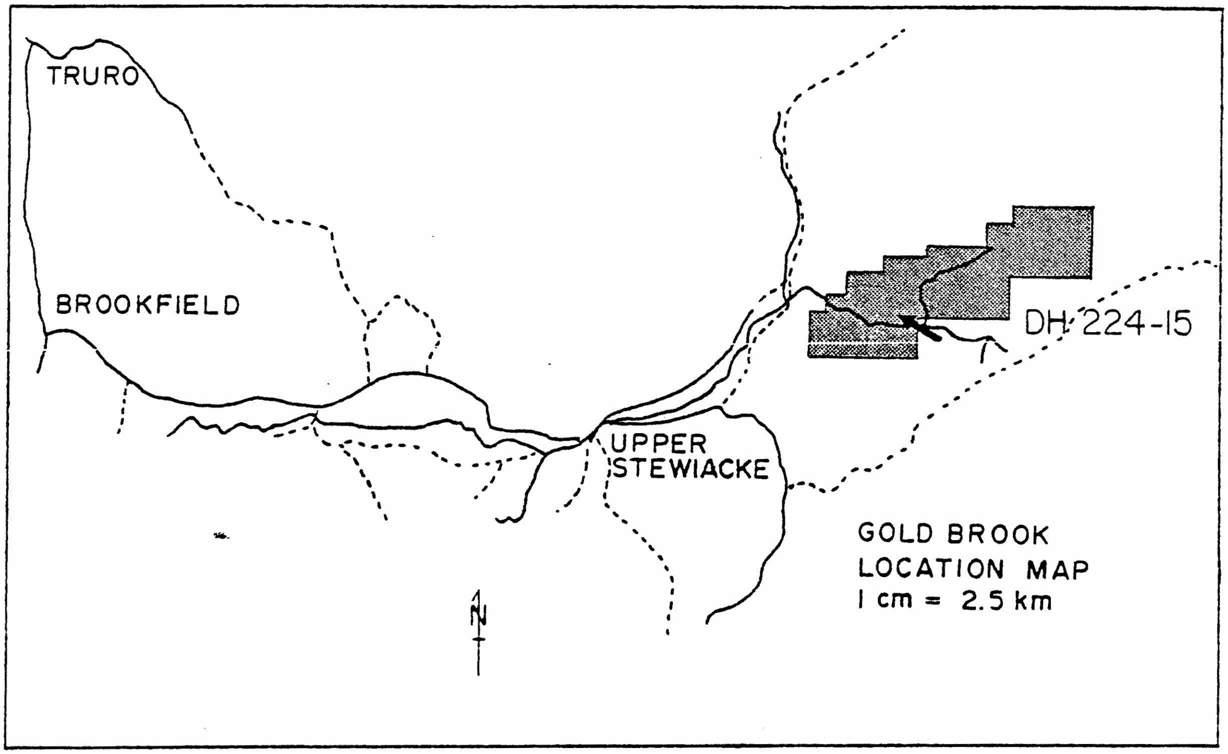


Figure 1.1. Location of DH 224-15 with respect to the study area.

More recently Sulpetro Minerals Limited (1976) mapped the Gold Brook property in detail on a scale of 1 cm = 100 m. Surface and subsurface data were obtained through geological and geochemical surveys on surface outcrop and drill core.

1.5 Purpose and Scope

Diamond drilling at Gold Brook proved worthwhile. Geologically interesting occurrences of sulfide mineralization were found within each lithological unit of the Meguma metasediments.

The purpose of this thesis was to describe the styles of mineralization and associated lithologies and offer a preliminary interpretation of the deposit. An attempt was made to understand the nature of the transition between the Halifax and Goldenville Formations in this area. In particular, the black graphitic slates and massive interbedded quartz metawackes associated with sulfide mineralization are described.

Because of the time constraints, detailed studies of individual aspects of the property are out of the scope of this thesis. Instead this report is intended only to represent a basis for further extensive research within the area.

1.6 Methodology

The study area was visited briefly in November 1981 and

January 1982 for the purpose of collecting samples and gaining an understanding of the local geology.

During the fall of 1981 core logging was carried out and a chart of the stratigraphy of 13 drill holes was compiled (Appendix 1). From this chart DH 224-15 was selected for sampling on the basis of its location, stratigraphic thickness and completeness.

Fifteen slabs from the drill core were selected for cutting and polishing to study the styles of mineralization. Eight of these slabs were thin sectioned for petrologic observation, four were polished for reflected light microscopy and three were polished and carbon-coated for microprobe analysis.

Chemical analyses were not performed especially for this report. The chemical data were obtained from confidential files, courtesy of Sulpetro Minerals Limited (1982).

CHAPTER 2

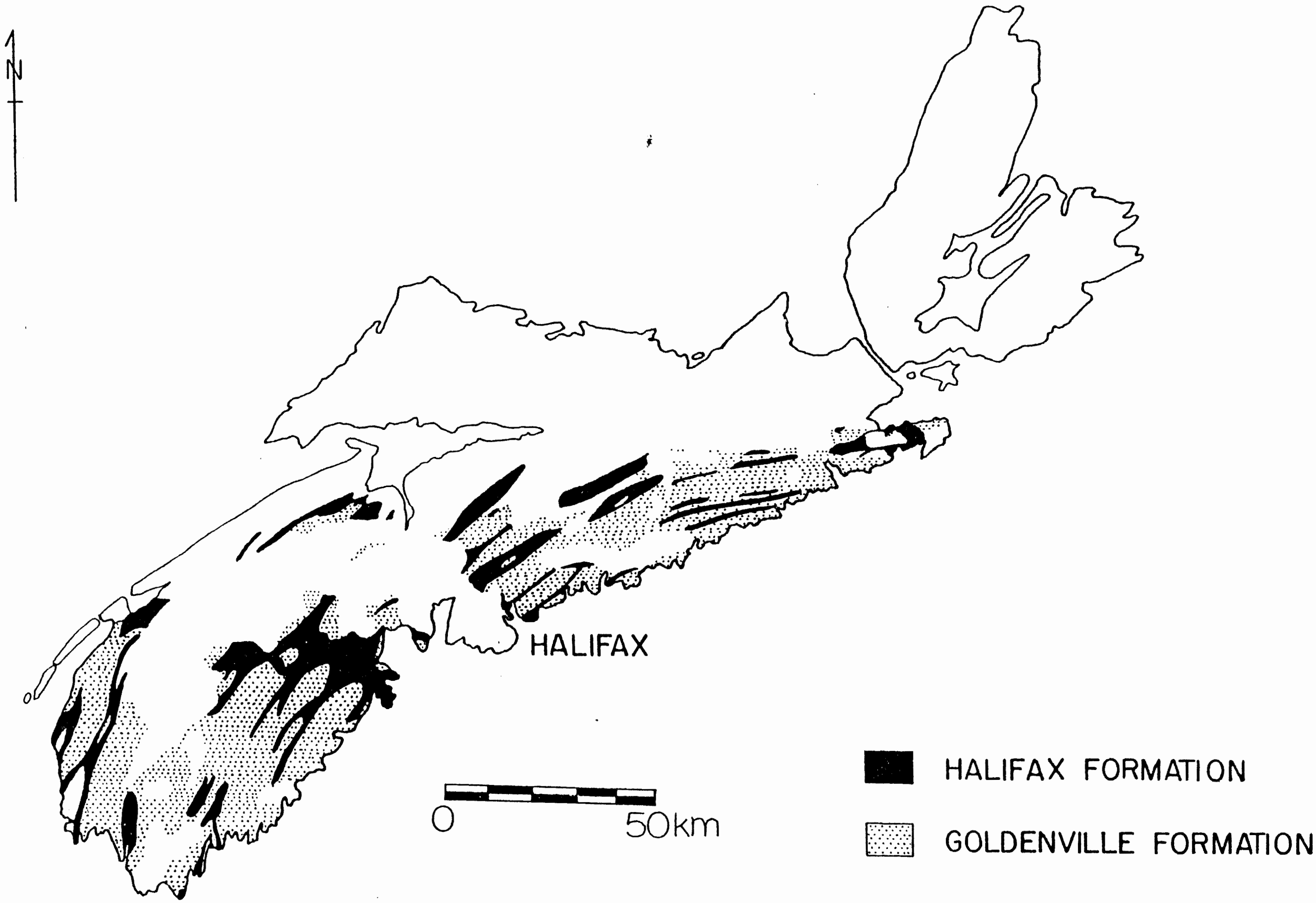
REGIONAL GEOLOGY

The Gold Brook property lies, geologically, in the Meguma zone of the Appalachian Mountain system (Schenk, 1978). The region, which is dominated by Cambro-Ordovician metasediments of the Meguma Group, was deformed and metamorphosed during the Devonian Acadian Orogeny and intruded by Devonian granitoid plutons (Figure 2.1).

The Meguma sediments of southern Nova Scotia consist of a large mass of alternating Lower Paleozoic quartz metawacke and slate units extending perhaps, to a thickness of over 10 kilometres and comprising a total area of 125 x 10^3 km^2 (Schenk, 1978). These sediments have been divided, for mapping purposes, into two formations; the basal Goldenville Formation and the upper Halifax Formation.

The Goldenville Formation constitutes a thick, massive unit of metamorphosed greywacke sandstone intercalated with thin slate beds in proportions characteristic of flyschoid sediments. The Halifax Formation comprises beds of thinly laminated siltstone, slate and argillite with minor interbedded sandstones becoming more abundant towards the base of the formation. Schenk (1976) has defined the boundary between

Figure 2.1. Distribution of the Cambro-Ordovician Halifax and Goldenville Formations in Nova Scotia (after Schenk 1976).


N
HALIFAX
0
50km
HALIFAX FORMATION
GOLDENVILLE FORMATION

these two formations on the basis of a slate to greywacke ratio of 1:1.

Combined lithologic and structural characteristics of these sediments suggest that the formation originated as a turbidite fan deposited in a passive euogeoclinal continental slope setting, the source of which was to the south (Harris and Schenk, 1976).

Paleontological data are limited but graptolite occurrences within the Halifax Formation, near Wolfville, have been identified as *Dictyonema flabelliforme* of Cambrian to Lower Ordovician age. K-Ar dating of detrital muscovite has given a similar (Lower Ordovician) age, 476 ± 19 m.a. to 496 ± 20 m.a., to the Goldenville quartz metawackes (Harris and Schenk, 1976).

Post-depositional metamorphism, deformation during the Acadian orogeny and subsequent intrusive activity have affected the Meguma rocks. For the most part the sediments underwent metamorphism of upper greenschist grade as a result of temperatures ranging upwards to 500°C and pressures from 3 to 5.5 kbs (Winkler, 1967).

Deformation resulted in a series of northeast-southwest trending, high angle, regional folds up to 100 kilometers in length with wavelengths extending for several kilometres (Fyson, 1966). A strong penetrative slaty cleavage imparted within the slates and less noticable in the quartz metawackes, has been attributed to this deformational period.

A large scale granitic pluton with a surface area of 10,000 km^2 was emplaced into the surrounding greenschist facies metasediments at 360 m.a. (Clarke and Halliday, 1980; Reynolds et al., 1981). Compositionally this pluton ranges from granodiorite to adamellite to monzonite.

CHAPTER 3

GEOLOGY OF THE DEPOSIT

3.1 Introduction

Rocks underlying the Gold Brook property consist predominantly of steeply dipping, Meguma slates and quartz metawackes with minor granodioritic associations in the eastern part of the claim group. At the western end of the property quartz metawackes are in contact with the Windsor limestones and siltstones (Geology Map in pocket). Sulfide mineralization is found only within the metasediments.

3.2 Stratigraphy

The boundary between the Halifax and Goldenville Formations stretches throughout the length of the property exposing a large stratigraphic section of the Meguma Group. A representative portion of this stratigraphy is contained in DH 224-15 extending from the lower 130 metres of the Halifax Formation to an additional 72 metres in the quartz metawacke assemblage. The pluton is exposed in the eastern part of the property, 8 kilometres north-east of DH 224-15 and may be related to quartz-feldspar veins apparent within the drill core. Local overprinting by contact metamorphism, near the pluton, has modified the surrounding metasediments to lower epidote-amphibolite grade resulting in the formation of biotite-andalusite schists containing almandine garnets (Binney, 1979). Thin section determinations to a depth of 201 metres revealed no evidence of an extension of this pluton at depth.

3.3 Structure

The study area encompasses the north limb of a large northeasterly-trending syncline. Rocks in the western part of the property dip south at angles of 40 to 50 degrees and are transected by a number of steeply dipping, northwesterly-trending, faults which have been traced for 20 to 80 metres and which offset the Halifax-Goldenville contact. Broken core and poor recovery in DH 224-15 may be related to some of these fault zones. Further to the east the rocks dip steeply to the south and on the east grid there is a low angle extensional fault (Binney, 1979).

A strong penetrative cleavage, parallel to the bedding plane of the Halifax slate has masked or obliterated primary bedding in surface outcrop. Less extensive secondary cleavage planes, perpendicular to the bedding, are visible within the slatey units of the drill core.

CHAPTER 4
DESCRIPTION OF ROCK UNITS

4.1 Introduction

The following chapter gives a generalized view of the lithology and petrology of the rock sequence as presented in Figure 4.1. Emphasis has been placed on DH 224-15, which is considered to be representative. Information has been incorporated from geological reports written by geologists of Sulpetro Minerals Limited (1977; 1978; 1979) and personal communication with P. Binney (1982), who has logged the core from the property in its entirety.

4.2 Massive Quartz Metawacke

The basal 9 metre section of DH 224-15 is composed of a monotonous sequence of impure, grey, siliceous quartz metawacke. These massive, fairly well-sorted sandstones grade upward into weakly bedded sequences. Pyrrhotite, pyrite and sphalerite are associated in amounts of up to 1 percent by volume.

Microscopically, the texture of the quartz metawacke reflects both primary and metamorphic features. Recrystallized quartz, muscovite, plagioclase and some accessory heavy minerals follow an indistinct primary bedding while

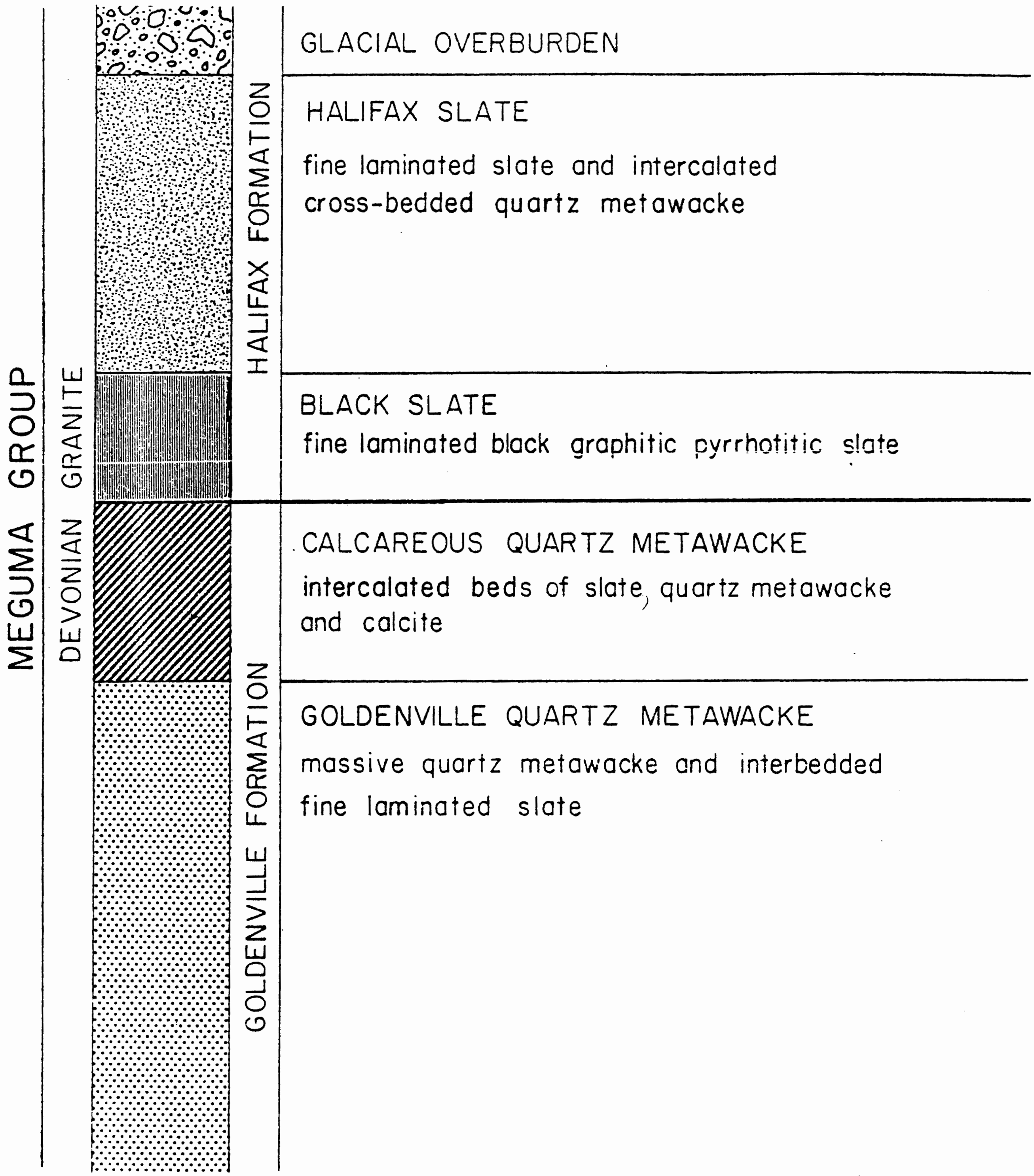


Figure 4.1. Generalized stratigraphy of the Meguma sediments represented at Gold Brook (after Binney, 1979).

subidiomorphic biotite and chlorite conform to a metamorphic foliation. Idiomorphic spessartite garnets are the most indicative features of a post depositional metamorphic phase for they overprint all of the original minerals. The coexistence of chlorite and biotite laths places the regional metamorphic grade in the middle greenschist facies at about 450°C (Winkler, 1967).

4.3 Interbedded Quartz Metawacke

Overlying the basal quartz metawacke is a 33 meter section of grey to green-grey, medium grained quartz metawacke and interbedded, black, fine grained argillite. Typical argillite beds range from 2 to 30 centimetres in thickness and comprise approximately 40 percent of the section. All of these interbeds are finely laminated and most have been silicified. The quartz metawackes display primary bedding features especially towards the top of the unit where argillaceous and graphitic material become more abundant. Cross-cutting carbonate veins contain sphalerite mineralization while blebs of pyrrhotite form up to 2 percent of the quartz metawacke unit. Additional lead and zinc exist along fracture surfaces.

Mineralogically, this unit resembles the underlying massive quartz metawackes with some minor distinctions. Quartz, muscovite, biotite, plagioclase and chlorite form an equigranular matrix surrounding elongated pyrrhotite blebs.

Idiomorphic spessaritite garnets are rare. Altered biotite crystals which are extensively developed within the massive basal unit appear sporadically within the interbedded quartz metawackes. Concentrations of organic matter impart a banded appearance to the sequence.

4.4 Calcareous Quartz Metawacke

The banded calcareous quartz metawacke is the most distinctive of the lithologies. Within DH 224-15 it is characterized by 11 metres of contorted, alternating bands of quartz metawacke, calcite and argillite (Figure 4.2). Light sandy calcite and light grey quartz metawacke are of medium to fine grain sizes and similar thicknesses, usually 1 to 2 millimetres whereas dark grey, fine grained interbeds of argillite, varying in size from 1 to 3 millimetres provide a distinct contrast. Lead-zinc mineralization occurs preferentially along fracture surfaces cross-cutting the unit.

Quartz, calcite, biotite and spessartite garnets are the most obvious mineralogic constituents of the slide with lesser amounts of associated chlorite and sphalerite. The groundmass of the argillite member contains alternating bands of carbon rich and quartz rich material consisting of recrystallized quartz mosaics interspersed with biotite laths

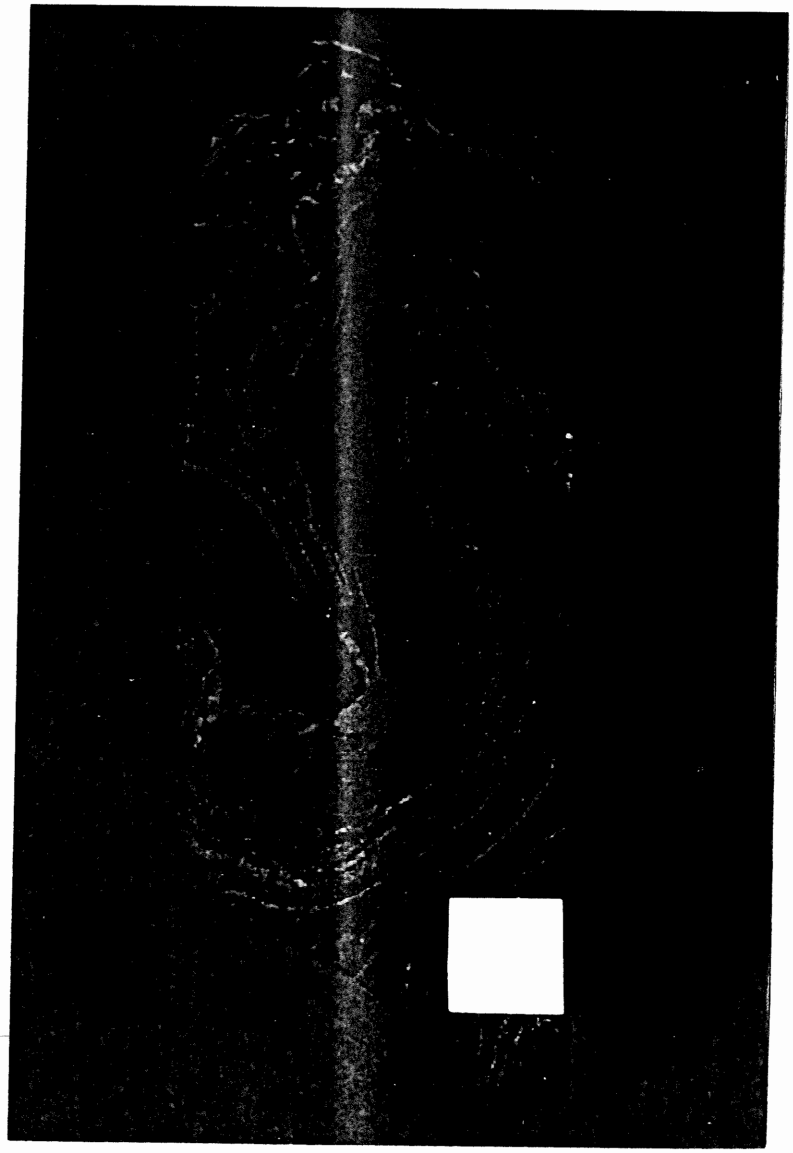


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Figure 4.2. Contorted nature of the calcareous quartz metawacke unit.

and sporadically distributed, subhedral sphalerite crystals. Idiomorphic spessartite garnets overprint all of these minerals, excepting sphalerite, without destroying the primary fabric.

The quartz metawacke member consists predominantly of recrystallized quartz and associated biotite. Crowded clumps of spessartite garnets are more distinctly visible than within the argillite member (Figure 4.3).

Most impressive of this unit is the carbonate component. Calcite crystals, 0.5 millimetres in size, are intermixed with recrystallized quartz and to a lesser extent sphalerite and are overprinted by spessartite garnets. Aggregates of fine grained quartz crystals have partially replaced the calcite as shown by cuspate structures separating the two minerals (pers. comm. Dr. P.E. Schenk). These unusual layers are enclosed by an upper and lower unit of quartz metawacke.

4.5 Black Slate

Black, thinly laminated, fine grained, graphitic rocks conformably overlying quartz metawacke beds are referred to in the study area as black slates. They are distinguished from the surrounding rocks by the absence of silicic

Figure 4.3. Crowded clumps of spessartite garnets overprinting quartz and biotite within the calcareous quartz metawacke unit.

interbeds and an abundance of pyrrhotite mineralization, usually 5-10 percent.

Compositionally, these sediments are very similar to the upper Halifax slates with the exception of a larger amount of carbonaceous, matter in the former. Quartz, muscovite and graphitic matter form the groundmass which is "spotted" with chlorite laths and spessartite garnets. Pressure shadows surrounding pyrrhotite blebs contain aligned muscovite and quartz crystals forming extensional wrap-around structures (Figure 4.4). This suggests that this mineralization crystallized before the development of the slatey cleavage and is, therefore, pre-metamorphic.

4.6 Upper Halifax Slate

A typical Halifax slate consists of very fine grained, thinly laminated, dark-grey to black argillite. Commonly these rocks are intimately interlayered with coarser grained quartz metawacke units, up to 50 centimetres thick, displaying both horizontal and cross bedding structures. Interbedded pyrrhotite and pyrite coexist with limited amounts of fracture-controlled sphalerite and galena.

The major mineralogic constituents of the slates are quartz, muscovite, chlorite and sulfides. Fine grained quartz mosaics exhibiting triple-point junctions are interspersed with muscovite laths and larger chlorite crystals.

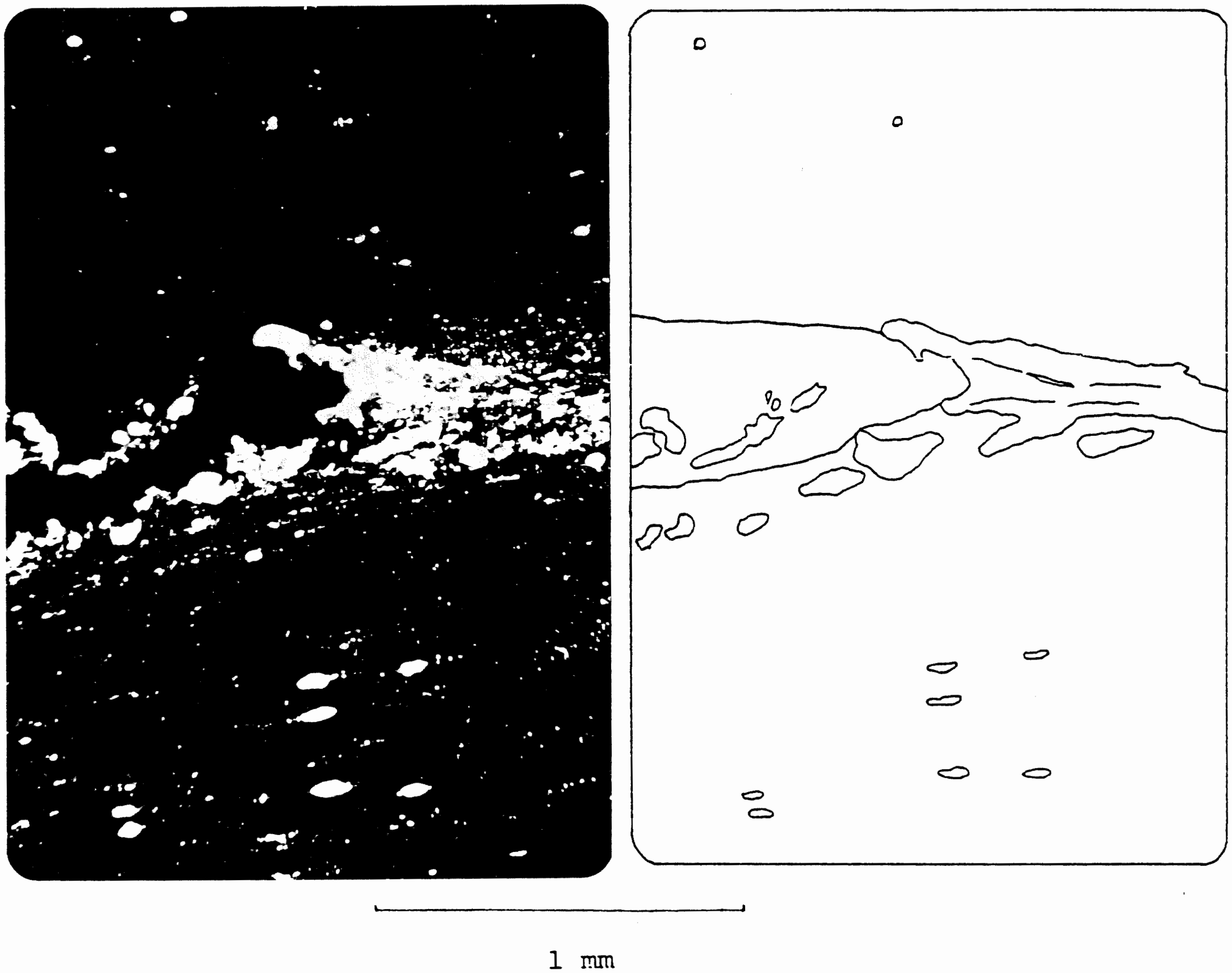
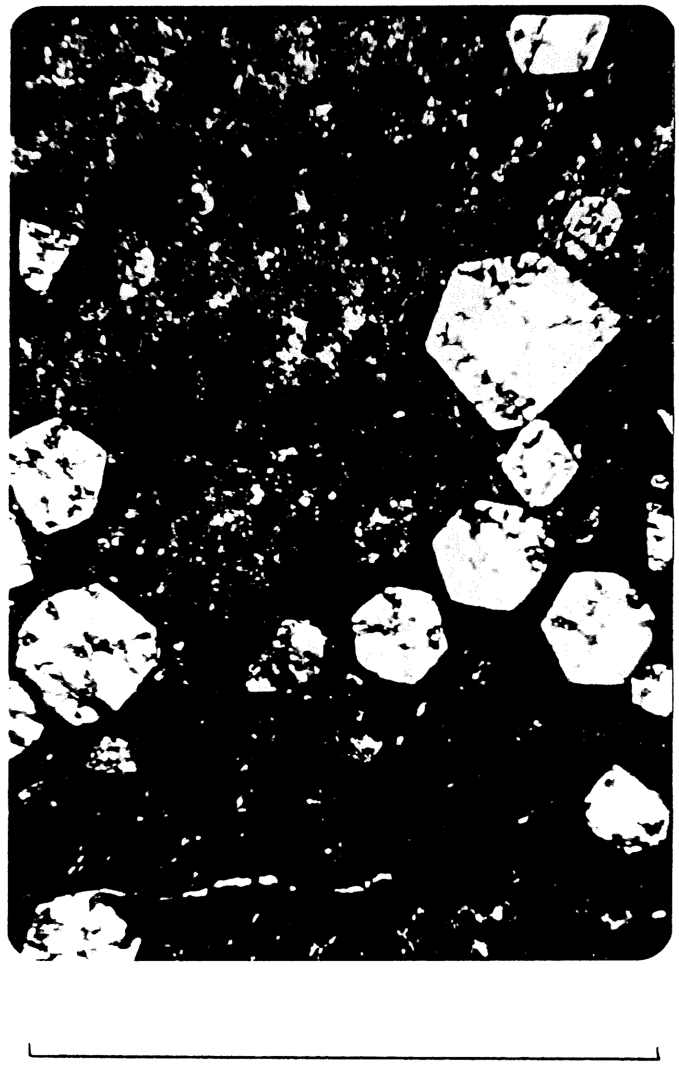


Figure 4.4. Aligned muscovite and quartz crystals forming pressure shadow around pyrrhotite mineralization.

Layers of organic matter, similar to those occurring within the interbedded quartz metawacke unit give these slates a banded appearance.

Quartz metawacke interbeds are compositionally similar to the slates, the only difference being in the relative abundances of the minerals. They are visibly distinguishable, in thin section, from the slaty units by an abundance of quartz mosaics, a coarser grain size and concentrations of stratiform sulfides along bedding structures.

Both the slate and the quartz metawacke have developed spessartite garnets as a result of regional metamorphism. Within the slaty members beautifully developed, six-sided idiomorphic garnets ranging in size from 0.2 to 0.5 millimetres have been concentrated within garnetiferous horizons. They are nearly always twinned and contain inclusions of carbonaceous matter (Figure 4.5). The garnets overprinting the quartz metawacke unit are strikingly different. Because of their dense distribution they are much smaller in size and have developed idioblastic crystal faces.



1 mm

Figure 4.5. Well developed idomorphic spessartite garnets containing inclusions of graphitic matter.

CHAPTER 5

MINERALIZATION

5.1 Introduction

Sulfide mineralization at Gold Brook consists predominantly of pyrrhotite, pyrite, sphalerite and galena with minor occurrences of chalcopyrite and arsenopyrite. Within DH 224-15 four distinct styles of mineralization were readily determined primarily by the shape of the sulfide aggregates. In more general terms the mineralogy of the sulfide and the lithology of the host sediment were associated with a particular style of mineralization. The styles of mineralization in order of decreasing abundance and importance include stratiform, fracture-vein filling, fabric controlled and disseminated.

5.2 Stratiform

The bulk of this style of mineralization consists of pyrrhotite, associated pyrite and lesser abundances of sphalerite and galena. Lenses and bands of pyrrhotite and pyrite often accentuate cross-bedding structures within the quartz metawacke interbeds of the upper slate unit and the lower interbedded quartz metawacke assemblage indicating synsedimentary emplacement. Pyrrhotite is also associated with the slatey

Block is 1 cm^2

Figure 5.1. Lenses of pyrrhotite within slate beds and cross-cutting quartz vein filled with pyrrhotite and pyrite mineralization.

units of the drill core (Figure 5.1) and particularly in the black, graphitic, slates as bands and beds in abundances of up to 10 percent. These bands are on the order of 5 to 10 millimetres in length and range up to 5 millimetres in width.

Stratiform sphalerite and galena is rare within DH 224-15 but occurs as small, thin beds, 0.5 to 1 millimetre in thickness, within higher grade slatey interbeds in the quartz metawacke unit.

The sulfide-host boundary may be irregular or sharp depending on the type of mineralization. Pyrite boundaries are typically sharp showing a pronounced cubic habit (Figure 5.2) while pyrrhotite edges are generally corroded and flecked with minute sphalerite crystals (Figure 5.3). In rare occurrences pyrrhotite has formed partial hexagonal crystal faces, 0.5 millimetres in size. Similar textures have been described by Ramdohr (1969) who suggests that these pyrrhotite crystals are a product of high temperature (greater than 350°C) crystallization. The largest percentage of pyrrhotite grains range from 0.1 to 1 millimetre in size and are either anhedral or angular forming a brecciated texture.

The presence of pyrite surrounding fractures within pyrrhotite in addition to cuspate structures of pyrrhotite into pyrite suggest that pyrite has been replaced by pyrrhotite (Figure 5.4). According to Ramdohr (1969), at

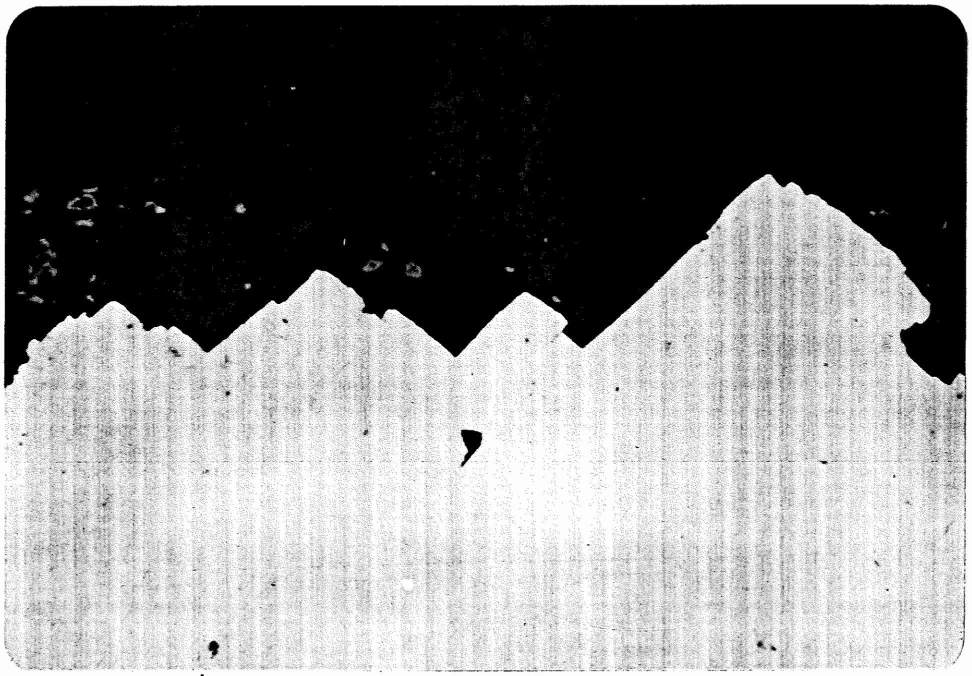


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Figure 5.2. Cubic habit forming pyrite sediment boundary.

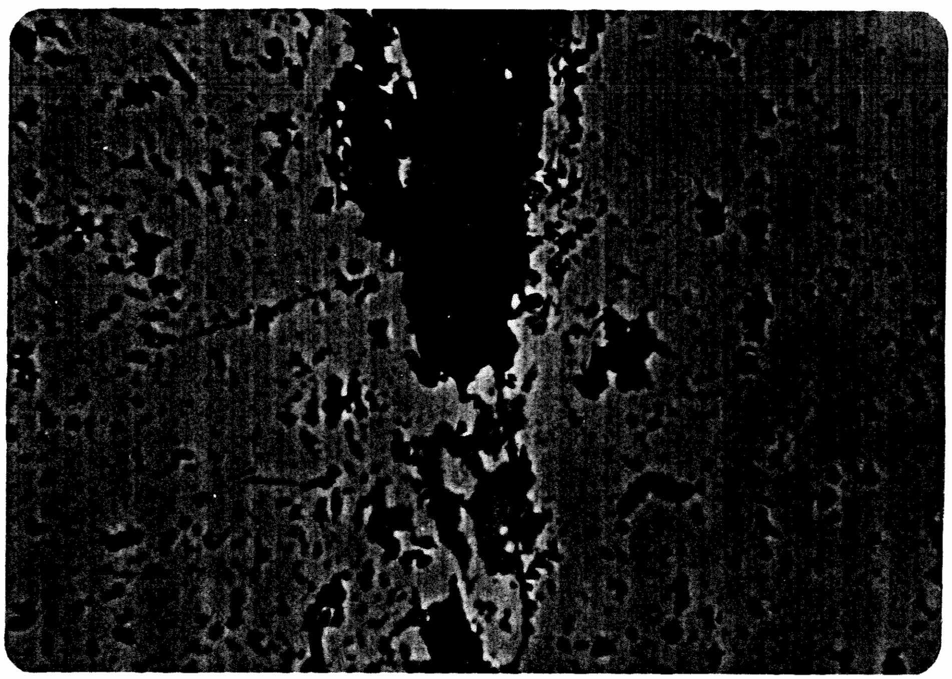

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Figure 5.3. Sphalerite inclusions in pyrrhotite cut by chalcopyrite.

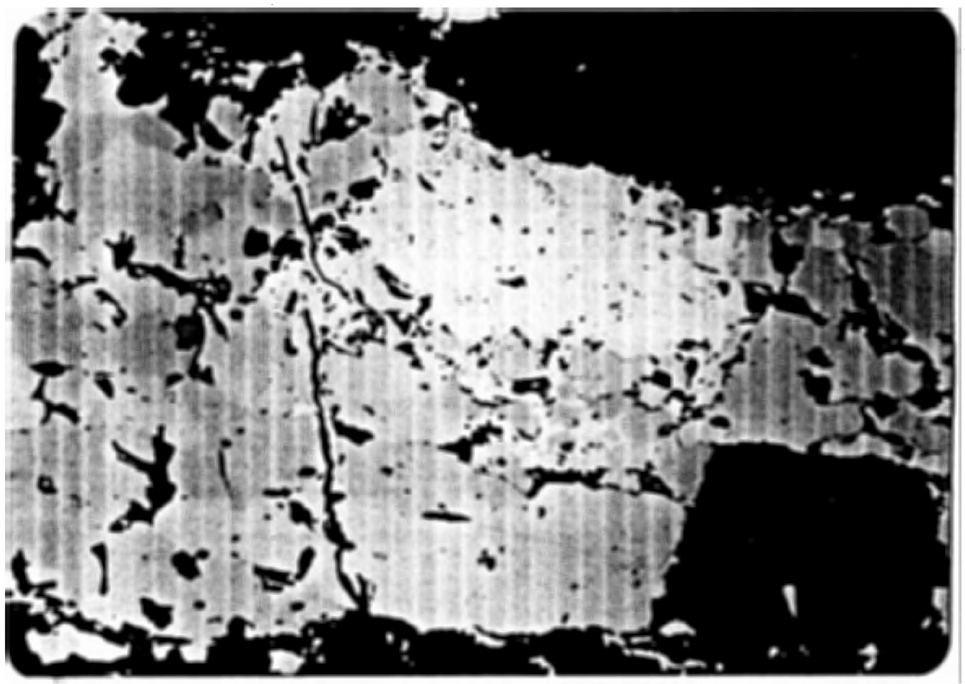

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Figure 5.4. Replacement textures of pyrite by pyrrhotite.

temperatures greater than 300°C pyrite becomes unstable and converts to equilibrated pyrrhotite. Because the temperatures of regional metamorphism were sufficiently high enough for this transformation to occur it is probable that pyrrhotite formed from pre-existing pyrite during deformation.

5.3 Vein-Fracture Filling

This style of mineralization consists of pyrite, pyrrhotite, galena and sphalerite. In the rocks examined, fractures and veins of pyrite and pyrrhotite are confined to the upper Halifax slate and the interbedded and massive quartz metawacked units. Sphalerite and galena are associated primarily within the calcareous quartz metawacke unit and along calcite veins, however insignificant mineralized fractures are located within most lithologies. Spectacular sphalerite and galena occur along brecciated zones within the Halifax slate, induced by faulting (Figure 5.5). That this style of mineralization is absent within the black, graphitic, slates is probably due to the ductile behaviour of this unit during deformation.

5.3.1 Veins

Pyrrhotite, pyrite mineralization occurs as discontinuous, irregular blebs within quartz or potassium feldspar veins up to 5 millimetres in width (Figure 5.1). Pyrrhotite appears

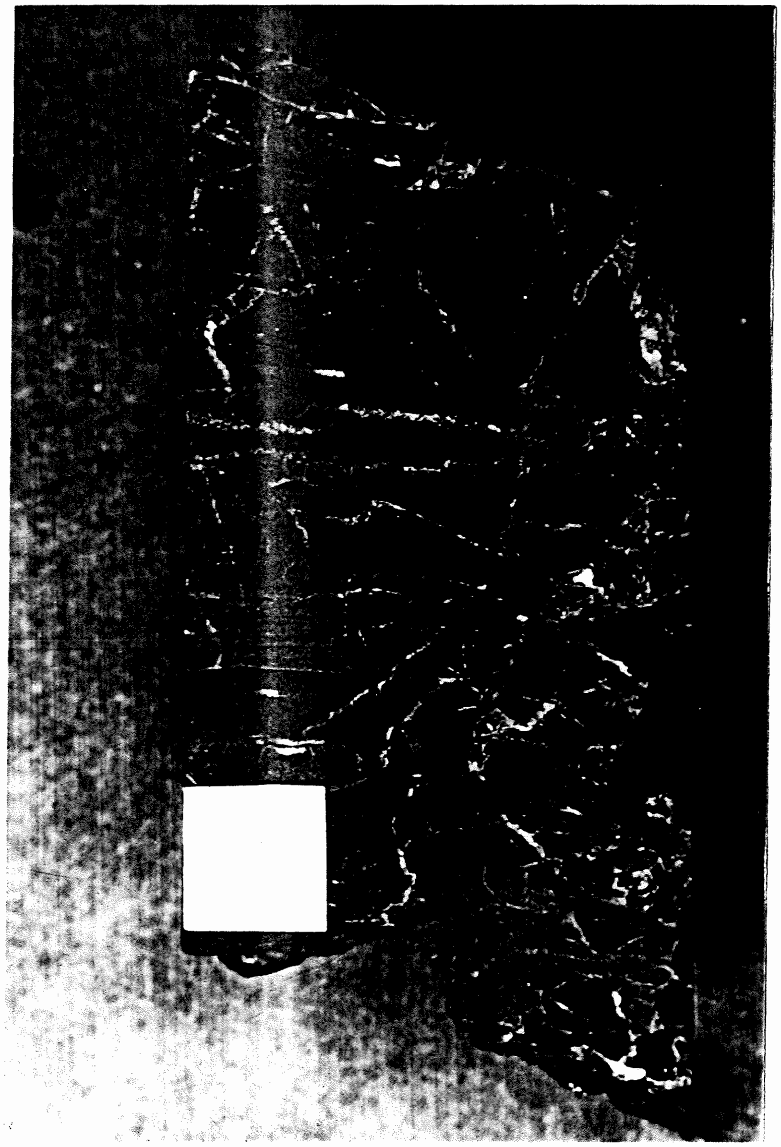

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Figure 5.5. Fault controlled galena and sphalerite mineralization.

to have replaced the silicate forming rounded recrystallized grains along the silicate-host boundary and containing inclusions of the silicate phase (Figure 5.6). Splendid recrystallized pyrrhotite grains, 0.5 millimetres in size, exhibit triple-point junctions inferring equilibration. In rare occurrences exsolution textures of pyrite in pyrrhotite (Figure 5.7) are indicative of temperatures in the range of 250°-300°C (Barton and Skinner, 1967; Ramdohr, 1969).

Larger blebs of pyrrhotite contain a network of thin (0.1 mm) fractures infilled by silicate. Disseminated sphalerite grains, up to 0.2 millimeters in size, occur as inclusions within the pyrrhotite while minor chalcopyrite grains, concentrated towards the edges of the sulfide, appear to be replacing pyrrhotite. Isolated, subhedral, pyrite associated with the silicate veins contain intergrown sphalerite and pyrrhotite grains as well as rare cubic inclusions.

Discontinuous subrounded sphalerite grains rim carbonate veins within the interbedded quartz metawackes and are intimately associated with calcite crystals in the calcareous quartz metawacke unit. The edges of these crystals are redder in colour than the cores (Figure 5.8). Microprobe analyses indicate that the rims of the sphalerite contain approximately 0.3 percent more iron than the cores, suggesting a partial reequilibration of iron preferentially

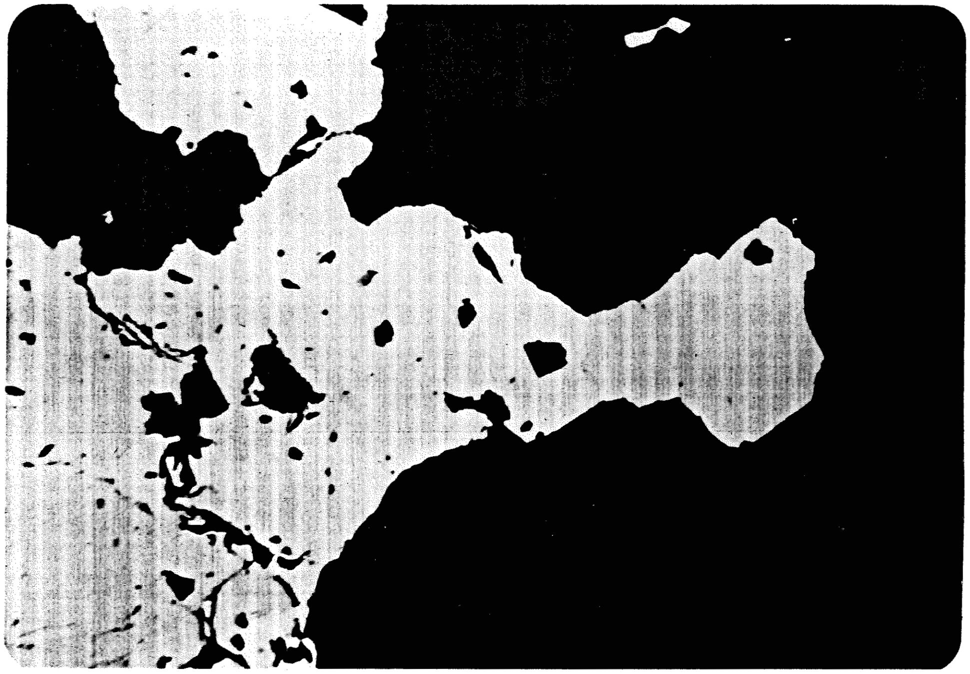

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Figure 5.6. Replacement by pyrrhotite.

0.5 mm

Figure 5.7. Exolution textures of pyrite in pyrrhotite.

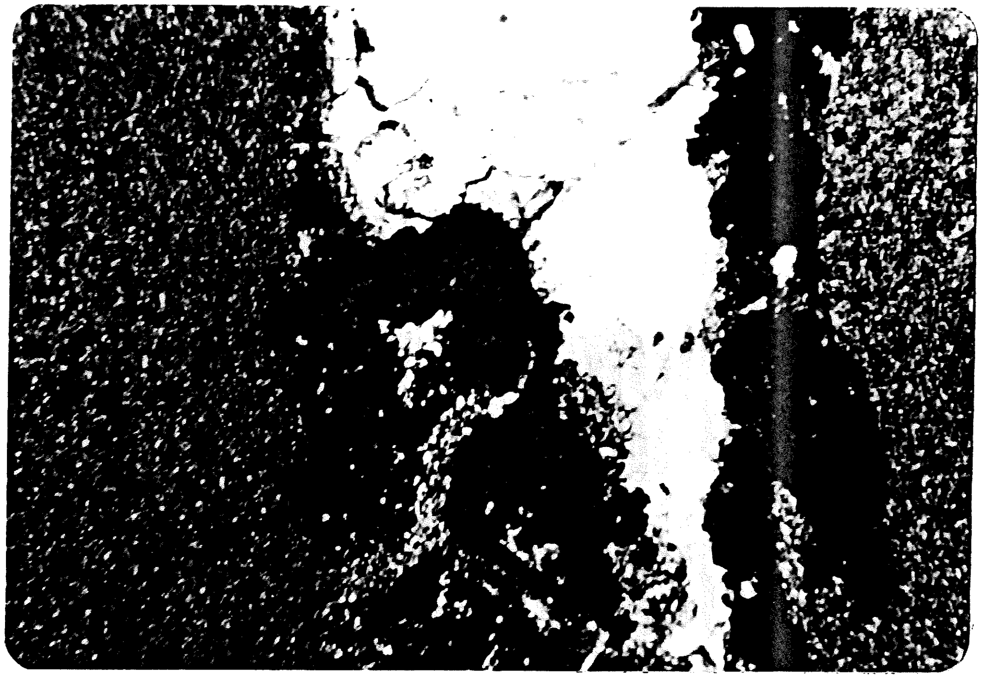

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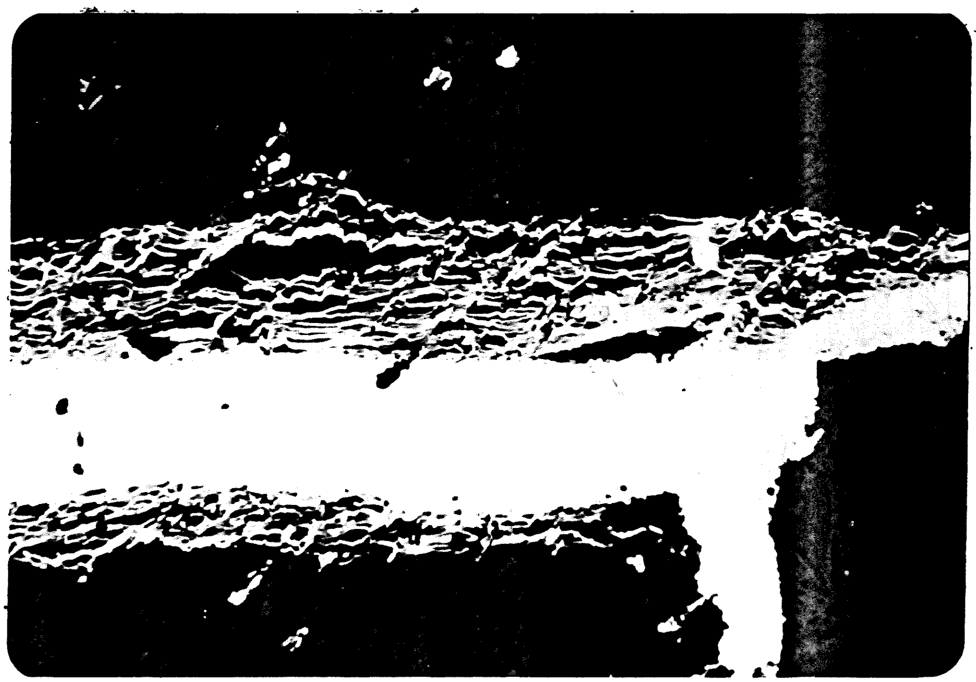
Figure 5.8. Reddish coloured sphalerite rims due to iron enrichment.



1 mm

Figure 5.9. Intricate pyrite stringers forming the pyrite-sediment boundary.

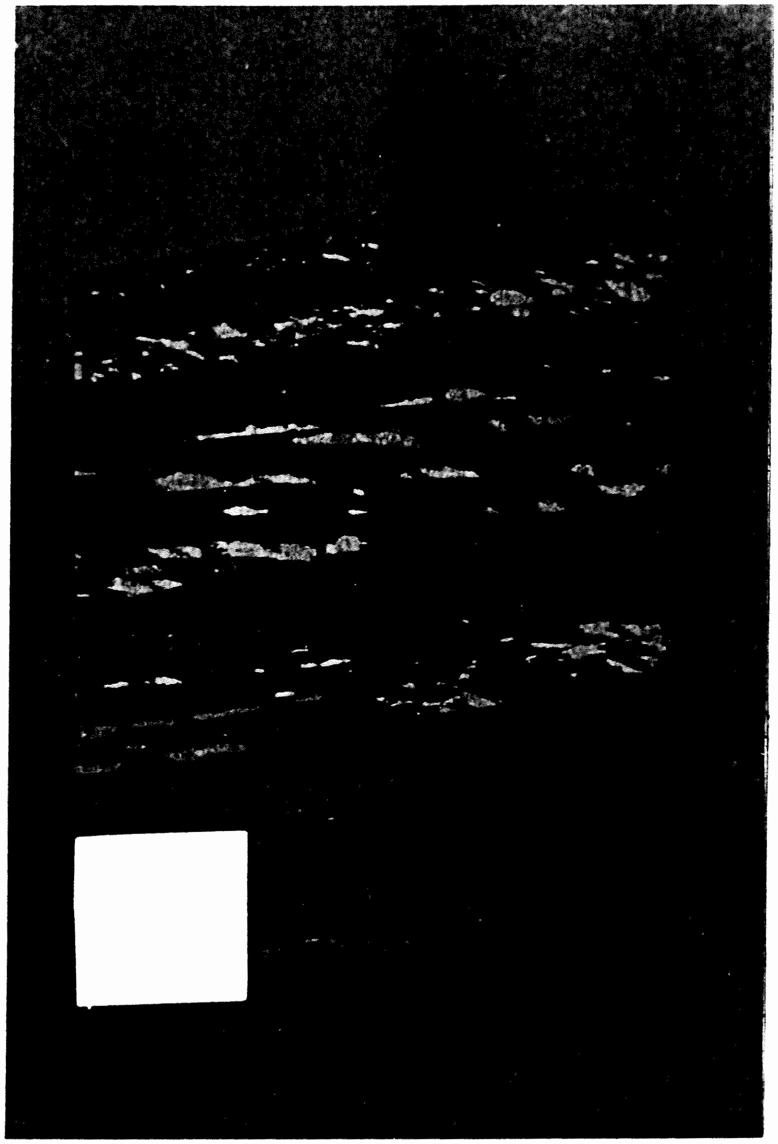
around the edges of the crystal. Minute grains of pyrite and traces of chalcopyrite are intergrown within the sphalerite.

5.3.2 Fractures

Pyrite-filled fractures ranging in width from 1 to 3 millimetres typically form granular and massive mineralization. The pyrite-silicate contact may be sharp, forming a perfect cubic habit, or irregular, exhibiting corroded textures. The most unusual boundary observed forms an intricate network of parallel stringers, less than 0.01 millimetres wide surrounding the pyrite mineralization (Figure 5.9). Most apparent is the close spacing, and ragged offset of these minute stringers suggesting perhaps that pyrite was being emplaced during some period of deformation.

5.4 Fabric Controlled

Pyrrhotite and pyrite are the most obvious sulfide minerals of this style of mineralization occurring within all units except the calcareous quartz metawacke. Typically lenses and blebs of mineralization are partially offset at an angle to the original orientation of the sulfide (Figure 5.10). In many cases the lense of mineralization has become completely remobilized along an induced foliation forming stretched out blebs 3 millimetres in length.



Block is 1 cm^2

Figure 5.10. Lenses of pyrrhotite mineralization offset along a foliation.

Microscopically, brecciated pyrrhotite blebs from 0.5 to 0.8 millimetres in size contain numerous sphalerite-filled inclusions elongated parallel to the foliation. The pyrrhotite-host boundaries are very irregular with an opaque layer forming a broken rim. Chalcopyrite and pyrite replacement is concentrated along the edge of the crystal.

Where the mineralization offset is not as extensive, the sulfide-host contacts are sharper and brecciated textures and inclusion patterns are less common. Strain effects are recognized as minute fractures perpendicular to the length of the crystal and minor inclusion patterns elongated in the direction of extension.

This style of mineralization was probably formed during regional metamorphism. Mineralization is clearly following a foliation, parallel to the direction of pyrite extension, which must have been induced during a period of intense deformation.

5.5 Disseminated

Pyrrhotite, sphalerite, and pyrite are the most abundant disseminated sulfides occurring in amounts of up to 0.5 percent. Pyrrhotite and pyrite are distributed as flecks within the upper Halifax and lower Goldenville Formations while specks of sphalerite predominate within the calcareous unit.

In thin section, angular crystals of chalcopyrite and pyrrhotite, approximately 0.1 millimetre in size, are associated with larger blebs of mineralization indicating possible brecciation during deformation. Remnant replacements of silicate minerals by sphalerite and pyrrhotite were also observed. Disseminated pyrite cubes completely replaced by pyrrhotite are rare.

CHAPTER 6

GEOCHEMISTRY

6.1 Data

Samples taken at 3 metre intervals throughout DH 224-15 were assayed by atomic absorption (Bondar Klegg, Toronto) for various elements. Of major concern are Pb, Zn, Mn and Fe values presented in Table 1.

The following observations of significance can be made:

1. High Pb and Zn values are concentrated within the calcareous quartz metawacke assemblage in amounts of up to 0.5 and 1.12 percent respectively, in addition to 0.4 and 0.5 percent within calcite veins of the lower quartz metawacke unit. These percentages are considerably higher than those within the other units of the drill core.

2. The calcareous quartz metawacke unit is significantly enriched in Mn, up to 0.38 percent, as compared to average values of 0.13 percent Mn throughout the remaining units.

3. Fe is enriched within the black graphitic slates at an average of 6.0 percent and within the Halifax slates at an average of 5.3 percent. These values are considerably higher than the 4.43 percent average of Fe within the quartz metawackes.

TABLE 1. Assay values from DH 224-15, Gold Brook.

ASSAY BOOK NO.	INTERVAL	Pb (ppm)	Zn (ppm)	Mn (ppm)	Fe (%)
5396	98.00 - 101.00	120	340	1680	4.90
5397	101.00 - 104.00	22	115	1320	5.40
5398	104.00 - 107.00	44	180	1640	5.10
5399	107.00 - 110.00	53	220	1300	5.90
5400	110.00 - 113.00	26	90	1260	5.20
5135	113.00 - 116.00	70	109	1400	6.00
5136	116.00 - 119.00	70	140	1440	5.80
5137	119.00 - 122.00	28	118	1360	5.80
5138	122.00 - 125.00	38	113	1340	5.90
5139	125.00 - 128.00	30	118	1360	5.40
5140	128.00 - 131.00	26	154	1200	5.10
5141	131.00 - 134.00	143	186	1860	4.60
5143	134.00 - 137.00	50	260	1120	4.60
5144	137.00 - 140.00	43	142	1120	6.00
5145	140.00 - 143.00	20	95	1100	5.70
5146	143.00 - 146.00	11	95	720	6.70
5147	146.00 - 149.00	63	192	1760	8.80
5148	149.00 - 150.90	168	280	3520	7.50
5243	150.90 - 153.00	5300	11200	2080	4.10
5244	153.00 - 156.00	2100	5200	2890	3.90
5245	156.00 - 157.80	800	1600	3660	3.65
5149	157.80 - 160.40	540	1060	3875	3.80
5150	160.40 - 163.40	183	315	1380	4.10
5151	163.40 - 166.40	20	122	2075	4.20
5152	166.40 - 169.40	400	820	1740	4.85
5153	169.40 - 172.40	73	212	1420	5.20
5154	172.40 - 175.40	4100	5000	2150	4.70
5155	175.40 - 178.40	2000	3250	1360	4.60
5156	178.40 - 181.40	510	940	1820	4.15
5157	181.40 - 184.40	185	540	2150	4.90
5158	184.40 - 187.40	640	1400	1200	5.20
5159	187.40 - 190.40	830	1550	1560	5.00
5160	190.40 - 192.50	690	1600	1320	4.80
5246	192.50 - 193.80	1300	2400	540	3.75

6.2 Discussion

A plot of the correlation index of the elements considered shows a strong positive correlation between Pb and Zn (Table 2), forming a straight line relationship when represented graphically (Figure 6.1). The graph of total base metals (Pb + Zn) as a function of depth (Figure 6.2) represents the association of Pb and Zn within the calcareous quartz metawacke unit at 150 metres depth and within calcite veins of the interbedded quartz metawackes at 172 metres depth. These high values of Pb and Zn are governed, to a large extent, by fracture controlled mineralization predominantly within the calcareous quartz metawacke unit. This can be interpreted to indicate that the calcareous unit was affected by brittle fracturing related to regional stresses, thus becoming favourable sites for the precipitation of metal rich solutions. It is unclear whether the metals came from a local source (the calcareous unit) or from a deeper source.

Mn values from the assay data (Table 1) are represented graphically in Figure 6.3, showing a well defined peak over the calcareous unit. Microprobe analysis (Table 3) of calcite from this calcareous assemblage give an average of 51.93 percent MnO of the three grains analyzed. When compared to an average percent of 55.73 MnO for three calcite grains analyzed from veins, in the interbedded quartz metawackes, a considerable increase of MnO is defined within the calcareous

TABLE 2

Correlation Coefficient

Pb	Pb	Zn	Mn
Zn	.966		
Mn	.218	.230	
Fe	-.371	-.388	-.195

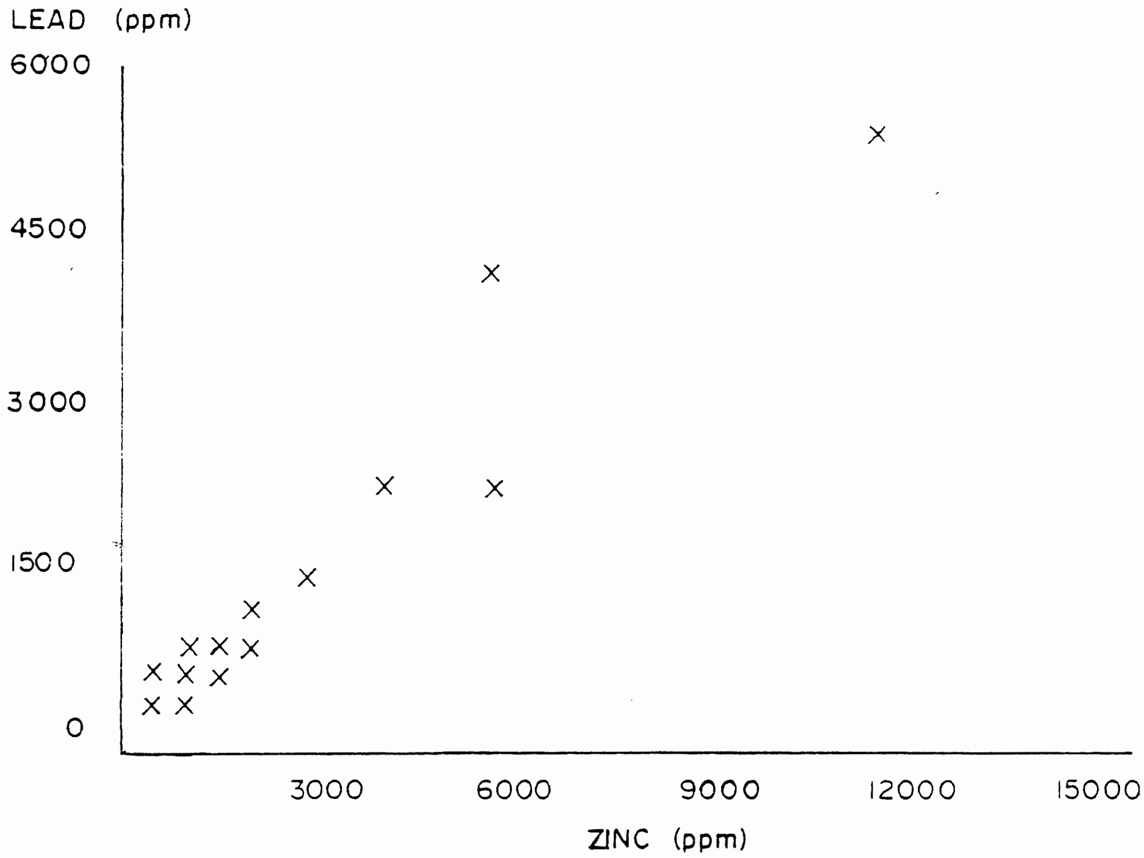
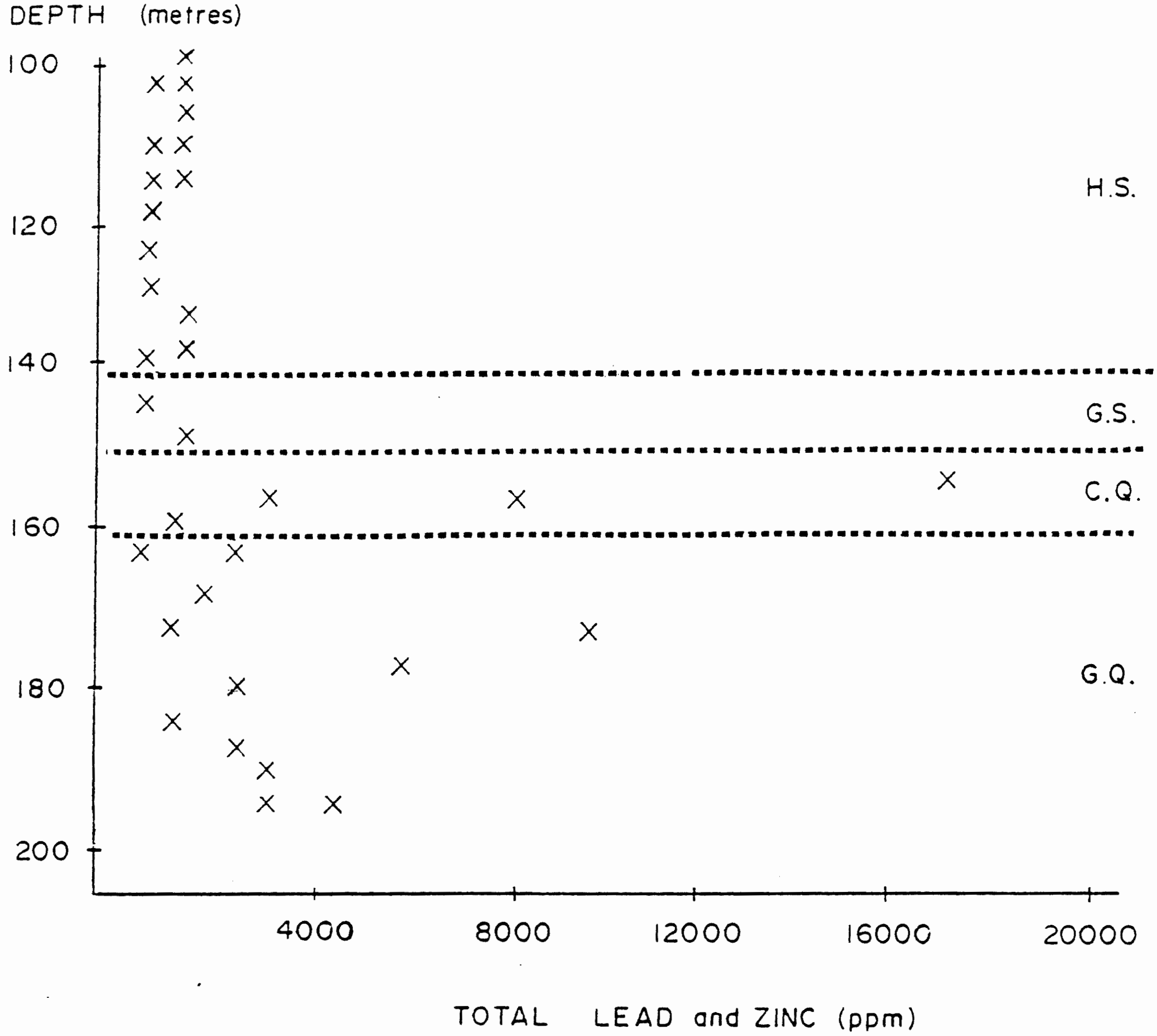


Figure 6.1. Correlation between lead and zinc.



H.S. - Halifax slate

G.S. - Graphitic slate

C.Q. - Calcareous quartz metawacke

G.Q. - Goldenville quartz metawacke

Figure 6.2. Relationship between total lead-zinc and depth.

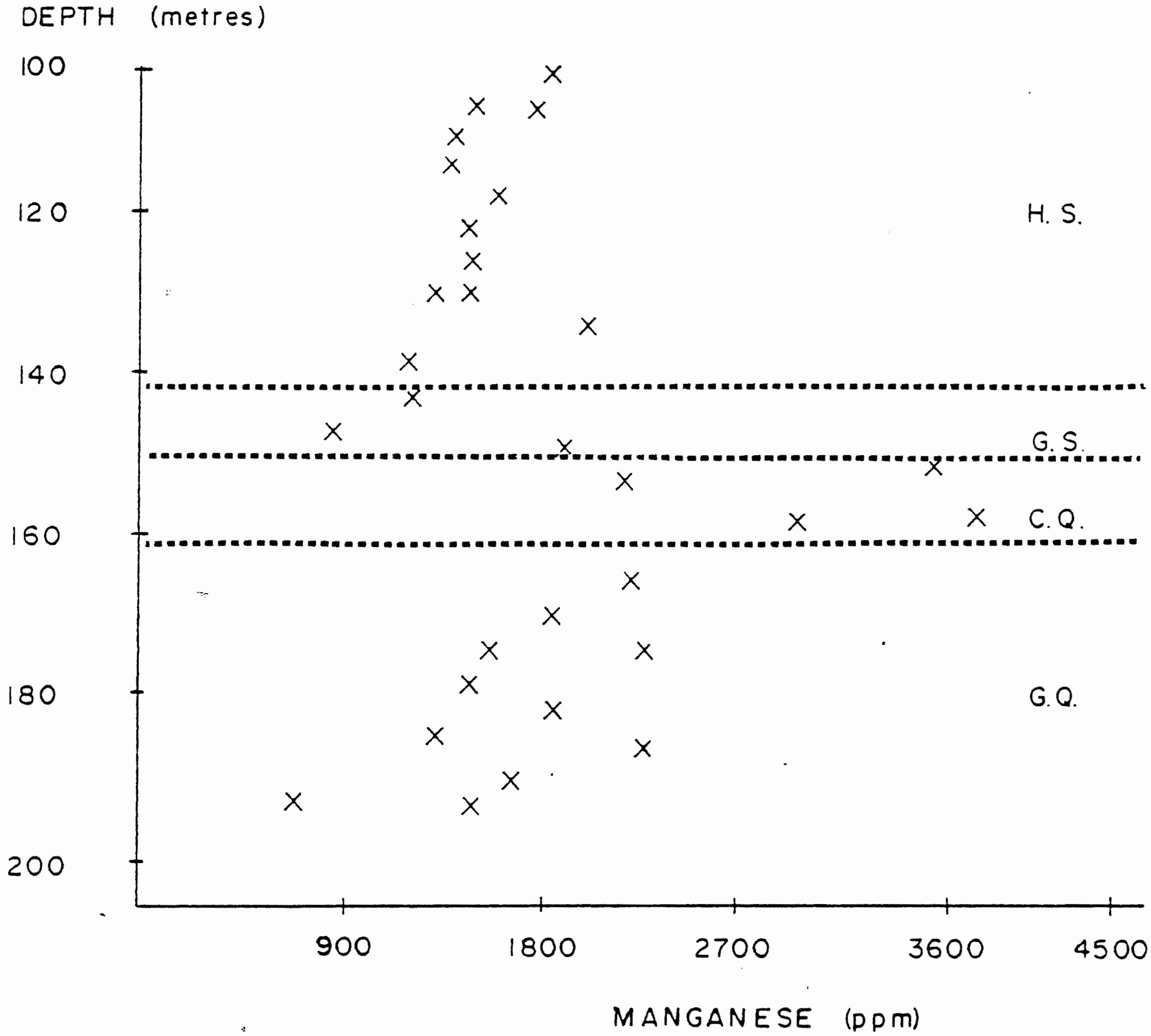


Figure 6.3. Relationship between manganese and depth.

TABLE 3

Microprobe analyses of MnO within calcite

CALCITE - calcareous quartz metawacke unit

GRAIN 1

	SiO_2	CaO	MnO	FeO
	.48	52.02	2.43	.16

Total = 55.09*

GRAIN 2

	SiO_2	CaO	MnO	FeO
	.75	52.39	1.37	.27

Total - 54.78

GRAIN 3

	SiO_2	CaO	MnO	FeO
	.44	51.38	3.06	.27

Total = 55.15

CALCITE - Vein in interbedded quartz metawacke unit

GRAIN 1

	SiO_2	CaO	MnO	FeO
	.00	55.82	.00	.00

Total = 55.82

GRAIN 2

	SiO_2	CaO	MnO	FeO
	.00	55.48	.20	.08

Total 55.76

GRAIN 3

	SiO_2	CaO	MnO	FeO
	.00	55.89	.10	.05

Total = 56.04

* Microprobe did not analyze for CO_2 component of $CaCO_3$

unit.

Microprobe analyses of perfectly-shaped, idiomorphic garnets within the Halifax Formation and smaller densely packed garnets overprinting the calcareous quartz metawacke unit indicate that both forms are of the spessartite variety. Garnets overprinting the calcareous unit contain an average of 29.18 percent MnO while those overprinting the Halifax slates contain an average of only 22.13 percent MnO. This suggests that enrichment of Mn within the calcite was partially incorporated into the garnets during regional metamorphism.

Concentrations of Mn within the calcareous quartz metawacke unit are most probably a result of primary enrichment of Mn during the formation of the assemblage. The distinct depletion of this element in the immediate surrounding lithologies and the absence of transitional values within the upper and lower units suggests that a later stage introduction of Mn into the assemblage would appear unlikely.

The Fe data from Table 1 were plotted graphically in Figure 6.4 as a visual representation of the enrichment of Fe within the black graphitic slates and the Halifax slates. Elemental Fe abundances within these units of the drill core indicate that Fe must have preferentially accumulated within the slates during deposition of the Halifax Formation. Iron Iron can be accounted for mainly as a constituent of pyrite and pyrrhotite, and probably in ferromagnesian minerals in the slates (eg. chlorite).

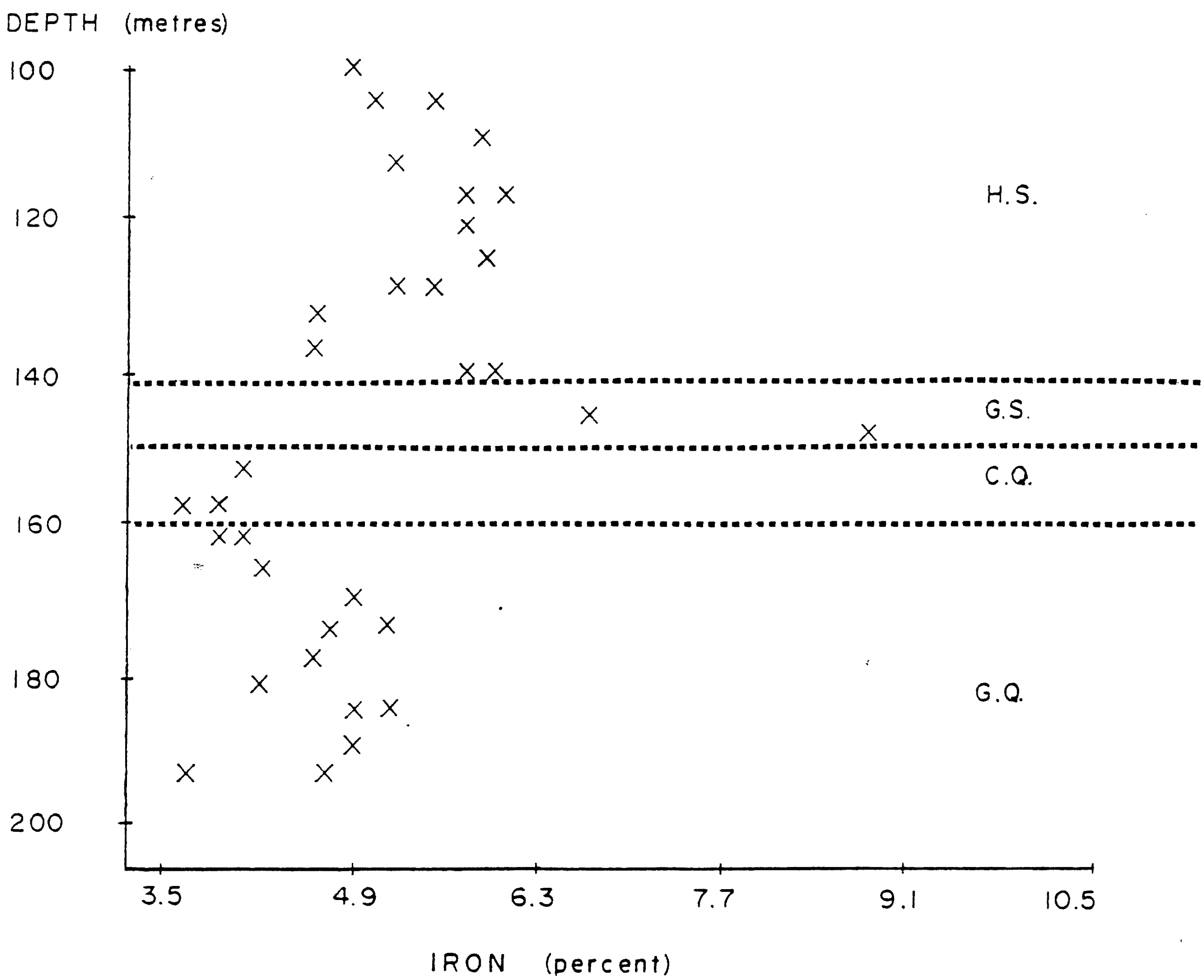


Figure 6.4. Relationship between iron and depth.

CHAPTER 7

DEPOSITIONAL INTERPRETATION

7.1 Introduction

Mineralization of Gold Brook is contained within a wide range of host sediments representing slightly different sedimentary environments. Unique to the study area are the thick accumulations of black graphitic slates at the base of the Halifax Formation and the underlying previously unmapped 11 metre thickness of calcareous quartz metawackes, at the top of the Goldenville Formation. Depositional models for these assemblages are considered below.

7.2 Interpretation

The basal, Goldenville quartz metawackes of the Meguma sediments were deposited at abyssal plain and deep sea depths by the mechanisms of fluidized sediment flow and turbidity currents (Harris and Schenk 1976; Schenk 1976, 1978). At Gold Brook, relatively rapid turbidite deposition of these sands is represented by the massive nature of the quartz metawackes and the absence of large scale cross-bedding structures. Up section, interbedded, laminated slatey units suggest a possible distal extension of the turbidite related to both turbidity currents and bottom current origin (Schenk 1976).

A different set of conditions was operative during the deposition of the overlying calcareous quartz metawacke unit. The stratigraphic location of this facies, at the top of the Goldenville sandstones, in addition to intercalated quartz metawackes and siltstones suggests abyssal plain or deep sea sediment deposition similar to that of the Goldenville sandstones. The problem to be considered is the formation of calcite below the carbonate compensation depth (C.C.D.) of 4 kilometres. Schenk(1976) proposes that acidic interstitial marine waters, below the C.C.D., were effective in dissolving shell debris, providing calcite for developing carbonate concretions found elsewhere within the Goldenville Formation. However, morphologically the calcareous member at Gold Brook is quite different. It forms a continuous, uniform, 11 metre thick unit absent of concretions. A possible explaination is that the calcite was derived from low pH calcium and metal-rich brines, underlying the turbidite deposits, and released along fracture zones, as has been suggested for the shale-hosted lead-zinc deposit at Sullivan (Morganti 1981). Low temperature, high salinity brines flow down slope, upon exhalation, due to a higher density than the surrounding sea water and are controlled, during deposition, by the sea floor topography (Morganti, 1981). Density stratification, characteristic of this form of deposition, is well developed at Gold Brook in the form of stratified slump structures indicative of soft sediment formation. Delicate thin banding of intimately interlayered calcite, sediment and sulfide may suggest coincidental sedimentation and metalliferous brine deposition under relatively quiescent oceanic conditions.

A distinct change in the depositional environment must have developed to cause the abrupt depletion of carbonate and the accumulation of fine grained, graphitic-rich, pyrrhotitic slates. The 7 metre compacted thickness of these black shales suggests that deposition of the sediments occurred over an extensive period of geological time, probably within a deepening basin. A quiescent reducing environment is proposed on the basis of the black, graphitic-rich, thinnly laminated nature of the slates.

The reason for this facies change is uncertain. Morganti (1981), in describing the environment of the analogous Howards Pass Formation, suggests that the thick succession of sulfide-rich, laminated mudstones was deposited within a sub-basin, as a sea floor depression. This model would account for quiet periods of sedimentation, under euxinic conditions within a deepening basin, characteristic of shale deposition at Gold Brook. The formation of this sub-basin is speculative but could result from slumping of the underlying turbidite sequence (Morganti 1981) or synsedimentary faulting (Sangster 1981). Subsequent influxes of low pH, hydrothermal carbonate into the basin and continued isolation of the basin accompanied by reducing conditions, would result in the carbonate-black slate sequence at Gold Brook.

The final stage of sediment deposition within the Meguma is represented by a succession of laminated slates and minor interlayered cross-bedded sandstones. It is possible that this sequence indicates more active periods of sedimentation along deep water and continental rise lithotopes (Schenk 1976). As a result, the reducing, stagnant, conditions of the black shale environment were replaced by more turbulent periods of sedimentation.

CHAPTER 8

ORE GENESIS

8.1 Introduction

The stages of ore deposition and subsequent remobilization of mineralization represented at Gold Brook are as follows:

1. Primary or diagenetic deposition of stratiform blebs and lenses of sulfides.
2. Remobilization of pre-existing mineralization along a foliation induced by regional metamorphism.
3. Introduction of sulfides into late-stage veins and fracture zones.

The proposal for ore genesis, within the study area, considers possible sources of synsedimentary or diagenetic mineralizing fluids, morphological and mineralogical changes of stratiform sulfides during new temperatures of metamorphism and probable sources of late-stage, fracture controlled mineralization.

8.2 Synsedimentary Deposition

A syngenetic origin is proposed for stratiform mineralization, particularly within the anomalous black graphitic slates, primarily due to the conformable nature of the ore and the presence of pressures shadows surrounding the sulfides.

Several sources have been proposed for this style of mineralization by Russell (1981), Morganti (1981), Badham (1981) and Gustafson et al. (1981) in an attempt to construct the ore genesis of analogous, but economically important, sedimentary-type stratiform ore deposits.

An immediate volcanic exhalative source of metal rich fluids can be excluded on the basis of two observations: volcanic associations have no spatial relationship with the Meguma sediments near the study area and the author is not aware of the presence of volcanic clasts within the Halifax and Goldenville Formations in this region.

Magmatic hydrothermal solutions seem inapplicable to syngenetic mineralization at Gold Brook since the intrusion of the granite appears to post date the deposition of the sediment and regional metamorphism.

The author suggests that the metals were sedimentary while sulfur was introduced to the sediments during diagenesis. Pyrite formation under euxinic conditions results from the bacterial reduction of sulfate-rich sea water ions and the reaction of H_2S with elemental iron in the host sediment (Meyer 1981; Berner 1970). Abundances of iron-bearing pyrite and pyrrhotite mineralization at Gold Brook indicate the availability of elemental iron in the black graphitic shales, probably as a constituent of ferric oxide coatings of clay minerals as described by Stevens et al.

(1975) for similar black shale environments. But the introduction of sulfate ions from sea water into sediment pore spaces was necessary for sulfide fixation to proceed (Holland 1981; Berner 1970). Graphitic, carbonaceous matter associated with sulfide mineralization at Gold Brook suggests the importance of organic reductants in the transformation of sulfate to sulfide and the ultimate formation of mineralization. Diagenetic changes may have been important in the remobilization and concentration of these metals.

8.3 Remobilization and Compositional Changes

The effects of regional metamorphism on the mineralization at Gold Brook are twofold. Sulfides have been remobilized along a metamorphic foliation and have undergone changes in mineralogy.

Pressures and temperatures of regional metamorphism were sufficient to remobilize stratiform sulfides along a foliation developed perpendicular to the maximum sulfide shortening. The result is an offset of the mineralization at an angle to the original orientation.

Of greater significance are the changes in the mineralogy of the pre-existing sulfides. These include the transformation of pyrite to pyrrhotite and the incorporation of iron within sphalerite crystals.

The Fe-S system (Vokes, Ramdohr 1969) can be utilized as a sulfide geothermometer for the mineralization in the study area. Barton and Skinner (1967) have determined that the pyrite and pyrrhotite solvus can be extended to as low as 200°C and that above 325°C pyrrhotite is stable. Because pyrrhotite is the dominant sulfide, formational temperatures in the range of 400°-500°C (encompassing the regional metamorphic grade) can be proposed for fabric controlled mineralization at Gold Brook. This is consistent with metamorphogenic arsenopyrite coexisting with pyrite and pyrrhotite in gold districts nearby (Caribou, 450 ± 40°C, Graves 1976).

An explanation for the presence of reddish rims surrounding sphalerite crystals is somewhat uncertain. Vokes (1969) interprets this as a geothermometer in which sphalerite mix-crystals incorporate increasing amounts of FeS into their lattice with increasing temperatures of metamorphic recrystallization. It is clear from the darkened edges of the crystals that a compositional change has taken place due to reequilibration but microprobe analyses indicate Fe enrichment of only 0.3 percent. Such a value does not seem significant for consideration of this system as a geothermometer. Possibly Fe from the surrounding sediments was only partially reequilibrated during metamorphism.

8.4 Late Stage Mineralization

Mineralized veins and fractures cross-cutting primary bedding and stratiform mineralization are characteristic of the sediments at Gold Brook. Of major interest are sphalerite and galena filled fractures associated with the interbedded quartz metawacke unit and particularly with the calcareous quartz metawacke unit.

There are two possible sources of base metals within these horizons. Assay data indicate an enrichment of lead and zinc within these lithologies suggesting a concentration of these elements prior to the emplacement of fracture zones. Lateral secretion of these metals from the host sediments and precipitation of the mineralizing fluids along fracture systems is a possible origin for this style of mineralization. The comparatively lower number of veins and fractures in the slates or graphitic horizons may be due to the less competent nature of these units, resulting only in plastic deformation.

An alternative theory also compatable witn the data is a mineralizing fluid source at depth released during faulting by the removal of pressure gradients. Preferential precipitation within the calcareous and interbedded quartz metawacke units is due to the competency of the carbonate horizon. It is also possible that the influx of mineralizing solutions in to the carbonate-rich horizon underwent substantial pH changes leading to immediate precipitation.

CHAPTER 9

CONCLUSIONS AND RECOMMENDATIONS

Sulfide mineralization occurs throughout the Meguma Group sediments at Gold Brook but predominates within the black graphitic slate horizon at the base of the Halifax Formation and the underlying calcareous quartz metawacke unit at the top of the Goldenville Formation. Concentrations of sulfide within the basal massive quartz metawacke unit are comparatively insignificant.

Unlike the turbidite derived sandstones and slates of the Meguma, the calcareous and black slate lithologies probably originated within a sub-basin controlled by relatively low rates of sediment deposition. It is proposed that the carbonate unit was formed in a deep water environment, below the C.C.D. by the influx of a low pH, calcium-rich brine. An abrupt transition to a deepening starved basin facies representative of euxinic, quiescent conditions prevailed during black shale deposition.

The styles of mineralization represented within these assemblages and the remaining stratigraphy are indicative of two periods of ore formation. Stratiform mineralization was deposited contemporaneously with the sediments and concentrated during subsequent diagenesis while vein-fracture mineralization represent later stages of ore deposition. Regional metamorphism of middle greenschist facies grade, was effective in remobilizing pre-existing mineralization along a foliation and changing the mineralogy of these sulfides.

Fluids responsible for the formation of the mineralization were probably derived from the host sediments and either concentrated during compaction, or precipitated at a later stage in favourable horizons.

Thus, the sediments at Gold Brook hold some potential for sulfide mineralization but further research must be done before generalizations on the potential of the property can be made.

It is recommended that additional drilling be undertaken in the western claim group where both the carbonate and black shale facies become more extensive. A facies change may result in higher grades of mineralization over a shorter vertical distance.

Fluid inclusion studies should be carried out to obtain a temperature of sulfide formation. This would determine if, in fact, both vein and fracture base metal mineralization were contemporaneous late stage emplacements.

Finally, sulfur isotope studies could be carried out to confirm the action of sulfate reducing bacteria in the formation of pyrite. If so then the role of regional metamorphism was significant in changing the mineralogy of some of the sulfide phases.

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