MINERALIZATION AND ASSOCIATED
WALL ROCK ALTERATION IN THE
GEORGE RIVER GROUP, CAPE BRETON ISLAND, NOVA SCOTIA

by

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Submitted in partial fulfillment of the requirement
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The undersigned hereby certify that they have read and recommended to the Faculty of Graduate Studies for acceptance a thesis entitled "MINERALIZATION AND ASSOCIATED WALL ROCK ALTERATION IN THE GEORGE RIVER GROUP, CAPE BRETON ISLAND, NOVA SCOTIA."

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ABSTRACT

The Precambrian rocks of the George River Group of Cape Breton Island include thick sections of quartzites, slates, limestone and dolomites and their metamorphic derivatives, together with lesser amounts of volcanic rocks and other sedimentary rocks. The wall rocks of mineralization can be grouped into two general types: (1) those containing moderately abundant calcium-magnesium silicates, and (2) those containing abundant feldspars and micas. The first group includes calcareous rocks of Meat Cove, Lime Hill, Whycocomagh and Boisdale Hills area, and the second group includes garnetiferous quartz-feldspar-biotite schists of Faribault Brook, quartz-K-feldspar-biotite gneisses of Nile Brook and sericite-biotite schists of Second Gold Brook area.

At Meat Cove, the forsterite-rich unit of the magnesian skarn was the site of most metallization. Sphalerite is the main sulphide mineral but also included are pyrite-pyrrhotite-galena-chalcopyrite, pyrite-pyrrhotite-germanite-renierite-magnetite and pyrite-pyrrhotite mineral assemblages. At Lime Hill hypogene minerals include sphalerite, pyrite, pyrrhotite, galena, tetrahedrite, chalcopyrite and bornite in the magnesian skarn and scheelite and hydrotungstite in the diopside-wollastonite skarn. At Whycocomagh the hypogene minerals are magnetite, scheelite, molybdenite, chalcopyrite, pyrite and pyrrhotite and all of these are confined to the andradite-diopside unit of the magnesian skarn. In the Boisdale Hills veins of pyrite-pyrrhotite-chalcopyrite-sphalerite and "spotty" distribution of scheelite are restricted to wollastonite-diopside-andradite skarn.

In the Faribault Brook area, the base-metal mineralization occurs in three zones, designated as Galena Mines, Silver Cliff and Core Shack prospects. The host rock in all three deposits is garnetiferous quartz-feldspar-biotite schists. The hypogene minerals are pyrite, pyrrhotite, arsenopyrite, magnetite, lollingite, enargite, tetrahedrite, chalcopyrite, galena, sphalerite, chalcocite and covellite in a dominantly quartz gangue.

An alteration halo surrounds all known sulphides; exception to this have not yet been found. Wherever the entire system is visible, the halo is zoned, and the zones are always in the same sequence. In areas too large to see in their entirety the same zone are present and the same sequences are found. The width of the altered rock zones that bound the mineralized zone ranges from a few centimetres up to a few hundred metres. The lateral zonation adjacent to the mineralization appears to have developed contemporaneously, or nearly, with the deposition of the vein material.

The altered carbonate wall rocks adjacent to the mineralized zones are similar throughout the region (i.e. Meat Cove, Lime Hill, Whycocomagh and Boisdale Hills) in that talc-antigorite mineral association is adjacent to the mineralized veins and tremolite-antigorite association is further out, in detail the degree of alteration, the width of altered zones and, to some extent, the type of alteration vary because of differences in lithology and structure of the host rocks and differences in the intensity of the hydrothermal environment.

The wall rock alteration halo enclosing the mineralization in quartz-feldspar schists demonstrates convergent zonal alteration in that intense alteration has changed the earlier metamorphic minerals to a uniform mineral association which consists of clays and sericite. Fresh garnetiferous quartz-feldspar-biotite schist of zone 4 grades into rock of zone 3 in which feldspars are altered incipiently to clay minerals. The clay mineral components in zones 3 and 2 consist of mixed assemblages of montmorillonite, illite and random mixed-layer montmorillonite clay minerals. Further alteration results in the remainder of the biotite and the clay minerals being converted completely into sericite.

The relative abundances of Cu, Pb, Zn and their relationships from mineral deposits of the Faribault Brook area are remarkably similar to a discordant ore body ascribed to magmatic-hydrothermal processes.

The migration of heavy metals into, or within, the wall rocks was tested by direct chemical analyses of the zones in the alteration halo surrounding the mineralization. Such analyses have shown that the anomalous concentrations of heavy metals are confined to the zones of alteration and this would imply that the metallization and the wall rock alteration are roughly synchronous. The galena from the Meat Cove zinc deposit yielded a model lead age of 415 Ma and a mica associated with the sphalerite yielded a K-Ar age of 409 Ma. This again suggests the time of metallization and the time of development of the alteration halo were synchronous.

The endogenic haloes of heavy metals in the wall rocks are extensive, and this parameter has considerable potential in detailed exploration programs.

The altered wall rocks are infallible guides to sulphide mineralization in the George River rocks of Cape Breton Island, for alteration was largely synchronous with the metallization.

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Most of the illustrations were drawn by the Cartographic Division of the Department of Mines. Personnel of the mining companies have been uniformly cooperative in furnishing information and access to the drill core and I extend my sincere gratitude. Special thanks are due to S. Clarke who edited the manuscript, D. Bernasconi who edited the diagrams and S. Parsons who typed the manuscript.

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CHAPTER 1

INTRODUCTION

Cape Breton Island lies entirely within the Appalachian Province of Eastern Canada. The exposed rocks range in age from late Precambrian to Pennsylvanian and contain many mineral deposits both metallic and non-metallic. Rocks of the George River Group, the oldest exposed, cover approximately 650 square kilometers, and are noteworthy not only for the number of minor occurrences of sulphides but also for the presence of Zn-Ge-Cd, Cu-Pb-Zn-As-Au-Ag, Fe-Cu, Cu-Fe-Mo-W and Cu-W mineralization in concentrations that are potentially of economic interest.

This investigation is a part of a comprehensive study of the George River Group by the Nova Scotia Department of Mines. The primary aim of this present work was to provide a detailed description of the major deposits, the mineralogy of the deposits, the distribution pattern of various minerals, and the wall rock alteration associated with the mineralization, in an effort to establish additional criteria useful in the search for other deposits.

The investigation has revealed that the George River rocks were subjected to intense metamorphism and that the sulphide minerals are accompanied by a halo of low-grade metamorphic minerals derived from the high-grade assemblages; the sulphide mineralization is therefore a later event than the intense metamorphism.

It was further revealed that the sulphide minerals are concentrated in certain compositional units of the George River rocks. This immediately raised the question of whether the sulphides had been derived from these units and concentrated into their present positions, leaving the halo as evidence of the zone from whence they came, or whether the sulphide minerals were introduced into the country rocks from some other source.

A detailed diagnosis of the available evidence is presented, and it leads to the concept of a hydrothermal origin for the ore minerals. In brief, the conclusion is reached that the sulphides were introduced, that the alteration haloes are entirely the result of a thermal effect accompanying the sulphide mineralization, that within the wall rocks any migration of trace elements seems to have been into - not out of - alteration zones, and that the alteration effects accompanying the larger bodies might be used as an aid in prospecting for them. It is hoped that the information presented in this thesis will contribute constructively to future exploration in the George River rocks of Cape Breton Island as well as to a better understanding of the origin of the deposits here and elsewhere.

This thesis is based on the work done by the author since 1967, but it also incorporates pertinent data from published literature and some unpublished data from the geological staffs of mining companies.

Method of Investigation

Because the methods of field collection and laboratory examination of samples change and are improved over periods of time, the methods here used are summarized briefly to provide a basis for interpretation or future re-interpretation of these data.

Field Studies

The wall rocks adjoining the mineralization thoughout the region were systematically examined and sampled in conjunction with the detailed mapping of the deposits. The aim was to discover any structural or lithological features with which the mineralization might be preferentially associated and which might indicate factors causing its localization. Where the zones of altered rocks bordering the mineralized veins were too narrow (<5m) it was not practical to map them. Instead, samples of different kinds of altered rocks that could be distinguished megascopically were collected, and sketches were made to show the locations of the samples with respect to the mineralization and other structural features. Also, during the field study more than 4000 metres of diamond drill core were systematically logged and sampled from those deposits that have witnessed considerable exploration activities. More than 2700 samples were collected from the outcrops and diamond drill core and were studied during this investigation. These samples represent a diverse group of rocks related to various kinds of mineralization.

Laboratory Studies

The samples were studied in the laboratory with the petrographic microscope; both the thin section and oil immersion methods were used in transmitted and reflected light microscopy. For many opaque minerals, precise measurements of reflectivity and Vickers microhardness were made using the Zeiss microscope equiped with a 01 Zeiss photometer and MHP microhardness tester; the reflectivity was measured at a wavelength of 546 nm using SiC (252) as reflectance standard. The identification of the majority of the silicate and sulphide minerals was confirmed by X-ray diffraction and electron microprobe (Norelco AMR-3 and Cambridge Mark V) analyses. A limited number of rock samples was analyzed chemically using standard wet-chemical and atomic absorption techniques.

General Geology: George River Group

For the resumé I have drawn on the publications of Kelly (1967) and Milligan (1970), unpublished maps of northern Cape Breton Island (open file, Nova Scotia Department of Mines), data from closure number 1 by McPhar Geophysics Ltd. (1955) and on Geological Survey of Canada Map 55-36 by MacLaren (1954).

The sequence of rocks consisting of clastic meta-sediments and metavolcanics of demonstrably pre-Middle Cambrian Age in Cape Breton Island is generally assigned to a group known as the George River Group (Figure 1). The basement to these rocks has not been recognized and conformable contacts with younger rocks have not been found. This group includes thick sections of quartzites, slates, limestones and dolomites and their metamorphic derivatives, together with lesser amounts of other sedimentary and some volcanic rocks.

A structurally simple, continuous and well-exposed stratigraphic section of the entire George River Group has never been described, and the lack of such a reference section has been one of the major obstacles to increased understanding of the George River stratigraphy. In the type locality (Boisdale Hills), dolomitic limestone is the chief lithological unit and it is associated with minor quartzites. This association led to the common belief that carbonates and quartzites are predominant in the George River rocks. However, as shown and described by Milligan (1970), within the framework of existing knowledge, the lithological section in the Craignish Hills is the most completely exposed.

Broadly speaking, the major lithological units in the Craignish Hills, in probable order of deposition, are dark quartzites and feldspathic quartzite, slate, volcanics, carbonates and light quartzite. Field mapping has indicated that lateral and vertical variations can be either gradual or abrupt. Locally, any one of these units may attain a thickness of several hundred feet (Milligan, op. cit.).

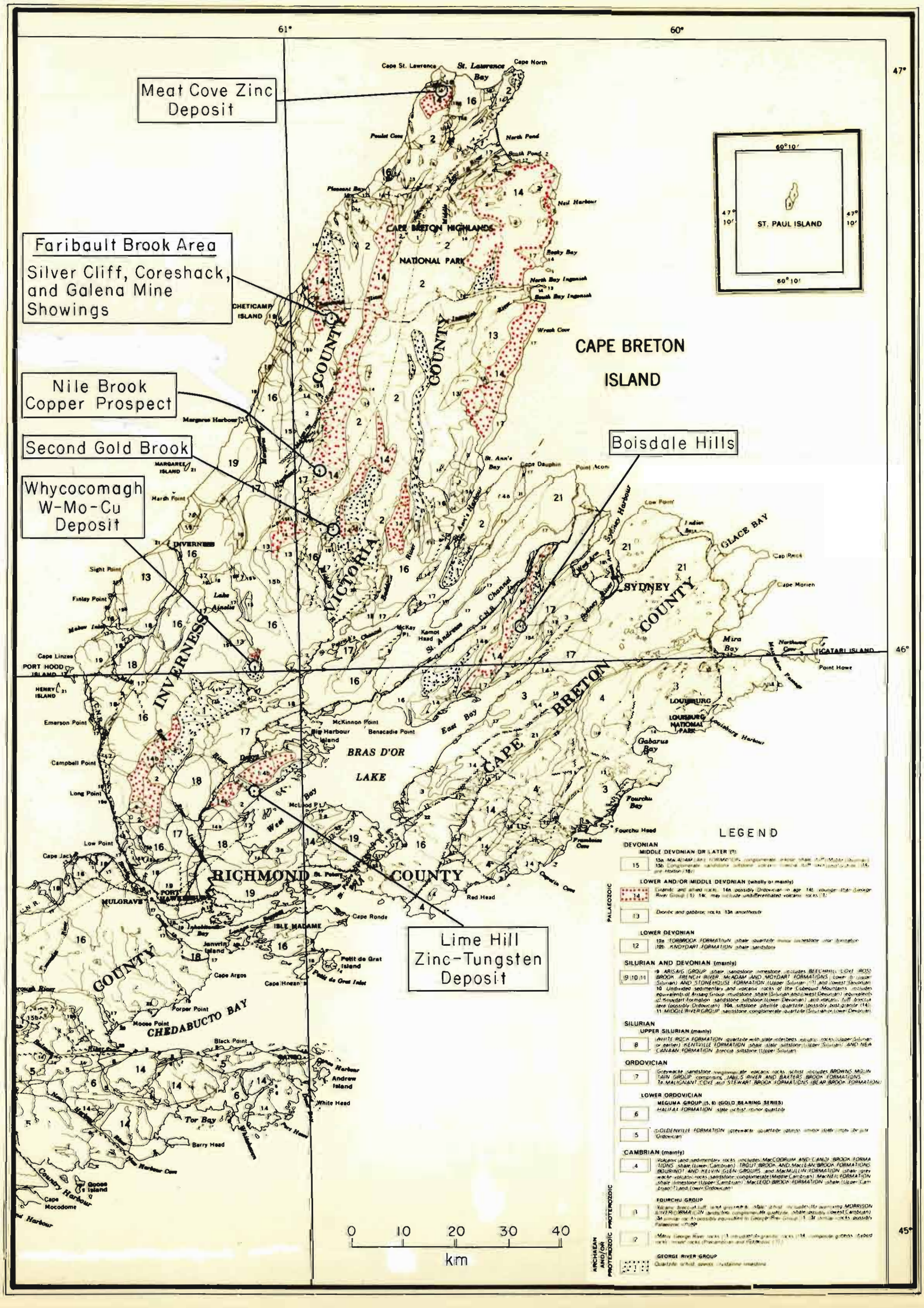


Figure l. - Location Map

The George River rocks have been intruded by plutons ranging in composition from gabbro to granite. Recent radioactive dating (Wanless, 1969; Cormier et al., 1970; Cormier, 1972) has shown that granites in the Boisdale, Craignish Hills and Cheticamp areas are pre-Devonian (563 to 485 million years) and many of the other intrusive rocks may be pre-Devonian also, instead of the Devonian age formerly assigned to them.

Type of Mineralization

The known sulphide deposits in the George River Group range from relatively small to the medium-size zinc deposit of Meat Cove. Some, such as the copper prospect at Nile Brook, have a small but impressive zone of oxidation. Generally, there has been very little post-glacial oxidation, and unaltered sulphides occur at the surface.

The mineralization occurs in rocks of two main lithological groups. The first is characterized essentially by carbonates and the second group is essentially argillaceous. The former group includes the zinc deposit at Meat Cove, the zinc deposit at Lime Hill, the copper-tungsten-molybdenum deposit at Whycocomagh and the sulphides in calcareous rocks of the Boisdale Hills. The latter group includes the "Silver Cliff", "The Core Shack" and "The Galena Mine" prospects at Faribault Brook, the gold-nickel prospect at Second Gold Brook and the copper prospect at Nile Brook. The locations of these are shown in Figure 1. The geological setting, mineralogy and wall rock alteration associated with the mineralization of these deposits are described in Chapters 2 to 8.

CHAPTER 2

Meat Cove Zinc Deposit

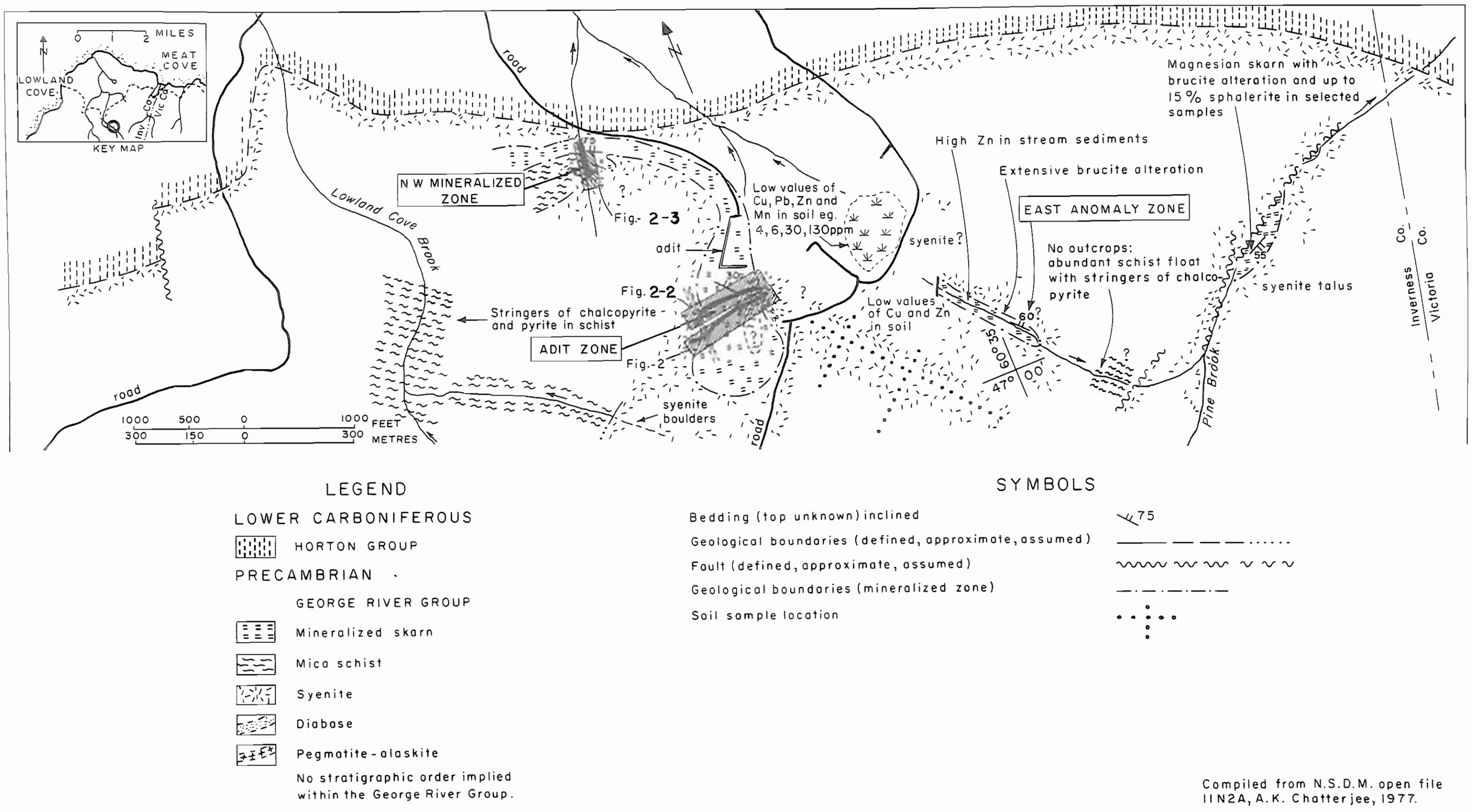
Introduction

The Meat Cove zinc deposit is situated at latitude 47°00' N and longitude 60°35' W, approximately 5 km southwest of the village of Meat Cove, Inverness County, Cape Breton Island. The property is accessible from Meat Cove, but the former road to Lowland Cove is no longer passable much beyond the turnoff to the prospect (Figure 2-1).

Previous Work

The first indications of possible zinc mineralization at Meat Cove were glacial boulders containing disseminated sphalerite, found by the personnel of the Minex Co. in 1953. As a result of a geological investigation, an electromagnetic survey and exploratory drilling, the main ore body (adit zone, Figure 2-1) was identified in 1955. Prospecting, trenching and diamond drilling have continued at intervals since the first discovery. By 1965, diamond drilling had outlined low-grade mineralization. Dunbar (1965) estimated a possible tonnage of 4.4 million tons of 4.0 per cent zinc, 0.15 to 0.47 pounds of cadmium per ton and 0.18 to 3 pounds of germanium per ton in two adjacent deposits. In 1968, several trenches were bulldozed and it was reported by the owner that a sample across 254 feet assayed 5.65 per cent zinc with a 32 metre section averaging 10.5 per cent zinc. In 1968-69 the author mapped the trenches in detail (Figure 2-2A and B), and the following results are based on this geological mapping, and on subsequent microscopic observations on thin and polished sections, X-ray diffraction and microprobe analyses of more than three hundred samples.

MEAT COVE ZINC PROSPECT



Compiled from N.S.D.M. open file 11N2A, A.K. Chatterjee, 1977.

Figure 2-1

Surface Plan, Meat Cove Zinc Prospect

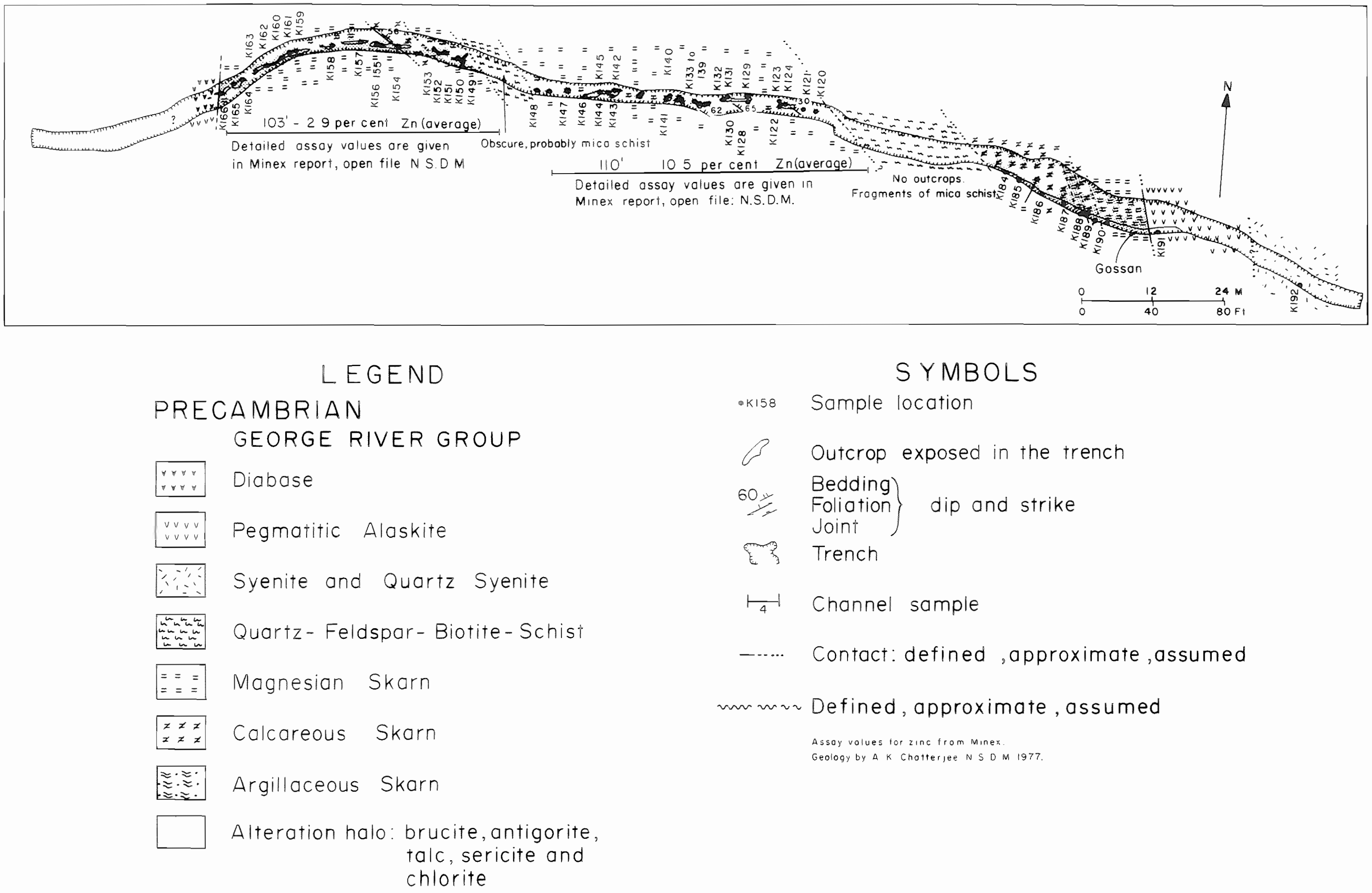
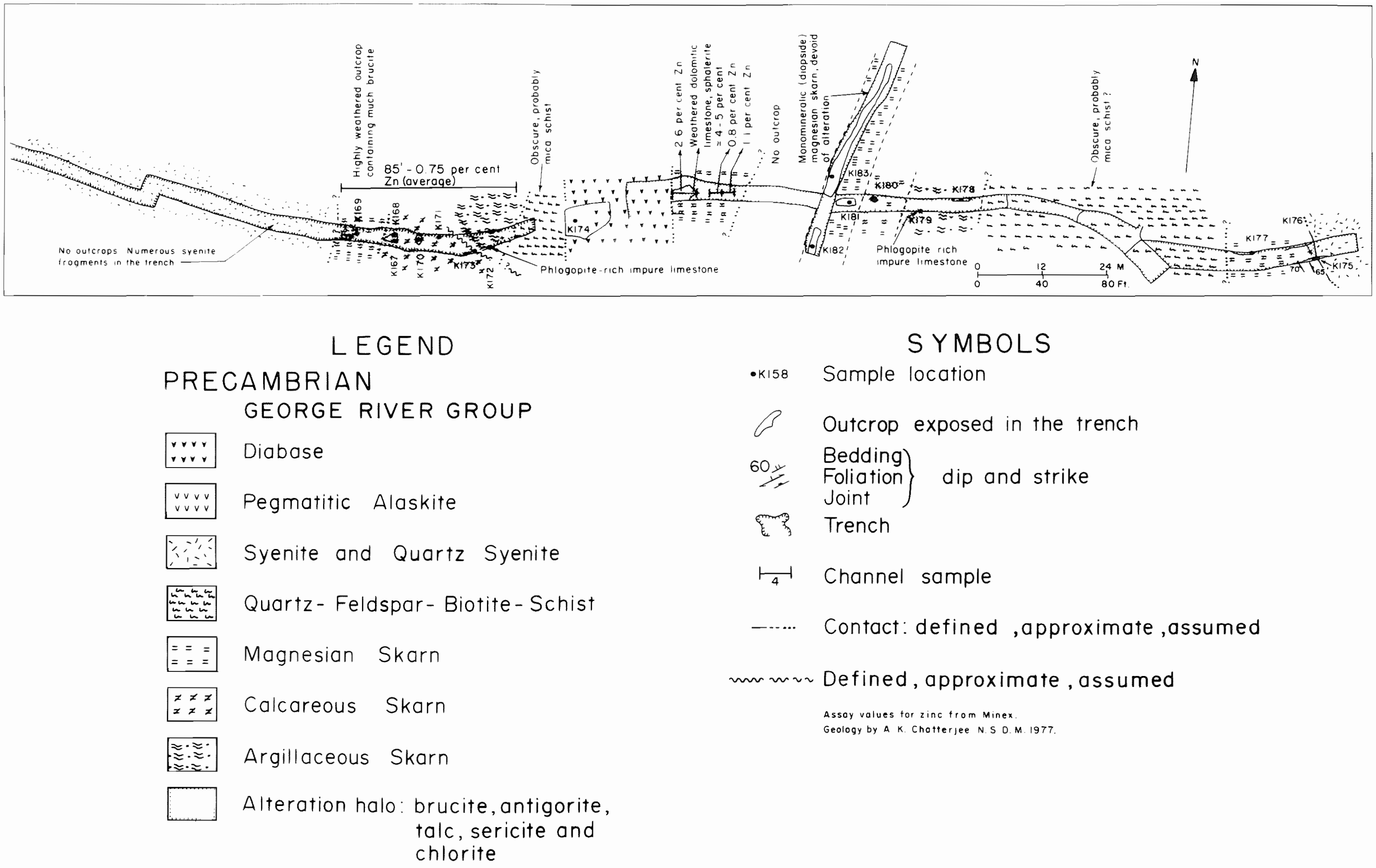


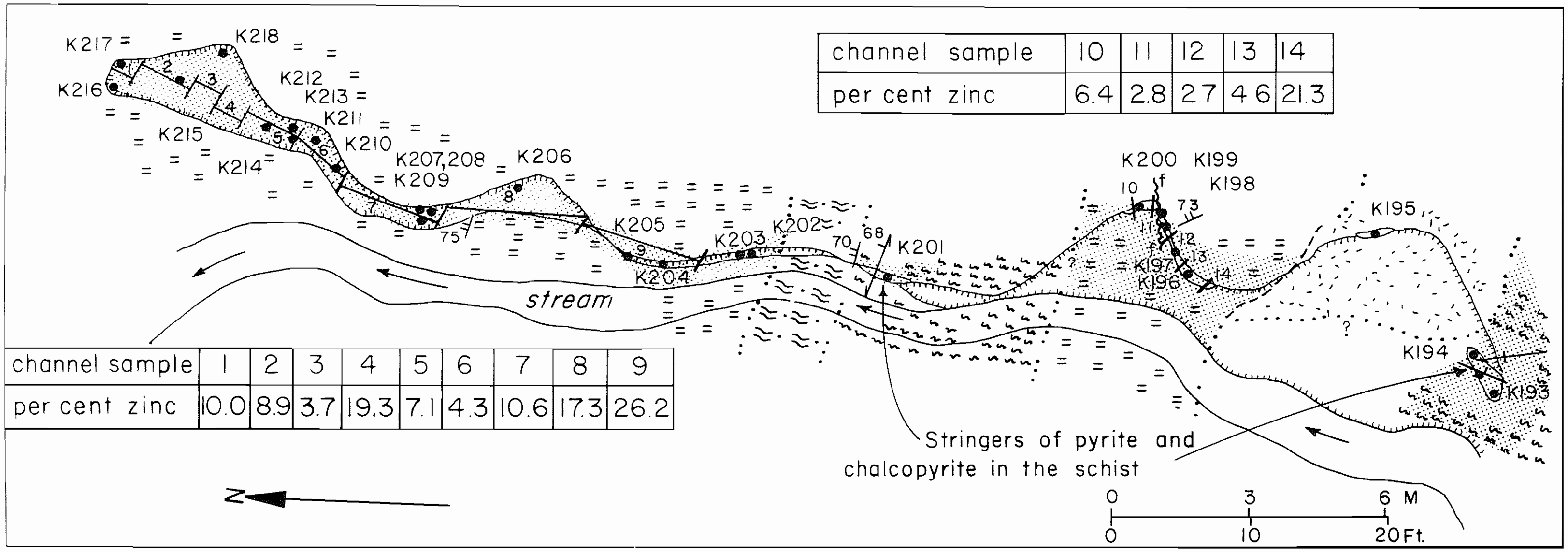
Figure 2-2 A

Surface Trenching, Geology and Assay Plan for Adit Zone, Trench 1



Assay values for zinc from Minex.
Geology by A. K. Chatterjee N.S.D.M. 1977.

Figure 2-2B
Surface Trenching, Geology and Assay Plan for Adit Zone, Trench 2



channel sample	1	2	3	4	5	6	7	8	9
per cent zinc	10.0	8.9	3.7	19.3	7.1	4.3	10.6	17.3	26.2

channel sample	10	11	12	13	14
per cent zinc	6.4	2.8	2.7	4.6	21.3

LEGEND

PRECAMBRIAN

GEORGE RIVER GROUP

▨	Diabase
▨	Pegmatitic Alaskite
▨	Syenite and Quartz Syenite
▨	Quartz-Feldspar-Biotite-Schist
▨	Magnesian Skarn
▨	Calcareous Skarn
▨	Argillaceous Skarn
☐	Alteration halo: brucite, antigorite, talc, sericite and chlorite

SYMBOLS

•K158	Sample location
	Outcrop exposed in the trench
60	Bedding Foliation Joint } dip and strike
	Trench
⊢4⊣	Channel sample
—-···	Contact: defined, approximate, assumed
~~ ~·~	Defined, approximate, assumed

Assay values for zinc from Minex.
Geology by A. K. Chatterjee N.S.D.M. 1977.

Figure 2-2C
Surface Trenching, Geology and Assay Plan for NW Mineralized Zone, Trench 3

An economic evaluation of the deposit was carried out by Huston and Associates in 1972. After assessment of all the relevant data and further exploratory drilling, it was concluded that the adit zone contains 3.5 million tons of 2.08 per cent zinc. The information on the NW zone and the East anomaly zone was not adequate to warrant any grade and tonnage calculations. However, according to Dunbar (1965), the NW zone contains about 400,000 tons of 2.76 zinc.

Geological Setting

The host rock is composed of interbedded argillaceous and siliceous dolomitic limestone and garnetiferous quartz-feldspar-biotite schist. Regional mapping by Neale (1964) indicates that it is a roof pendant in a large body of syenite. Later diabase, alaskite and aplite dykes cut both the syenite and the metasediments. Figure 2-1 shows the general geology of the Meat Cove region and the location of the adit zone, NW mineralized zone and East anomaly zone.

The Meat Cove deposits are confined to skarns which developed at the contact of syenite with the siliceous dolomitic limestone, argillaceous limestone and siliceous limestone. The skarns are characterized by complex mineral associations resulting from repeated alteration of carbonate rocks. These bodies have a lenticular shape with rather irregular contacts and attain a maximum width of approximately 25 metres.

Several types of mineralization have been distinguished in the metasedimentary and igneous rocks of the Meat Cove area. These are as follows:

(a) Rare veins (seen only in drill core samples) of pyrite-chalcopyrite-bornite-sphalerite-quartz-carbonate occur in the syenite. These veins are rimmed by sericitic alteration.

(b) Dissemination and stringers of pyrite and chalcopyrite are seen in the fine-grained quartz-feldspar-biotite schist. The rocks show some tourmalinization and abundant chlorite and sericite alteration.

(c) Mineralized veins composed of sphalerite-galena-pyrite occur in brecciated magnesian skarn. The brecciation is due to fault movements which predate the mineralization.

(d) Impregnation and stringers of sphalerite are common in argillaceous and calcareous skarns.

(e) Layered pyrrhotite and sphalerite mineralization are found on a small scale in the magnesian skarn (NW mineralized zone). The finely banded gossan exposed in the trench may have been derived from this type of mineralization.

(f) Extensive selective replacement of forsterite-bearing units by massive sulphides. This is the main type of mineralization and is the most abundant. It is developed chiefly as a zone along the contact between syenite and magnesian skarn. The magnesian skarn with sphalerite mineralization has a distinct, and intense, brucite-antigorite-talc alteration, which is described in the next paragraph.

In addition to contact metamorphism and skarn formation, intense magnesian alteration is associated with the mineralization. The three most abundant products of alteration are brucite, antigorite and talc. The colour of the antigorite ranges from pale greenish yellow to dark greenish black. On the weathered surface, brucite occurs as white spots in which a pitted clayey surface showing onion-skin structure is characteristic. Talc occurs as aggregates of thin plates and is invariably intergrown with brucite and antigorite (Plate 2-1, a,b, and c).

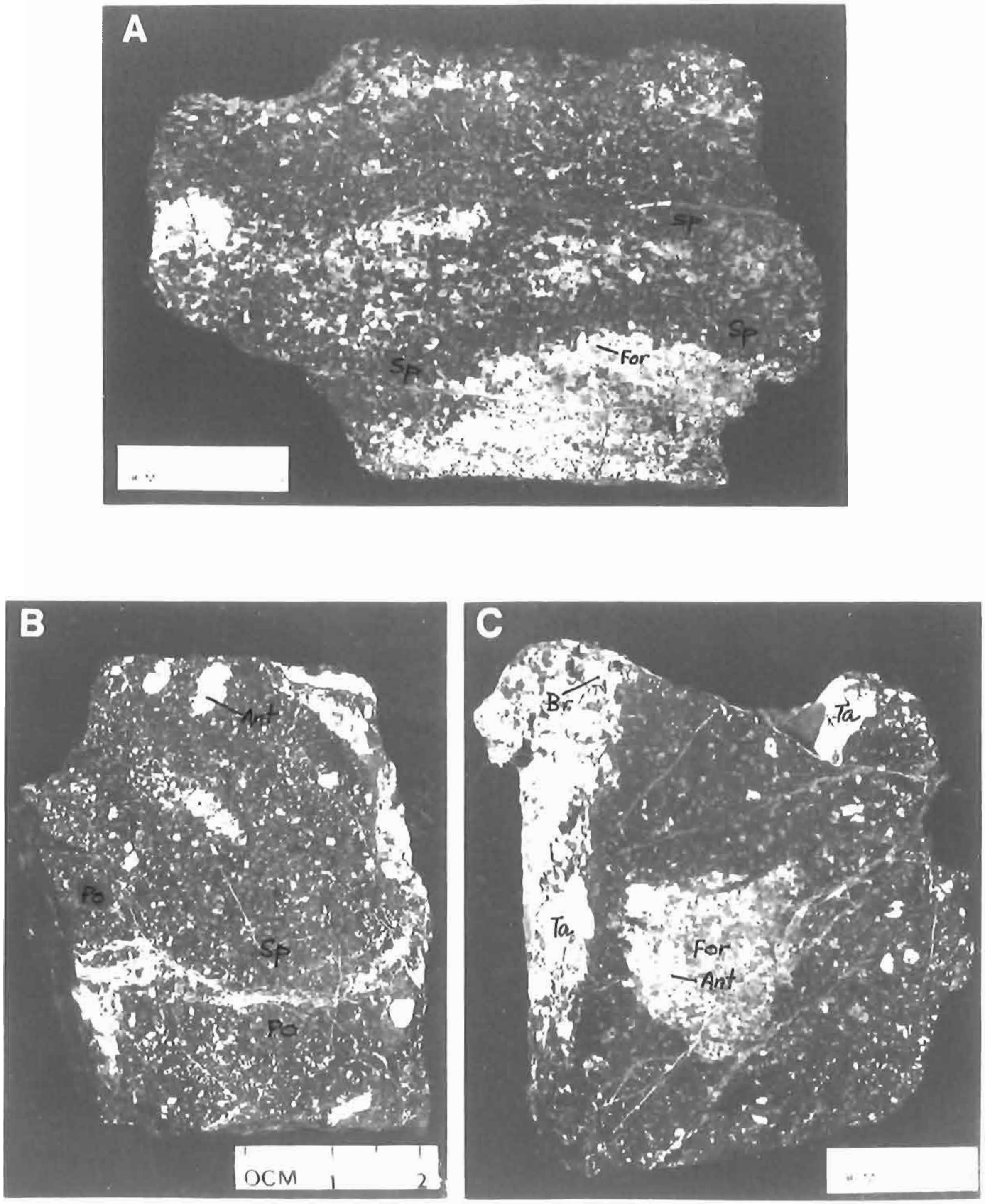


Plate 2-1

Photographs showing the selective replacement of forsterite rich rock by massive sulphides. Figure A, banded sphalerite in magnesian skarn. Figures B and C, photographs showing the association of antigorite, brucite and talc with the massive sulphides. Sp, sphalerite; Br, brucite; Po, pyrrhotite; Ta, talc; Ant, antigorite; For, forsterite.

At several places the presence of sulphides below the surface is indicated by gossan on surface. In a few places, the gossan is rather hard and massive, probably indicating massive sulphides. In other places the gossan is layered; the colours of the individual bands are different combinations of pale yellow to dark reddish brown colours with distinct pink patches randomly distributed.

Description of Sulphide Minerals

Before presenting discussion of the sulphides present at Meat Cove, it is necessary to consider briefly the criteria used in this work to establish relations among minerals.

The general criteria used in determining paragenetic sequences of minerals have been described in several publications (Barton et al. 1963; Bastin and others 1931; Bastin, 1950; Edwards, 1954; Schwartz 1951, 1954; Schouten, 1963; Zen, 1963), but the subjective aspects of paragenetic determinations make desirable a brief discussion of the criteria used in the present study.

Crosscutting Relations:

(a) Veinlets of one or more minerals that cut other mineral masses. The veinlet may or may not completely traverse the mineral mass.

(b) Prongs of one mineral mass that penetrate a second mineral mass. The term "prong" is meant to connote a protruberance of length greater than its width at the base. The contacts of the two minerals involved may be relatively straight elsewhere. The chief distinction between a prong and a veinlet is perhaps, first, the greater length of a veinlet and, second, the fact that the parent mass of the prong is clearly visible.

Inclusions:

(a) Inclusions that are uniformly oriented optically: these inclusions, being older than the host, are considered diagnostic. Due consideration has also been given to the possibility that optically oriented inclusions are exsolved phases, although this criterion can be used only with anisotropic minerals. Conversely, if closely grouped inclusions of anisotropic minerals are not uniformly oriented optically, they are considered to replace the host mineral.

(b) "Trains", i.e. inclusions that are aligned and closely spaced. The trains are actually incomplete veinlets and might well be included in crosscutting relations criteria.

The crosscutting relations appear to be the only criteria generally considered diagnostic of age relations among both isotropic and anisotropic minerals. However, even they must be used with care, inasmuch as veinlets that antedate their host mineral (antecedent veinlets) have also been recognized. No attempt has been made in this study to determine the relative age of inclusions of isotropic minerals.

Non-diagnostic Features:

"Caries" and "rounded-grain" textures are considered of little or no diagnostic value. Caries were described by Schwartz (1951, p. 582) as "scalloplike contacts or smooth concave and convex boundaries"; they are distinguished from prongs in that their penetration is no greater than the width of the base. The caries texture has been particularly misleading in determining the relative ages of garnet, pyrite, arsenopyrite, lollingite and magnetite minerals that tend to have euhedral shapes but that form skeletal grains. Rounded mineral grains have been interpreted, on occasion, as being partially replaced or corroded by surrounding material. If a mineral does not characteristically form euhedral grains, no interpretation of rounded corners can be made safely. Rounded corners on minerals that tend to have euhedral shapes may have some, but not diagnostic, value, but again only if the possibility is excluded that the grains are poikilitic or skeletal.

Criteria of Simultaneity:

In considering simultaneous deposition, the discussion and usage of Bastin and others (1931, p. 563) have been followed, "substances being considered to be simultaneous only if their precipitation from solution begins and ends at the same time". To quote further, "It is recognized that under natural conditions simultaneous deposition, as so limited, is probably comparatively rare. It is recognized also that overlap is partial simultaneity and that the evidence of overlap consists, in the last analysis, of evidence of simultaneous deposition in part of the specimen and of successive deposition in an adjacent part. Positive evidence of simultaneous deposition or contemporaneity is in general difficult to secure, and in most cases simultaneity has been doubtfully and tentatively inferred from the absence of any evidences of age diversity."

The following are criteria of simultaneous deposition as listed in the literature:

1. Exsolution intergrowths; Bastin and others (1931, p. 566)
2. The association of different minerals in a zonal intergrowth of definite origin; Edwards (1954, p. 133)
3. Narrow, rapidly alternating, crustified, banded texture; Edwards (1954, p. 133)

4. Partial automorphism; Bastin (1950, p. 161)
5. A eutectic; Bastin (1931, p. 565).

Edwards (1954, p. 133) suggested, "Minerals crystallizing simultaneously, but not in solid solution, also develop mutual boundaries. However, this texture, while suggestive of contemporaneous formation, is not a reliable criterion, because such textures can readily develop from replacement." (I agree with Edwards' opinion.)

Examples of generally accepted criteria of simultaneous deposition do not occur in sulphides of the George River Group. Without any useful evidence of simultaneous deposition, it is impossible to demonstrate overlap in deposition. Consequently, only successive deposition can be demonstrated, although several minerals may occur in two generations, or in veins belonging to entirely different periods.

Pyrite:

At Meat Cove, pyrite is abundant but generally is subordinate to sphalerite. It generally occurs as independent crystals and granular aggregates. Some is finely crystalline but the larger part is in coarse, cubic form. The variety of shapes, forms and relations suggests that it was formed at different times. At least two, possibly three, generations of pyrite have been recognized.

Pyrite of Generation I: This ranges in size from 0.03 mm to 1.0 mm and is idioblastic. It usually occurs as scattered grains. Most of the crystals show (magnification 200 X) some rounding and corrosion. Its relations with other sulphides are not fully understood.

Pyrite of Generation II: Pyrite of this generation ranges in size from 2 mm to 4 mm and many samples show cataclastic textures. Sphalerite, chalcopyrite and bornite are seen replacing pyrite II and, in extreme cases, complete pseudomorphs composed of sphalerite are seen. Pyrite of generation II is clearly more commonly replaced by other sulphide minerals than pyrite of generation I.

Pyrite of Generation III: Another generation of pyrite is suspected, as thin rims surrounding the grains of antigorite and brucite. These rims may be partial or complete. It also occurs along the grain boundaries between sphalerite and antigorite. Pyrite of generation III exhibits feeble but distinct anisotropism.

Pyrrhotite:

This mineral generally occurs in trace amounts. Morphologically, two types of pyrrhotite may be distinguished. Pyrrhotite I occurs as very minute grains in sphalerite, as inclusions showing definite crystallographic orientation. These inclusions have roughly the same reflectivity as the host sphalerite; however, under crossed nicols they are very easily identified. In all probability these are exsolution products (Plate 2-2, Fig. A). Pyrrhotite II appears as layers alternating with sphalerite in brecciated ore (Plate 2-2, Fig. B). These composite bands are entirely devoid of inclusions. The brecciation and bending of the composite bands are probably due to later structural deformations. Vokes (1969) classified this kind of banding as "metamorphic banding"; however, in the present situation it appears that the banding is due to the replacement of pyrrhotite by sphalerite or to the contemporaneous deposition of pyrrhotite and sphalerite. It may be noted that thin-banded gossan (observed in trench No. 3) may have resulted from the oxidation of this type of banded sulphides.

Sphalerite:

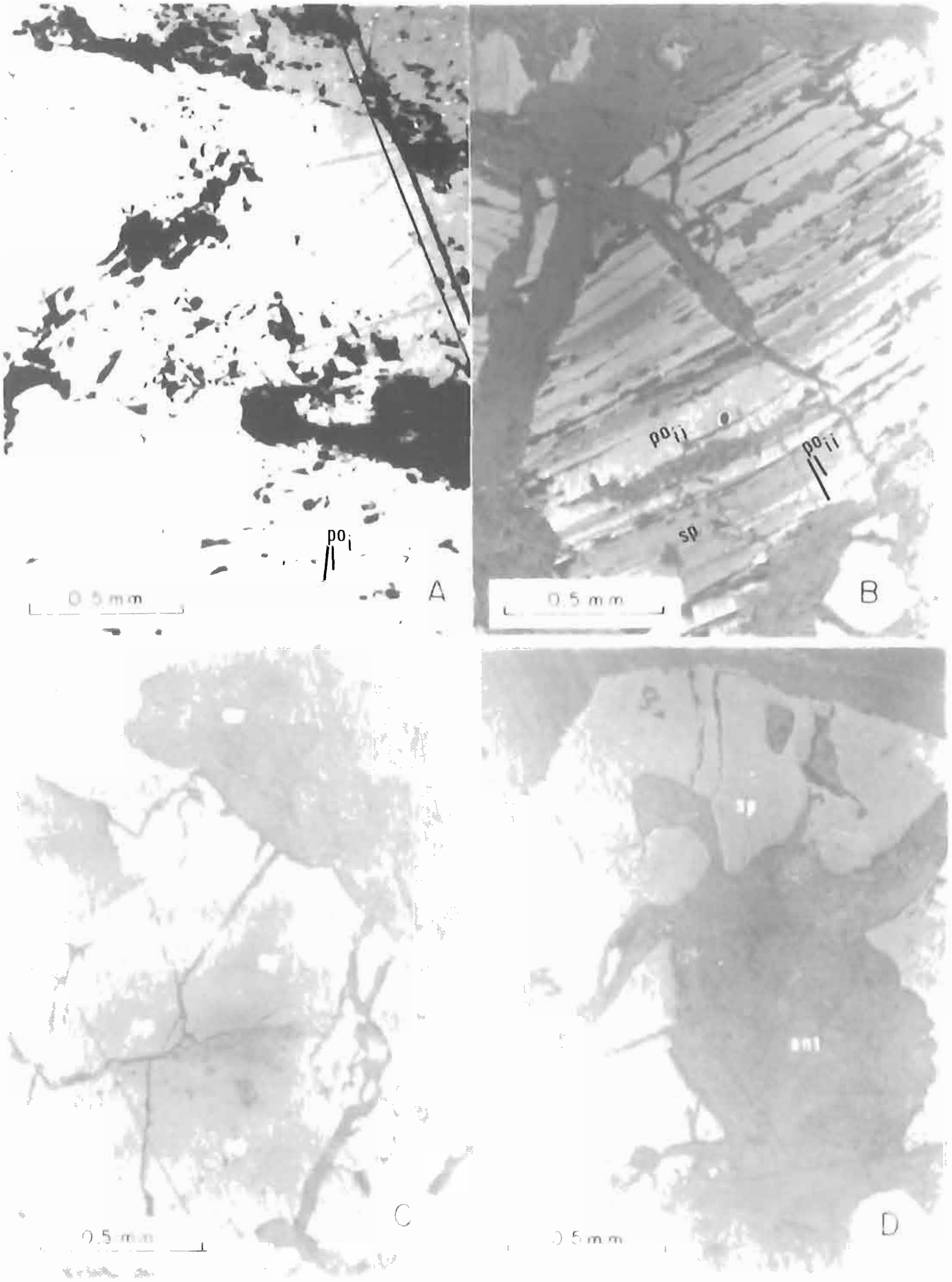
Sphalerite is the dominant hypogene mineral. It occurs as coarse-grained massive crystalline aggregates, as disseminations, as bands and also as veins. It may form up to 95 per cent of the massive crystalline aggregates.

The relations of the sphalerite to the pyrite are particularly noteworthy. Complete replacement has formed pseudomorphs of sphalerite after cataclastic pyrite (pyrite II), with preservation of the cataclastic texture of the host. When the replacement is incomplete, the sphalerite is commonly littered with unreplaced remnants of the pyrite. Partial to complete replacement of brucite and antigorite by sphalerite is also seen, and in such cases the typical fracture pattern of the gangue minerals is retained (Plate 2-2, Fig. C and D). Galena, germanite and stannite (?) are common associates of sphalerite.

Chalcopyrite:

Trace amounts of chalcopyrite can be found in most of the polished sections. It generally occurs as blebs or as streaks or as irregular, thin stringers.

None of the chalcopyrite examined contains cubanite or other exsolved minerals. Whether chalcopyrite has, or has not, been exsolved from any of the sphalerite of Meat Cove has not been satisfactorily determined, although is suggested by chalcopyrite occurring as blebs within sphalerite and by small irregular veinlets (stringers) that follow sphalerite grain boundaries. Formation temperatures for much of the sphalerite were high enough that chalcopyrite would have exsolved when the sphalerite cooled, if sufficient copper had been present, but whether sufficient copper was actually present to produce exsolved chalcopyrite is not known. Trellis or lattice patterns of chalcopyrite, which would most clearly demonstrate an exsolution origin, were not observed. Some chalcopyrite veinlets cut across sphalerite as well as


po_i
0.5 mm
A
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sp
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B
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C
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anl
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D

grains of pyrrhotite, carbonates and other mineral grains and are, therefore, not of exsolution origin.

Stannite:

The presence of stannite was confirmed by X-ray diffraction study, but it is a rather difficult mineral to identify under the microscope. The stannite forms somewhat elongate grains, but shapes are irregular because of uneven penetration by younger minerals. Its properties were correlated with those listed in Short (1964), Uytenboogardt (1951), and Schouten (1963). Its position in the paragenetic sequence is highly speculative.

Galena:

Galena is somewhat less abundant than pyrrhotite, but it is, nevertheless, an important ore mineral. In some places it surrounds and fills the spaces between grains of sphalerite, but generally it has replaced the sphalerite, as well as pyrite II and pyrrhotite.

Bornite:

Bornite was seen in only one polished section, in close association with chalcopyrite. Bornite appears to be later than chalcopyrite but no clear-cut evidence was seen.

Germanite and Renierite (?):

The occurrence of germanium, but not its mineralogical expression, has been known in the ore body at Meat Cove since the explorations of 1954-55. Germanite and renierite (?) appear to occur in approximately equal amounts. They are principally associated with sphalerite, and to a lesser degree with pyrite II. Both germanium minerals are also disseminated through the dolomitic host rock, and, as will be shown in the succeeding discussion, the germanium minerals occur together in most cases.

Germanite invariably occurs as ovoid "islands" or chains of ovoid "islands" disseminated through aggregates of coarse-grained sphalerite and pyrite (Plate 2-3, Fig. A). It also occurs rarely as perfect, euhedral cubic crystals together with euhedral pyrite crystals (Plate 2-3, Fig. B). In places, veinlets of the matrix (sphalerite) cut across and replace the germanite ovoids (Plate 2-3, Fig. C). The germanite ovoids range in size from about 10μ to 75μ; the average is about 30μ.

Some of the germanite ovoids contain minute, rod-shaped to anhedral inclusions of an unidentified, grey, isotropic mineral (Plate 2-3, Fig. D) that is distinctly harder than germanite. Essentially all the inclusions are less than 10μ long and 5μ wide. The rod-shaped inclusions are commonly oriented along the cubic or octahedral planes of the germanite host. Both the rod-shaped inclusions and the anhedral, unoriented inclusions are probably of replacement origin. The unidentified mineral is very similar in appearance to sphalerite and is difficult to distinguish from sphalerite unless both minerals are present in the same field, although an oil-immersion objective will enhance the slight difference in reflectivity between the two.

Renierite was observed to occur in the following characteristic microtextural relationships (Plate 2-3, Figs. E and F): (1) continuous and discontinuous rims of variable thickness around germanite ovoids and as intergranular networks in aggregates of germanite grains; (2) rims of variable thickness around the inclusions of the unidentified mineral in germanite; (3) irregular patches within germanite grains; (4) lamellae of variable thickness developed along the cubic or octahedral planes of germanite so as to form a regular intergrowth with that mineral; (5) irregular grains disseminated through the host rock; (6) discontinuous veinlets cutting sphalerite.

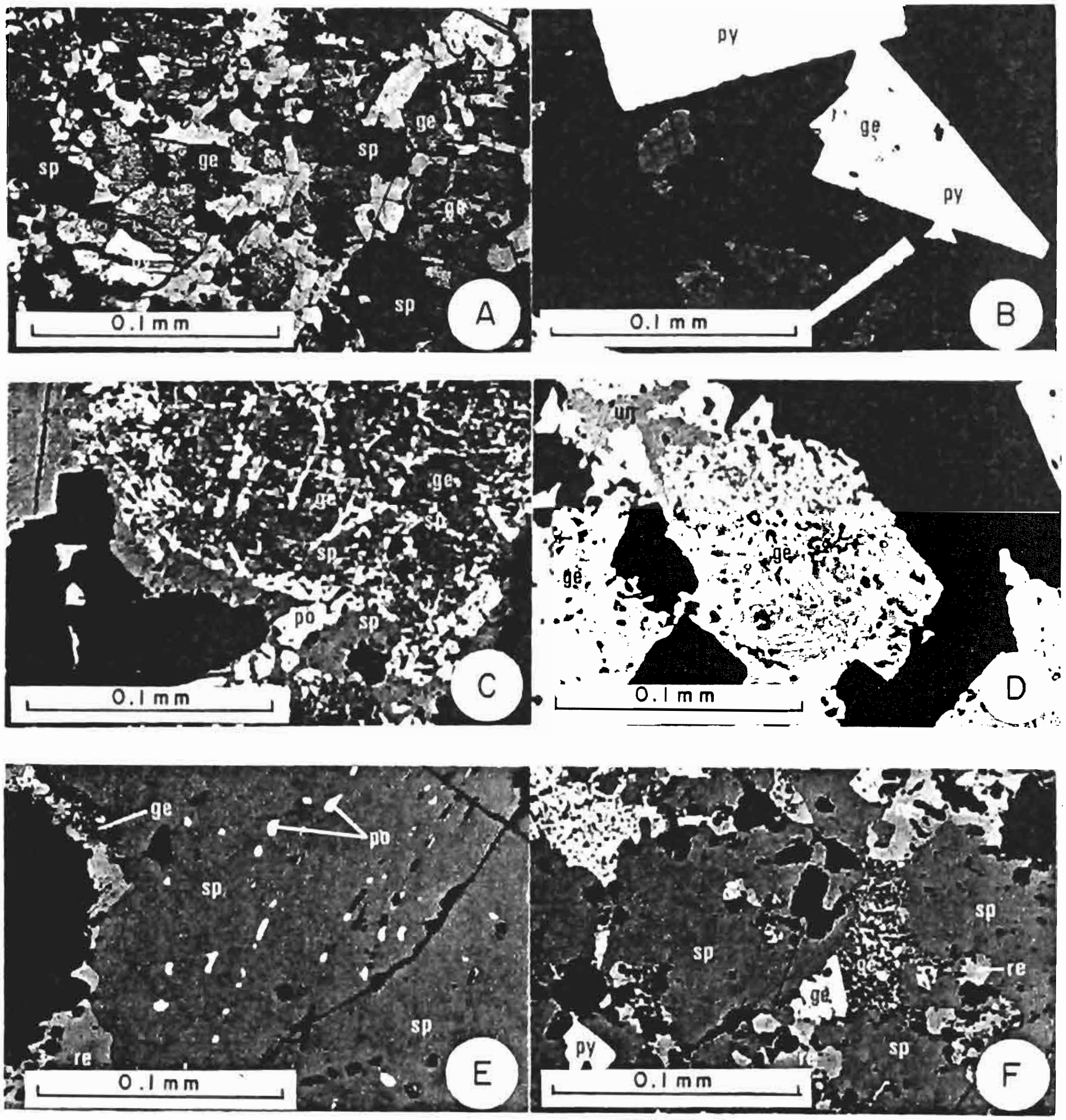


Plate **2-3** Photomicrographs showing the textural relationships of germanite and renierite. A, Ovoid islands of germanite disseminated through aggregates of coarse-grained sphalerite and pyrite. B, Euhedral cubic crystal of germanite with euhedral pyrite. C, Sphalerite crosscutting and replacing germanite. D, Inclusion of an unidentified isotropic mineral in germanite. E and F, Veinlets of renierite crosscutting sphalerite. py, pyrite; sp, sphalerite; ge, germanite; re, renierite; un, unidentified grey isotropic mineral; po, pyrrhotite.

The textures that resulted from partial replacement of germanite by renierite range from highly regular, in which certain crystallographic planes in the germanite host guided the development of the renierite, to unsystematic, in which directional control of growth of the metasome by the host is not apparent. In regard to the paragenesis of the two germanium sulphides, it is noteworthy that germanite is one of the youngest minerals in the sequence.

The mineralogical properties, mode of occurrence and mineral associations of germanite and renierite, from all reported occurrences known to the author, are summarized in Table 2-1. Detailed mineralographic data on germanite are available in standard works by Fleischer (1968), Harcourt (1942), Short (1948), Uytenboogardt (1951) and Murdock (1953).

The observed sulphide mineral associations from Meat Cove are tabulated below.

TABLE 2-2

Sulphide Mineral Assemblages at Meat Cove

Each assemblage has been found within a single polished section. There is no implication that these are all equilibrium assemblages.

Pyrite-pyrrhotite-sphalerite
Pyrite-pyrrhotite-sphalerite-germanite-renierite
Pyrite-pyrrhotite-sphalerite-germanite-renierite-magnetite

Pyrite-pyrrhotite-sphalerite-chalcopyrite
Pyrite-pyrrhotite-sphalerite-chalcopyrite-galena
Pyrite-pyrrhotite-sphalerite-chalcopyrite-galena-bornite

Pyrite-pyrrhotite-sphalerite-galena-germanite-renierite

Mineral Composition of the Skarns

The term "skarn", borrowed from Swedish miners, was introduced into the literature by Lindgren (1902, 1905). Hess (1918) originally

TABLE 2-1

Mineralographic Data, Mode of Occurrence, and Mineral Associations of Germanite & Renierite

Properties	Germanite Tsumeb, S.W. Africa	Germanite Meat Cove, N.S.	Renierite Tsumeb, S.W. Africa	Renierite Meat Cove, N.S.
Color (polished section)	Deep rose to pink	Pale violet	Orange brown	Pinkish gray
Quality of polish	Very good	Very good	Very good	Very good
Hardness	>galena, bornite; slightly <tennanite; >sphalerite	>galena <sphalerite	>galena, chalcopyrite; <tennantite sphalerite	>galena, <sphalerite
Cleavage	None	None	None	None
Reflectivity	Low	Low	Moderate	Low
Reflection pleochroism	None	None	Not reported	Orange to brown
Optical behavior	Isotropic	Isotropic	Yellow-brown to brown	Pinkish grey to yellowish brown
Twinning	None	None	Polysynthetic	None
Magnetism	Non-magnetic	Non-magnetic	Not reported	Powder magnetic
Etch reactions	Negative	Aqua regia stains brown others negative	HNO_3 slowly stains brown, fumes tarnish slightly, others negative	HNO_3 and aqua regia slowly stains brown.
Mode of Occurrence	Minute single grains and aggregates disseminated through galena-tennantite and host rock	Ovoid islands disseminated through coarse-grained sp. & py. Inclusions of unidentified isotropic mineals are abundant.	Irregular patches replacing germanite, irregular grains in host rock	Rims of variable thickness around germanite and as intergranular networks in aggregates of germanite grain. As veinlets cross-cutting sphalerite.
Mineral Associations	Chalcopyrite, galena tennantite, sphalerite and renierite	Sphalerite, galena pyrite (II), renierite, and chalcopyrite	Germanite, tennantite, sphalerite and galena	Sphalerite, galena, chalcopyrite, bornite, pyrite and germanite.

applied the term "tactite" to contact metasomatic rock "... of complex mineralogy formed by the contact metamorphism of limestone, dolomite, or other soluble rock into which foreign matter from intruding magma has been introduced by hot solutions". "Skarn" and "tactite" have been applied synonymously to contact metamorphosed rock by many authors (Bateman, 1965; Burt, 1972). Others, however, applied "skarn" to both regionally and contact metamorphosed rock (Rainberg, 1952). Gary, McAfee and Wolf (1972) define skarn as "... lime-bearing silicates of any geologic age derived from pure and impure limestones and dolomites near the igneous intrusion". Titley (1973) suggested that the term "pyrometasomatic" or "skarn" be used in a purely descriptive sense, as a type of alteration commonly occurring in the contact zone of intrusives.

The term "skarn" is here applied to recrystallized carbonate rocks containing calcium, magnesium, iron, and aluminum silicates, and formed in high-temperature zones of contact haloes of intrusions.

The skarns at Meat Cove are subdivided into various types on the basis of certain typical metamorphic minerals (Table 2-3). The minerals mentioned in the table are of special interest because they have been useful in differentiating lithological units (Figure 2-2A, B and C) and establishing certain relationships of the units to the mineralization. The details on various types of skarns are given below.

TABLE 2-3

Diagnostic Minerals in Various Types of Skarns

Compositional unit	Skarn type	Diagnostic minerals
Siliceous dolomitic limestone	Magnesian skarn	Periclase, chondrodite, monticellite, forsterite, diopside & tremolite.
Siliceous limestone	Calcareous skarn	Wollastonite, akermanite
Argillaceous dolomitic limestone	Argillaceous skarn	Idocrase, scapolite, epidote and phlogopite.

Magnesian Skarn (Siliceous Dolomitic Limestone)

The magnesian skarn is characterized by an alternation of almost pure dolomites and strongly silicated units. Emphasis here is placed on the lithologic unit containing ore grade mineralization, where mapping has provided much, although far from conclusive, information. Within the magnesian skarn, 10 units are recognized and their relationship to mineralization is shown in Table 2-4.

Many of the silicated units, in turn, can be subdivided into sub-units that include interlayered dolomitic or calcitic marbles, serpentinous and silicated marbles, and quartzose and micaceous rocks. The repeated alternation of competent and incompetent beds on all scales, from tens of metres down to centimetres, is undoubtedly a prime factor in the formation of the usually complex mineralization at Meat Cove. The observed mineral associations identified in the magnesian skarn from the Meat Cove area are listed in Table 2-5. Each association has been seen within the limits of a single thin section and there is no implication that these are all equilibrium assemblages.

Argillaceous Skarn (Argillaceous Dolomitic Limestone)

Argillaceous skarns are characterized by recrystallized rocks made up of calcium-magnesium-potassium-iron silicates and aluminosilicates. In the field, argillaceous skarn is easily identified on the basis of the "schistose" character of the carbonate rock and a large amount of phlogopite. The argillaceous skarns generally do not carry ore-grade mineralization and the details of mineralogy are omitted here. However, detailed discussion on mineral associations has been outlined by Chatterjee (1979).

TABLE 2-4

Units of the Magnesian Skarn and Their Relation to Mineralization

No.	Unit	Mineralization	Gangue minerals
1.	Dolomite-periclase	Sparse mineralization; scattered grains of sphalerite, pyrite and pyrrhotite.	brucite
2.	Forsterite-spinel-chondrodite	Massive sphalerite mineralization. Chondrodite and forsterite show intense alteration and complete pseudomorphs composed of antigorite and brucite are found.	antigorite, brucite, and minor talc
3.	Forsterite-monticellite-chondrodite		
4.	Forsterite-monticellite-spinel		
5.	Dolomite-diopside-forsterite	Massive zinc mineralization; diopside and forsterite show intensive antigorite alteration.	antigorite, minor talc
6.	Dolomite-forsterite-monticellite		
7.	Diopside (monomineralic)	Barren skarn. Devoid of any mineralization.	absent
8.	Dolomite-diopside		
9.	Diopside-tremolite (bimineralic)	Disseminated sulphide, generally less than 10% sulphides, mostly pyrite.	antigorite, talc
10.	Dolomite-forsterite-diopside-tremolite	Massive Zn mineralization; complete replacement of forsterite and diopside by sphalerite.	tremolite, minor talc and brucite

TABLE 2-5

Magnesian Skarn: Mineral Associations

Meat Cove

(Individual assemblages here listed have each been seen within the limits of a single thin section. There is no implication that these are all equilibrium assemblages.)

Dolomite-talc-antigorite
Dolomite-talc-antigorite-brucite
Dolomite-talc   -diopside
Dolomite-talc   -diopside-tremolite
Dolomite   -antigorite-brucite   -forsterite

Dolomite-forsterite-monticellite
Dolomite-forsterite-monticellite-talc-antigorite
Dolomite   -monticellite-talc
Dolomite-forsterite   -talc-antigorite

Dolomite-forsterite-monticellite-antigorite-brucite
Dolomite   -antigorite-brucite
Dolomite-forsterite-monticellite   -brucite
Dolomite-forsterite-monticellite-antigorite

Dolomite-talc-antigorite-tremolite-forsterite
Dolomite-talc-antigorite-tremolite   -diopside
Dolomite-talc   -tremolite-forsterite-diopside

Dolomite-talc-antigorite-periclase
Dolomite   -antigorite-periclase-brucite
Dolomite-talc-antigorite-periclase-brucite
Dolomite-talc-antigorite   -forsterite
Dolomite   -antigorite-periclase-brucite-forsterite
Dolomite   -antigorite-periclase   -forsterite

Dolomite-antigorite-brucite-forsterite-monticellite
Dolomite-antigorite   -forsterite-monticellite
Dolomite-antigorite-brucite   -monticellite

Calcareous Skarn (Siliceous Limestone)

Calcareous skarns are characterized by minerals such as wollastonite, diopside, akermanite and idocrase. The author has not found any mineralization in these rocks. In view of the presence of tungsten mineralization associated with the wollastonite-diopside skarn of the Boisdale Hills, however, the calcareous skarns of the Meat Cove area are worthy of re-examination.

Host Rock Alteration: Descriptive Features

In hand specimen, brucite, antigorite and talc are closely associated with the sulphides. Textural relations, summarized below, indicate that the talc, antigorite and brucite were all derived largely from pre-existing high-grade minerals:

Brucite: (1) has resulted from the action of water on forsterite; antigorite is an additional product. Corroded relics of forsterite are generally present when the reaction is incomplete. (Plate 2-4, Fig. A).

(2) has resulted from the alteration of antigorite (Plate 2-4, Fig. B).

Antigorite: (1) has been derived from tremolite; in this type the amphibole cleavage is preserved (Plate 2-4, Fig. C).

(2) has been derived from periclase; in this the antigorite grains are rounded and show residues of a periclase core (Plate 2-4, Fig. D).

(3) has been derived from forsterite; the antigorite grains show relics of forsterite and the fracture pattern is also preserved (Plate 2-4, Fig. E).

Brucite and antigorite were both derived directly from dolomite as well; the formation of antigorite from dolomite releases calcite as a separate phase (Plate 2-4, Fig.F). The direct alteration of periclase to form brucite has apparently not occurred; instead the periclase formed antigorite. From the preceding, it appears that some brucite and antigorite were formed directly from dolomite by the agency of a solution containing water and silica. The bulk of these two minerals, however, was derived from pre-existing minerals which formed during high-grade metamorphism, and this must therefore represent a retrogressive change.

Mineralization at Meat Cove was a complex process which can be divided into four principal stages. The first occurred during the contact metamorphic stage which was associated with the intrusion of syenite. Carbonate rocks near the intrusion were metamorphosed to magnesian skarn mineral assemblages, and impure siliceous rocks were changed to quartz-feldspar-biotite schist. Of the sulphide minerals, probably only pyrite (generation I) was formed during the contact metamorphic stage.

The second stage, called "hydrothermal", probably followed contact metamorphism without a perceptible break and many of the processes carried over from one to the other. During this stage, minerals that had formed earlier were altered. The first minerals that developed during alteration were chlorite and sericite, antigorite, talc and brucite. The first two formed in quartz-feldspar-biotite schist, and the other three in dolomitic limestone.

The hydrothermal stage (which is here confined to the deposition of the gangue minerals mentioned above) was followed closely by the main sulphide mineralization stage during which most of the sulphides

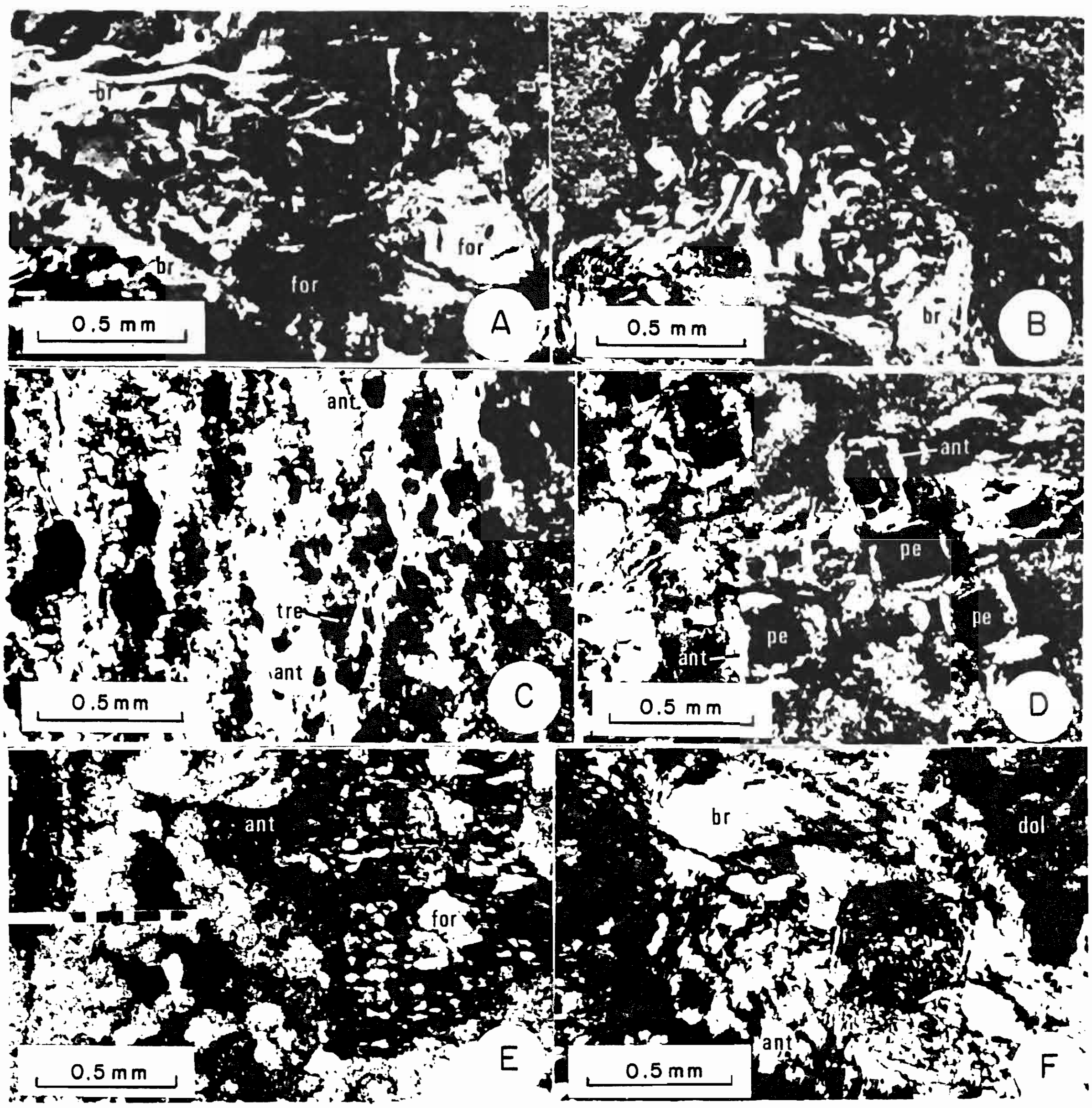
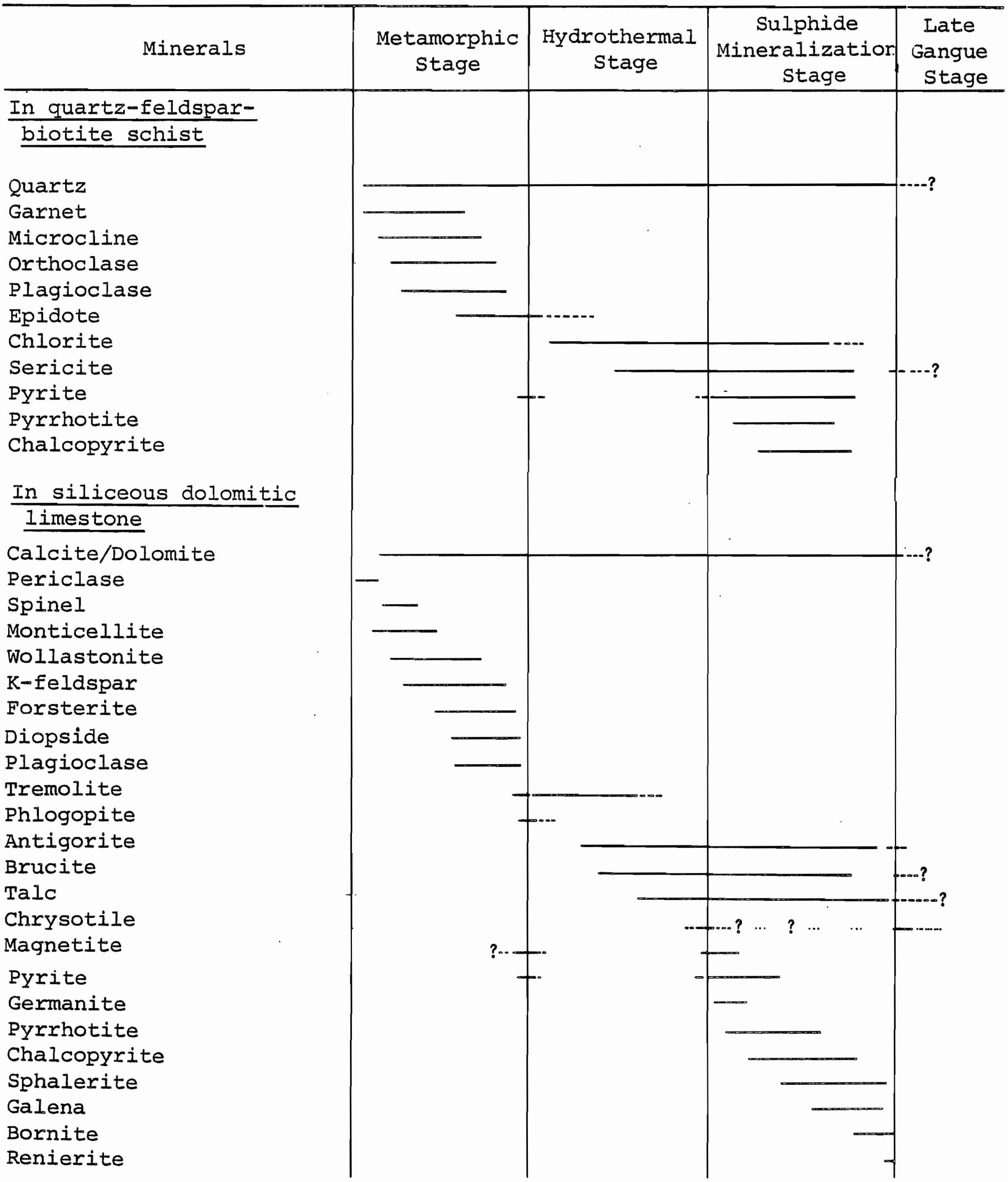


Plate 2-4 Photomicrographs showing the textural relationships of antigorite and brucite. A, Alteration of forsterite to brucite. B, Alteration of antigorite to brucite. C, Alteration of tremolite to antigorite. D, Alteration of periclase to antigorite. E, Alteration of forsterite to antigorite. F, Alteration of dolomite to brucite and antigorite. for, forsterite; dol, dolomite; ant, antigorite; br, brucite; pe, periclase.

TABLE 2-6

PARAGENETIC SEQUENCE OF MINERALS
MEAT COVE ZINC PROSPECT



were deposited. This main sulphide mineralization consisted of pyrite, germanite, pyrrhotite, chalcopyrite, sphalerite, galena, bornite and renierite, in this sequence. The textural relations, of course, can indicate only the sequence but, again, for reasons discussed later, it is probable that the hydrothermal and sulphide mineralization stages were separated by no significant time interval.

The formation of sericite, brucite, antigorite and talc probably continued from the hydrothermal stage to the late gangue stage.

The paragenetic classification of minerals has been determined for the quartz-feldspar-biotite schist and siliceous dolomitic limestone in each of the four stages. The proposed paragenetic sequence is shown in Table 2-6. Certain minerals were deposited in more than one stage and also were formed over a considerable range of temperature. An almost continuous deposition of quartz, for instance, from the metamorphic stage to late gangue stage seems probable.

CHAPTER 3

LIME HILL ZINC-TUNGSTEN DEPOSIT

Introduction

The zinc-tungsten mineralization is located on North Mountain, Inverness Co., at 45° 47'N latitude and 61°09'W longitude, approximately 2 km northwest of West Bay of Bras d'or Lake, near the headwaters of McCuish Brook. A jeep road, passable in dry weather, leads to the deposit from the all-weather, gravel road parallel to the lake (Figure 3-1).

Previous Work

Belcher Mining Corporation, on the basis of geochemical and geophysical anomalies, located the zinc mineralization at McCuish Brook in 1957. In 1959, Conwest optioned the property and conducted an exploration program consisting of geological mapping, geophysical surveys and 2375 feet of diamond drilling. Cominco acquired the property in 1960 and did detailed geological and geochemical surveys and diamond drilling. Their work indicated 4 zones of low-grade zinc mineralization in magnesian skarns.

In 1967, Patino Mining Corporation carried out diamond drilling on zone 3, and Boyd (1968) concluded that "the length of the zinc zone is approximately 270 metres from 0+30S to 8+50N with widths from 2 to 8 metres, average 4 metres. Some 132,000 tons of 8.9 per cent zinc, with a minimum horizontal width of 6 feet, and to a vertical depth of 280 feet, are estimated to be present in the above block."

Silvermaque Mining Corporation acquired the property in 1974 and conducted a systematic program of trenching, geological mapping,

Figure 3-1 Geology of North Mountain area, Inverness County

(In pocket at back of thesis)

Figure 3-1
GEOLOGY

NORTH MOUNTAIN

INVERNESS COUNTY, NOVA SCOTIA.

0 1 2

SCALE IN MILES

geochemical and geophysical survey and more than 7000 feet of diamond drilling in 35 holes. Brascan Resources, the present property holder, conducted a further drilling program and drilled an additional 22 holes and outlined 3 zones of mineralization designated as zone A, zone B and West zone (See Figures 3-2 and 3-3).

The average grade of the deposit, according to an initial estimate (based on the recent drilling data), is 5.5 per cent zinc, and tonnage is in excess of 2 million tons.

In 1977, the author recognized tungsten mineralization (as scheelite, hydrotungstite and sanmartinite) in the cores from the 1974 drilling.

Geological Setting

The general geological setting is very similar to that at Meat Cove. The wall rock is mainly dolomictic limestones and dolomite, or argillaceous and siliceous limestones with intercalations of quartz-feldspar-biotite schist.

The George River rocks occur as a roof pendant (or a number of roof pendants) in an acidic intrusive, and in consequence the grade metamorphism is extreme. The entire sequence has been cut by later aplite, diabase and lamprophyre dykes.

Zinc mineralization occurs as massive layers, as veins and as disseminations in the magnesian skarn derived from dolomitic limestone; tungsten mineralization is in calcareous skarns. A few stringers of calcite-sphalerite-chalcopyrite also occur in quartz-feldspar-biotite schist. The mineralization is accompanied by an alteration halo in which the serpentine and talc alteration is distinctive and pronounced. The color of serpentinized rock ranges from bright greenish-yellow to

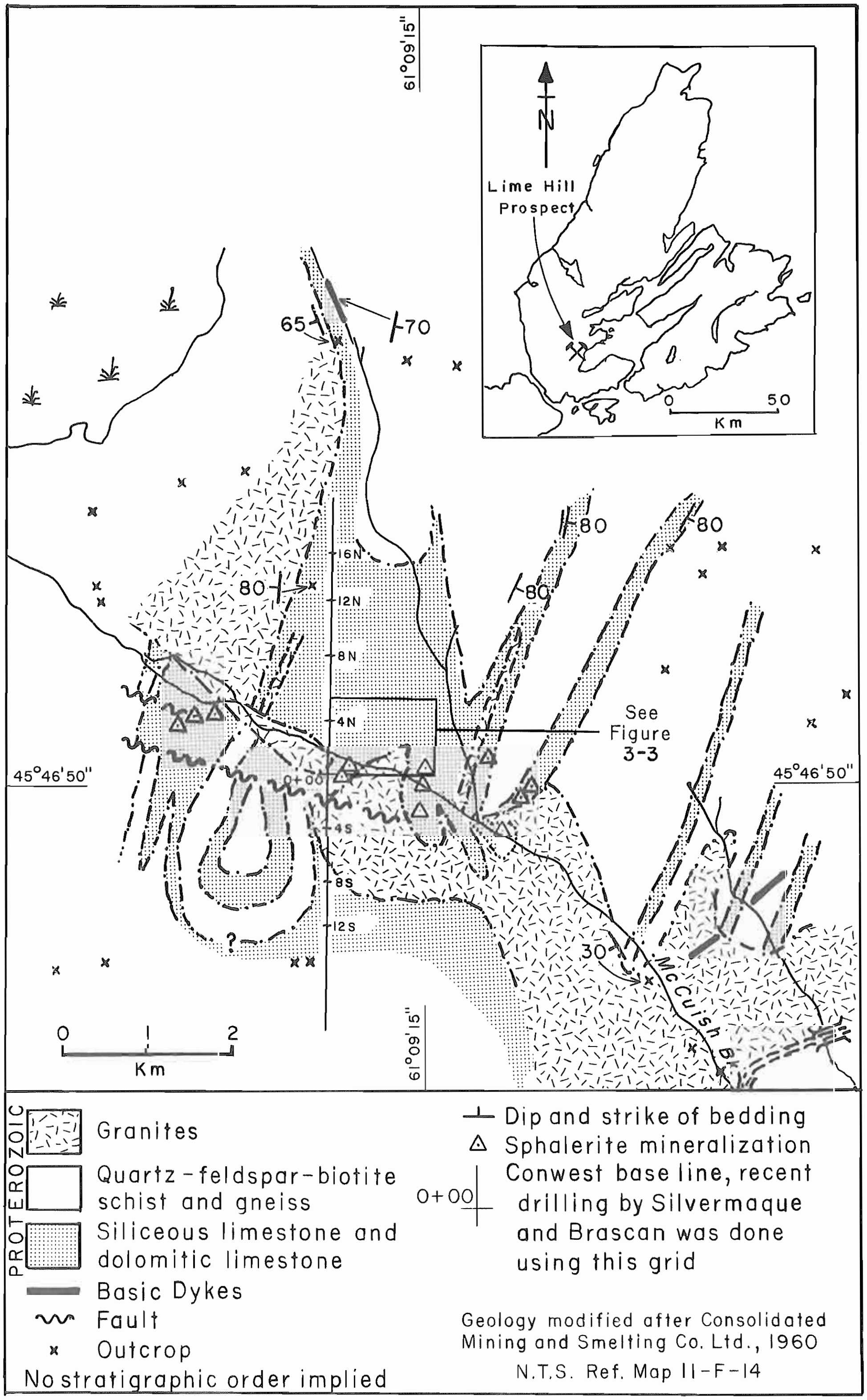


Figure 3-2. Surface Plan, Lime Hill Prospect

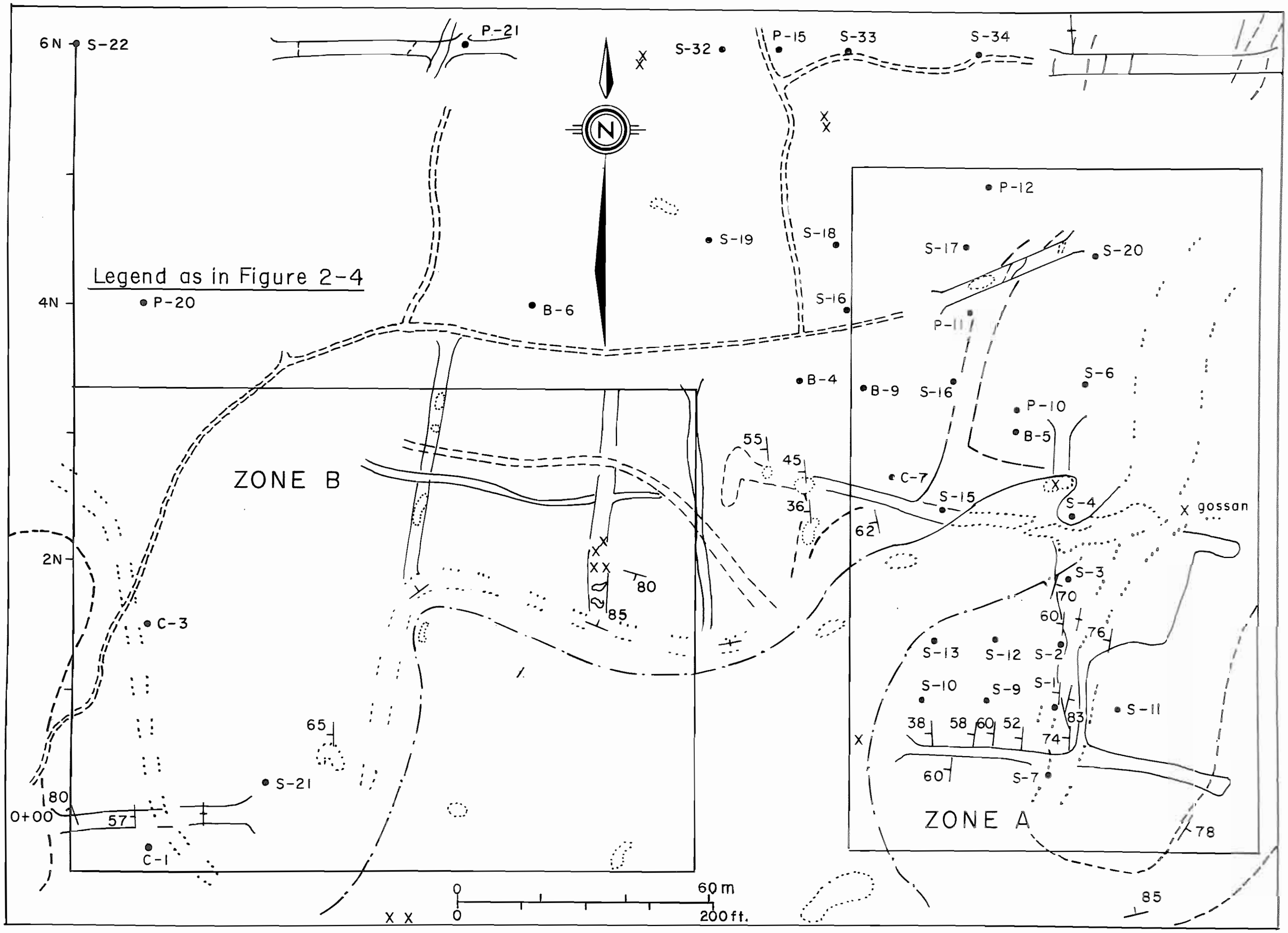


Figure 3-3. Geology and Drilling Plan at Lime Hill Zinc-Tungsten Deposit

dark greenish-black, and gives a very fine-grained, almost waxy, appearance in hand specimen.

Description of Sulphide Minerals

Sphalerite is the major sulphide mineral at Lime Hill. Pyrite, pyrrhotite and chalcopyrite are common accessories, and galena, bornite, covellite and tetrahedrite occur locally.

Pyrite:

At Lime Hill, pyrite is widely and erratically distributed in irregular forms throughout the crystalline dolomitic limestone. It is found in the main depositional stage of metallic minerals and with calcite in late fracture fillings. For these reasons, it is believed to have had a long time-range of formation, and may have been deposited throughout the entire period of mineralization. It is extensively replaced and veined by pyrrhotite and sphalerite. The replacement of skarn minerals by pyrite produced irregular, narrow veinlets in many samples.

Pyrrhotite:

Pyrrhotite is medium- to fine-grained and very little of it is euhedral. Most pyrrhotite contains varying amounts of country rocks and unreplaced remnants of pyrite. In a few polished sections, schistose pyrrhotite (Plate 3-1, Fig. A) produced by post-mineral, fault movement has also been observed.

Chalcopyrite:

Chalcopyrite occurs as disseminated blebs and seams, in places constituting up to 1 per cent of the vein material. It has replaced to some extent the dolomite on which it commonly grows. Chalcopyrite may invade along a cleavage crack of the dolomite, or may form irregular blebs in the dolomite, with a marked tendency to lie parallel to cleavage directions of the dolomite crystal. Such blebs may contain irregular islands of the replaced dolomite. The replacement boundary is generally minutely jagged.

In an unusual and minor occurrence noted in two polished sections, chalcopyrite occurs as minute inclusions in sphalerite. Such inclusions may be irregularly rounded, or they may have straight-line crystal boundaries on one or more sides. They are either irregularly and sparsely scattered, or arranged zonally in the sphalerite crystals. As the straight-line crystal boundaries usually face the surface of the sphalerite crystal, these inclusions, by and large, must represent small, euhedral crystals formed as surface overgrowths at a stage during the growth of the sphalerite crystal. Inclusions that lie in the zonal lines evidently record short pauses in the growth of the sphalerite crystal. There is no resemblance to the textures that have been ascribed to exsolution in the solid state, or to replacement (Bastin, 1950; Ramdohr, 1969).

Sphalerite:

Sphalerite is the most abundant of the sulphide minerals. Typically it is dark brown, massive and rather coarse-grained. No sphalerite is devoid of pyrrhotite inclusions. It is replaced by galena and tetrahedrite.

In a few polished sections pyrrhotite and sphalerite show "schistose" banding and "augen" structures (Plate 3-1, Fig. B). At first glance, it appears that the sulphides have replaced a shear zone, thus preserving the original character of the shear. However, clear evidence of rolling of corroded pyrite grains and the flow structure

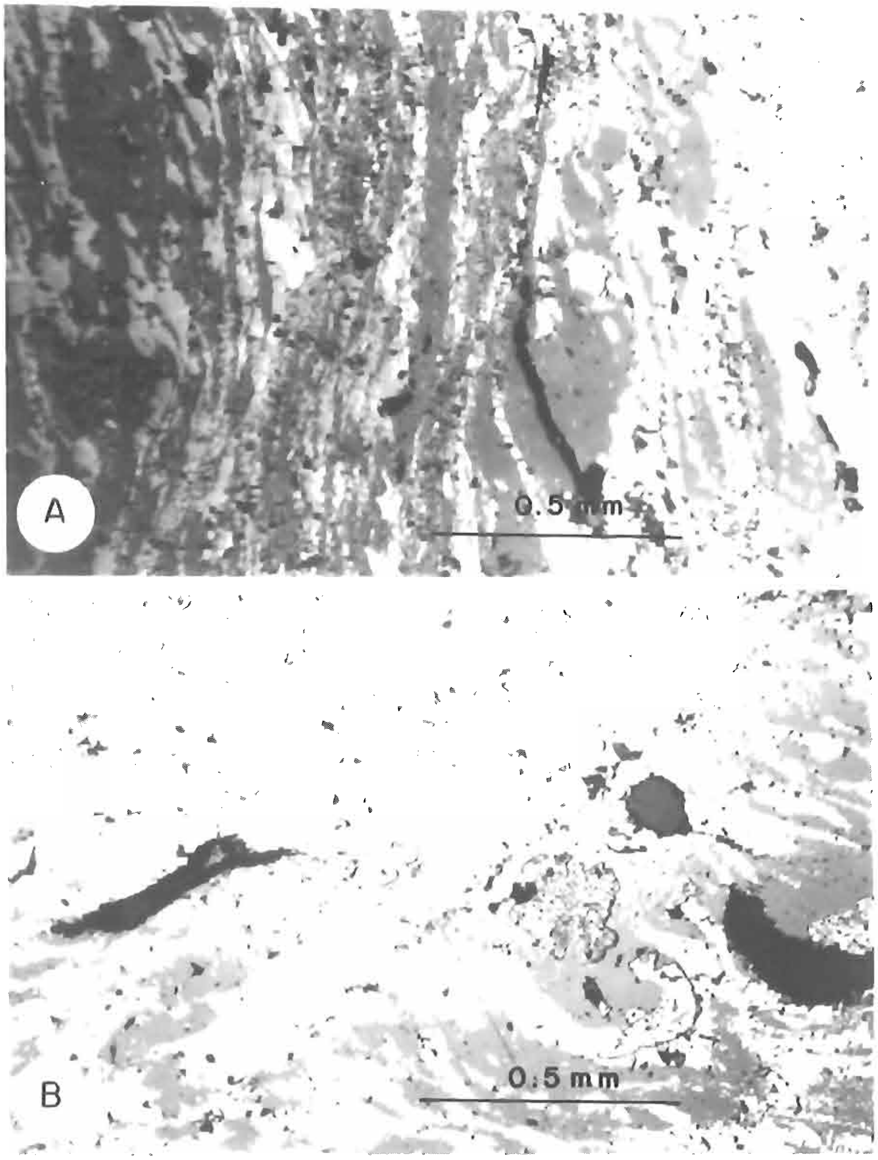


Plate 3-1

Figure A. Photomicrograph showing the deformation of pyrrhotite and sphalerite by post-mineral fault movement. Figure B. Schistose banding and augen structures in pyrrhotite and sphalerite. Corrded-grains of pyrite and flow structure around these grains are indicative of post-mineralization shearing.

developed around these grains is indicative of post-mineralization shearing. Also, staining of one polished section with potassium chromate and by hydrochloric acid shows extensive development of polysynthetic twinning in sphalerite, and Buerger (1928) has indicated that such twinning on (111) planes can be caused by applied pressure. The flow banding described above undoubtedly is of local extent, because sulphides five centimetres away from the shear show no sign of deformation.

Galena:

Galena is not abundant in the ore but some is always present in the specimens of sphalerite and pyrrhotite. Where it is in contact with sphalerite, the mutual boundaries are very irregular, and there may be rounded, elongated or wedge-shaped inclusions of the sphalerite within the galena along, and near, the contact.

Tetrahedrite:

Tetrahedrite is somewhat less abundant than galena. It is visible in some of the specimens as small streaks and irregular masses. Some of it was deposited on the surface of the sphalerite but much of it was deposited by replacement. Thin streaks of tetrahedrite generally cut across galena.

Bornite and Covellite:

Trace amounts of bornite and covellite are also seen in a few polished sections. These are always associated with chalcopyrite. Chalcopyrite is replaced by sphalerite, galena, bornite and covellite. The replacement of chalcopyrite by covellite is hypogene, as it is effected by embayments and veining and does not show the incipient development along cleavages that is so characterisitic of supergene replacement. The following sulphide mineral associations are identified from Lime Hill. Again each assemblage has been found within a single polished section and there is no implication that these are all equilibrium assemblages.

TABLE 3-1

Sulphide Mineral Assemblages at Lime Hill

Each assemblage has been found within a single polished section.

Pyrite-pyrrhotite-sphalerite
-pyrrhotite-sphalerite
Pyrite-pyrrhotite-sphalerite-galena-tetrahedrite

Pyrite-pyrrhotite-sphalerite-chalcopyrite
Pyrite-pyrrhotite-sphalerite-chalcopyrite-covellite
Pyrite-pyrrhotite-sphalerite-chalcopyrite -bornite

Pyrite-pyrrhotite-sphalerite-chalcopyrite-tetrahedrite
Pyrite-pyrrhotite-sphalerite-chalcopyrite-tetrahedrite-bornite

Tungsten Mineralization

The tungsten-bearing minerals from Lime Hill are scheelite ($CaWO_4$), hydrotungstite ($H_2WO_4.H_2O$) and sanmartinite ($ZnWO_4$).

Scheelite occurs as grains disseminated in massive sphalerite (Plate 3-2A and B), as massive granular aggregates with diopside, wollastonite and lizardite (Plate 3-2C and D), as nodular replacement patches with molybdian (Plate 3-3A and B), and as thin (<1 cm) layers following the original compositional layers of the calcareous rocks (Plate 3-3C and D). Scheelite was identified in transmitted light, by X-ray diffraction and microprobe analyses.

Hydrotungstite occurs as yellowish white, dull, earthy, granular coatings on scheelite and calcite. The grains of hydrotungstite range in size from 5 to 25 microns. It also occurs as radiating needles (≃1/2 cm in long dimension) forming rosettes in fractures and cavities. The core of the rosettes is, in every case, made of calcite (Chatterjee, 1978).

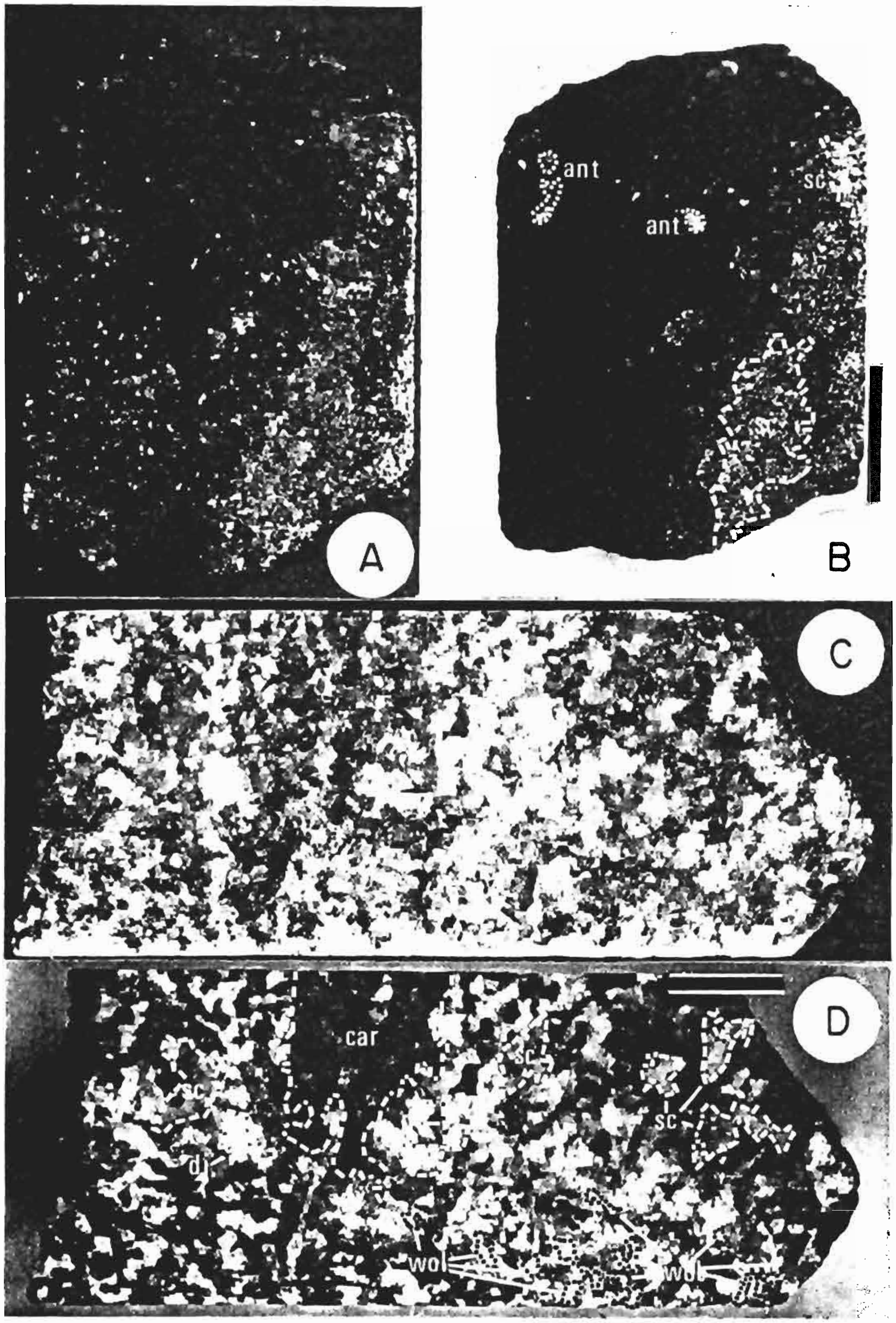


Plate 3-2

Photographs showing the mode of occurrence of scheelite at Lime Hill. Bar represents 1 cm. A, Disseminated scheelite with massive sphalerite. B, Photograph of the same specimen in short-wave ultraviolet light. Both the 6(2)-layer orthosilicate and scheelite are fluorescent (DDHS9-169'). C, Massive granular aggregate of scheelite in diopside-wollastonite skarn. D, Photograph of the same specimen in short-wave ultraviolet light. Note the slight differences in fluorescence colour between scheelite, diopside and wollastonite (Sample No. DDHS9-143'6"). car, carbonate; sc, scheelite; sp, sphalerite; ant, antigorite; di, diopside; wol, wollastonite

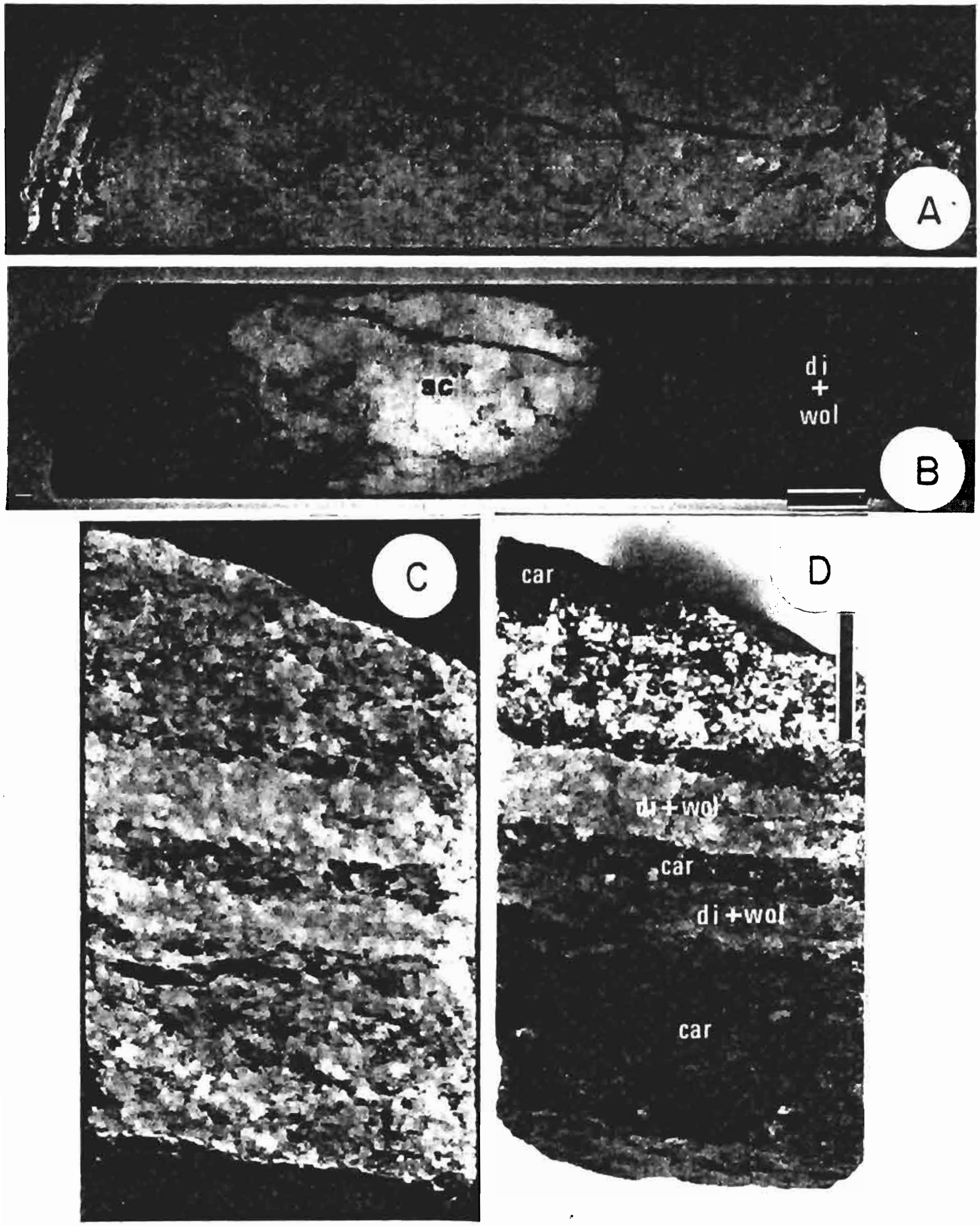


Plate 3-3

Photographs showing the mode of occurrence of scheelite at Lime Hill. Bar represents 1 cm. A, Scheelite and molybdian as nodular replacement patches in diopside-wollastonite skarn (Sample No. DDHS13-250'). B, Photograph of the same sample in short-wave ultraviolet light. C, Scheelite as thin layers following the compositional layers of wollastonite skarn (Sample No. DDHS4-82'). D, Photograph of the same sample in short-wave ultraviolet light. car, carbonate; sc, scheelite; di, diopside; wol, wollastonite.

Radiating crystals of hydrotungstite forming rosettes on rhombohedral calcite crystals were observed on fractures and they resemble the scalenohedron variety of calcite. However, when tested with dilute HCl, the crystals of hydrotungstite turned dark, yellowish brown and showed no other reaction with the acid. A semiquantitive spectrographic analysis by H. Champ of the Geological Survey of Canada showed the principal metal to be tungsten (G.S.C. Lab. Report No. R48-77, Lab. Records 9054, 9055a). Subsequently, X-ray powder data were obtained (see Table 3-2). Visually, the X-ray powder film compares well with photographs of films of hydrotungstite published by Kenn and Young (1944) and the d-spacings listed by Mitchell (1963).

Sanmartinite was identified by X-ray diffraction analysis in one sample of massive sphalerite DDHS1-165'. It is probably of rare occurrence. This mineral is easily mistaken for light-coloured sphalerite.

Associated Sulphide and Skarn Minerals

The zinc deposit at Lime Hill is a body of base-metal sulphides, consisting of metallic sulphides associated with the calc-silicate minerals typical of contact metamorphic aureoles. The sulphides replace the minerals of the containing rock.

The silicate minerals found in association with the sulphides include chondrodite, diopside, forsterite, merwinite, monticellite and tremolite of the magnesian skarn series; also spinel, scapolite, diopside, phlogopite, plagioclase, epidote and tremolite of the argillaceous skarn series. Slight differences can be recognized in the overall sulphide mineralogy of the magnesian and argillaceous skarns. The most important difference between the two, however, is the relative abundance of

TABLE 3-2

Powder X-ray Data for Hydrotungstite and Calcite from Lime Hill Zinc Prospect

Camera Diameter 114.6 mm, CuK$_1$ radiation
NSDM Sample Number S-12.72*
NSDM Film Number 8927: Good contrast on low angle side. No high angles.

			Hydrotungstite ASTM 16-166		Calcite ASTM 5-0586	
θ	d	I/Io	d	I	d	I
23.8	3.74	m				
26.1	3.42	s	3.46	60		
27.2	3.276	m	3.27	80		
29.5	3.03	vs	3.02	10	3.035	100
33.0	2.715	m	2.63	50		
36.1	2.488	m	2.46	50	2.495	14
37.5	2.398	m				
28.6	2.332	m	2.31	50		
39.5	2.281	w			2.285	18
41.0	2.202	w				
43.0	2.104	m	2.09	50	2.095	18
45.8	1.981	s	1.96	60		
∿		vw				
48.5	1.877	m	1.88	10	1.875	17
50.1	1.820	w	1.85	10		
			1.81	20		
52.5	1.743	s	1.73	50		

Note; Because some strong and medium reflections are only accounted for by the tungsten mineral, one could conclude that it is present in higher proportion than the calcite. However, the atomic scattering factor of tungsten is essentially higher than that of calcium, hence, no comparison can be made without quantitative intensity measurements and calculations.

θ = the measured value of the glancing angle
d = the interplanar spacing between regularly spaced identical planes measured in Angstrom units
I - intensity
I/Io - visual estimate of intensities
vs = very strong; s = strong; m = medium;
w = weak; vw = very weak

* Silvermaque diamond-drill hole #12 (1+02N, 7+24E) depth 72'.

sulphide minerals: a higher concentration of sphalerite occurs in the magnesian skarn.

Mineral Composition of the Skarns

The rocks from Lime Hill show a wide range of composition; hence, wide variations in the skarn-mineral assemblages have also been noted. This variation in lithological types is present on a large scale or may also be present in layers so thin that most may be encountered in a single thin section (Figure 3-4). The mineral associations observed in siliceous dolomitic limestone are listed in Table 3-3. Again, each assemblage has been found within a single thin section and there is no implication that these are equilibrium assemblages.

Host Rock Alteration

As mentioned, dolomitic limestone is the most important host for sulphides, which occur as massive bands and as heavy disseminations. In hand specimens, antigorite and talc are closely associated with the sulphides as a waxy yellow to green alteration. Textural relations show that chondrodite, forsterite, diopside and tremolite alter to antigorite and talc. The relation between the mineralized vein and the adjacent wall rock has been illustrated in Figure 3-5. It may be seen that intense talc and antigorite alteration is present near the vein; away from it forsterite grains show advanced alteration to antigorite, and in most cases pseudomorphs of antigorite after forsterite are preserved. Approximately ten metres away from the vein, monticellite grains show feeble alteration to antigorite along fractures.

In argillaceous bands, cordierite, diopside, tremolite and antigorite, when associated with the sulphides, show alteration to talc.

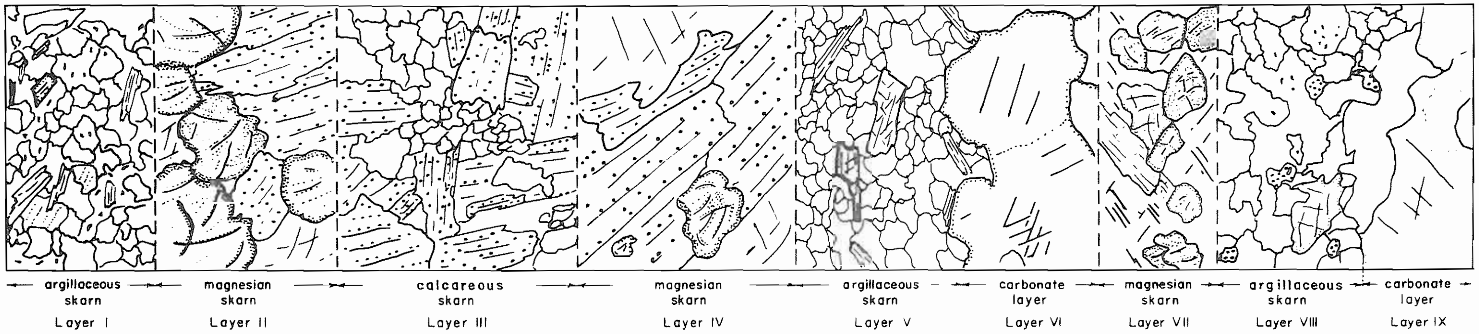


FIGURE 3-4

VARIATION IN LITHOLOGY IN A SINGLE THIN SECTION

Mineral Association In Various Composition Layers

5 ...% as visual estimate
** ...major
* ...minor
Tr ...trace
— ...not present

Minerals —	LAYER I Argillaceous Skarn	LAYER II Magnesian Skarn	LAYER III Calcareous Skarn	LAYER IV Magnesian Skarn	LAYER V Argillaceous Skarn	LAYER VI Carbonate Layer	LAYER VII Magnesian Skarn	LAYER VIII Argillaceous Skarn	LAYER IX Carbonate Layer
Calcite /dolomite	—	Tr	—	*	—	≐ 100	60	—	100
Quartz	70	—	*	—	**	—	—	**	—
K-feldspar	< 5	—	—	—	—	—	—	—	—
Muscovite	< 5	—	—	—	*	—	—	*	—
Biotite	< 5	—	—	—	—	—	—	—	—
Zoisite	< 2	Tr	—	—	*	—	—	**	—
Amphibole (tre)	< 5	—	—	—	*	—	—	—	—
Plagioclase	< 2	Tr	—	—	Tr	—	—	Tr	—
Forsterite	—	40	—	Tr	—	Tr	30	—	—
Diopside	—	40	**	**	—	—	—	—	—
Chondrodite	—	Tr	—	—	—	—	< 5	—	—
Merwinite	—	Tr	—	—	—	—	—	—	Tr
Monticellite	—	—	—	—	—	—	Tr	—	—
Wollastonite	—	—	*	—	< 5	—	—	< 5	—
Idocrase	< 2	—	Tr	—	—	—	—	—	—
Phlogopite	—	—	—	—	Tr	—	—	—	—
Opaque	< 1	—	—	—	—	—	—	—	—

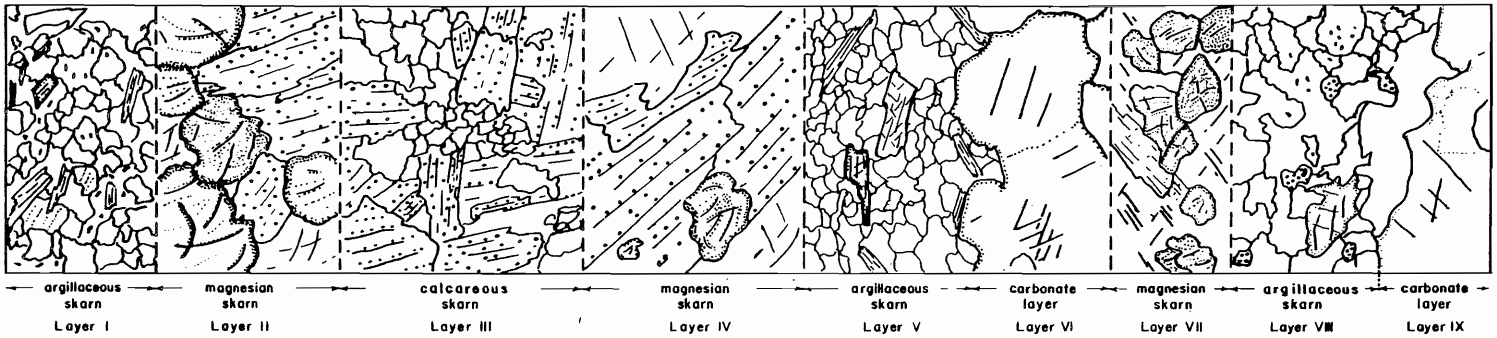


FIGURE 3-4

VARIATION IN LITHOLOGY IN A SINGLE THIN SECTION

Mineral Association In Various Composition Layers

5 ...% as visual estimate
** ...major
* ...minor
Tr ...trace
– ...not present

Minerals –	LAYER I Argillaceous Skarn	LAYER II Magnesian Skarn	LAYER III Calcareous Skarn	LAYER IV Magnesian Skarn	LAYER V Argillaceous Skarn	LAYER VI Carbonate Layer	LAYER VII Magnesian Skarn	LAYER VIII Argillaceous Skarn	LAYER IX Carbonate Layer
Calcite /dolomite	–	Tr	–	*	–	≃ 100	60	–	100
Quartz	70	–	*	–	**	–	–	**	–
K-feldspar	‹ 5	–	–	–	–	–	–	–	–
Muscovite	‹ 5	–	–	–	*	–	–	*	–
Biotite	‹ 5	–	–	–	–	–	–	–	–
Zoisite	‹ 2	Tr	–	–	*	–	–	**	–
Amphibole (tre)	‹ 5	–	–	–	*	–	–	–	–
Plagioclase	‹ 2	Tr	–	–	Tr	–	–	Tr	–
Forsterite	–	40	–	Tr	–	Tr	30	–	–
Diopside	–	40	**	**	–	–	–	–	–
Chondrodite	–	Tr	–	–	–	–	‹ 5	–	–
Merwinite	–	Tr	–	–	–	–	–	–	Tr
Monticellite	–	–	–	–	–	–	Tr	–	–
Wollastonite	–	–	*	–	‹ 5	–	–	‹5	–
Idocrase	‹2	–	Tr	–	–	–	–	–	–
Phlogopite	–	–	–	–	Tr	–	–	–	–
Opaque	‹1	–	–	–	–	–	–	–	–

TABLE 3-3

Magnesian Skarns: Mineral Association at Lime Hill

(Individual assemblages here listed have each been seen within the limits of a single thin section. There is no implication that these are equilibrium assemblages.)

Dolomite-talc
Dolomite-talc-antigorite
Dolomite-talc-antigorite-diopside
Dolomite-talc-antigorite   -tremolite
Dolomite   -antigorite-diopside-tremolite
Dolomite-talc-antigorite   -tremolite-forsterite
Dolomite   -antigorite   -tremolite-forsterite
Dolomite   -diopside-tremolite

Dolomite-talc-quartz
Dolomite-talc-quartz-antigorite
Dolomite-talc-quartz-antigorite-tremolite
Dolomite   -quartz   -tremolite-diopside
Dolomite-talc-quartz-antigorite   -diopside

Dolomite-forsterite-monticellite-chondrodite
Dolomite-forsterite-monticellite
Dolomite   -chondrodite-diopside
Dolomite-forsterite-monticellite   -diopside

Dolomite-monticellite-chondrodite-merwinite-spinel
Dolomite   -chondrodite-merwinite-spinel
Dolomite-monticellite-chondrodite   -spinel-forsterite

Dolomite-antigorite-diopside
Dolomite-antigorite-diopside-talc-chondrodite
Dolomite   -diopside-talc

Dolomite-tremolite-diopside-monticellite-chondrodite
Dolomite-tremolite   -monticellite-chondrodite

Dolomite-forsterite-monticellite-talc
Dolomite-forsterite-monticellite-talc-antigorite

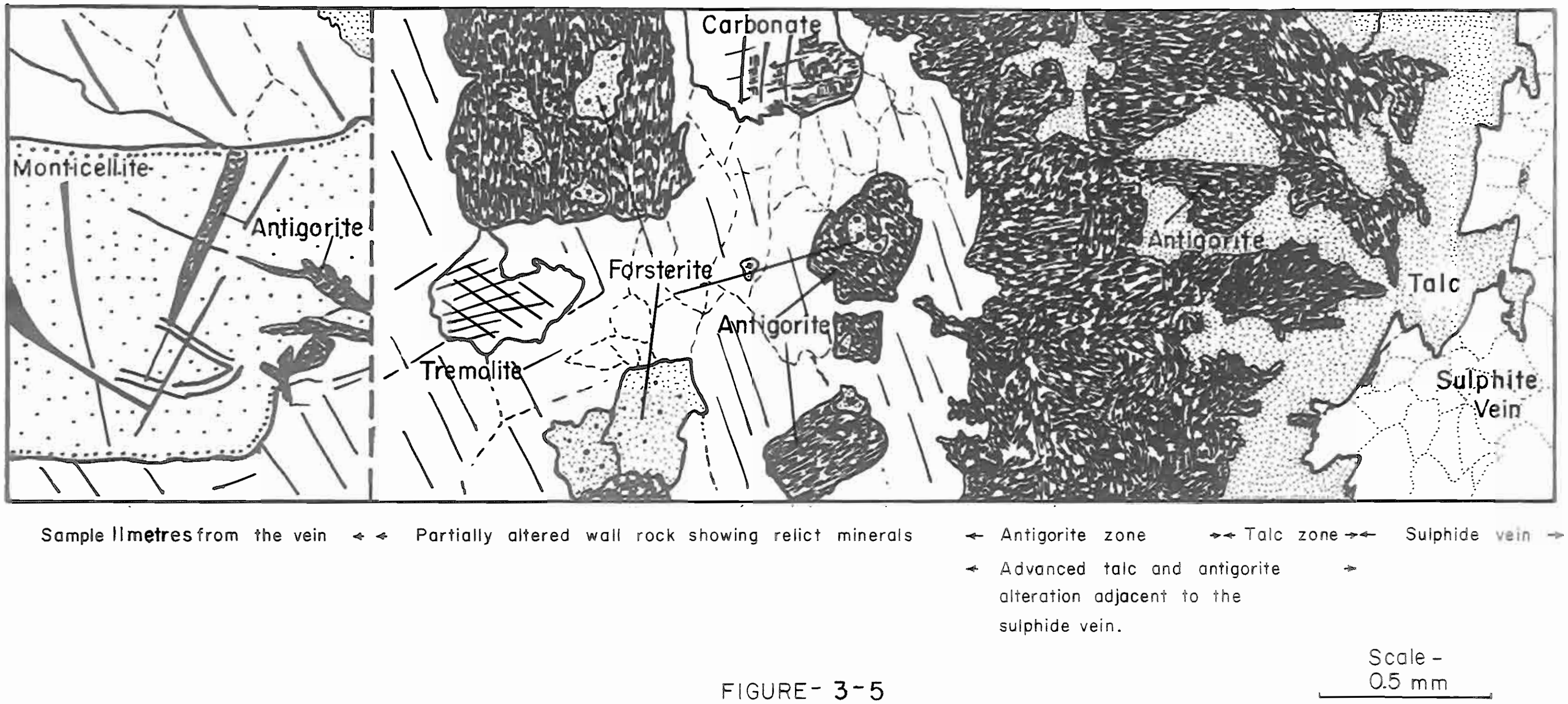


FIGURE- 3-5

Diagram showing the mineralized vein-wall rock relationship at Lime Hill. Near-vein alteration is characterized by intense talc and antigorite. Away from the vein, forsterite and dolomite grains show advanced alteration to antigorite. Approximately **11 metres** from the vein, monticellite grains show feeble alteration to antigorite along fractures.

The calcic plagioclase (Ab 40) grains alter to a mixture of epidote and "sericite".

The quartz-feldspar-biotite schist interclations contain garnet, potassium feldspar and a calcic plagioclase (An 40), and show alterations of garnet to biotite and chlorite, K-feldspars to sericite, and calcic plagioclase to epidote, calcite and sericite.

The sulphide minerals are predominantly sphalerite, pyrite and pyrrhotite with lesser amounts of chalcopyrite, galena, tetrahedrite, covellite and bornite. The sulphides vein and replace the associated silicates and, because everywhere accompanied by a halo of retrograde alteration, must have accompanied the conversion of the earlier-formed high-grade mineral assemblages to antigorite and talc. The assemblage that was formed and partially replaced by sulphide minerals was calcite-dolomite-antigorite-talc.

CHAPTER 4

WHYCOCOMAGH TUNGSTEN-MOLYBDENUM-COPPER DEPOSIT

Introduction

The Whycocomagh deposit is located on Whycocomagh Mountain, about 1.5 km northeast of the village of Whycocomagh, Inverness County, at 45° 59'N latitude and 61° 00' 30" W longitude. The Trans-Canada Highway passes through the village, and from there the deposit can be reached on foot, via Whycocomagh Mountain road.

Previous Work

The occurrence of copper on Whycocomagh Mountain has been known for at least 100 years. Numerous pits, trenches and an old shaft testify that attempts were made to locate a commercial grade of copper. No records of these early workings are known to the author, although Fletcher (1884) noted that "a specimen of iron ore from this locality...was found to contain about 50 per cent magnetite and traces of copper pyrites and green carbonates."

In 1960, Kerr-Addison Gold Mines, Ltd., acquired the property and carried out a program consisting of geological, geophysical and geochemical surveys and 2300 feet of diamond drilling. Their finds indicated that "copper mineralization, associated with a magnetic anomaly is limited in extent and occurs in irregular pods and/or lenses" (Grant, 1960).

In 1977, the author re-examined the deposit and found that significant grades of tungsten and molybdenum are associated with copper mineralization in hand-size samples. The initial results on the discovery were announced in December 1977 by the Nova Scotia Department of Mines and have been described by Chatterjee (1978b). Because of the economic importance of W-Mo-Cu mineralization and the implication that the widespread George River rocks of Cape Breton Island may be an important host for such types of deposits, I have re-examined all the information that is presently available from this deposit, and it is hoped that the data presented below will facilitate future exploration and further understanding of its genesis.

The following description is based on a study of more than 350 samples of diamond drill core and also samples collected from the outcrop and dump.

Geological Setting

The general geology in the vicinity is insufficiently known. According to Kelly (1959) the George River rocks, consisting of quartzites, limestone, paragneiss, chlorite schist, quartz-sericite schist with minor volcanic types, occur as a small inlier on Whycocomagh Mountain (G.S.C. Map 17, 1959). Intrusive into these rocks are granite, syenite and granodiorite. In the immediate area the following lithological units are encountered: (1) hornblende gneiss, (2) garnetiferous quartz-feldspar schist, (3) amphibolite, (4) garnetiferous quartzites and (5) altered, dolomitic limestone. These have been intruded by porphyrites and diabase (seen only in diamond drill cores) and by granite. The general strike of the lithological units is NNE and the dip is to the southeast (Figure 4-1). The W-Mo-Cu mineralization, accompanied by magnetite, is restricted to the altered siliceous dolomitic limestone. I have examined the mineralization in 11 drill holes* (Kerr-Addison drill holes 1,2,3,4,5,6,7 and 4 drilled by Amax Canada Ltd. in 1978) and in every case, the mineralization is accompanied by an alteration

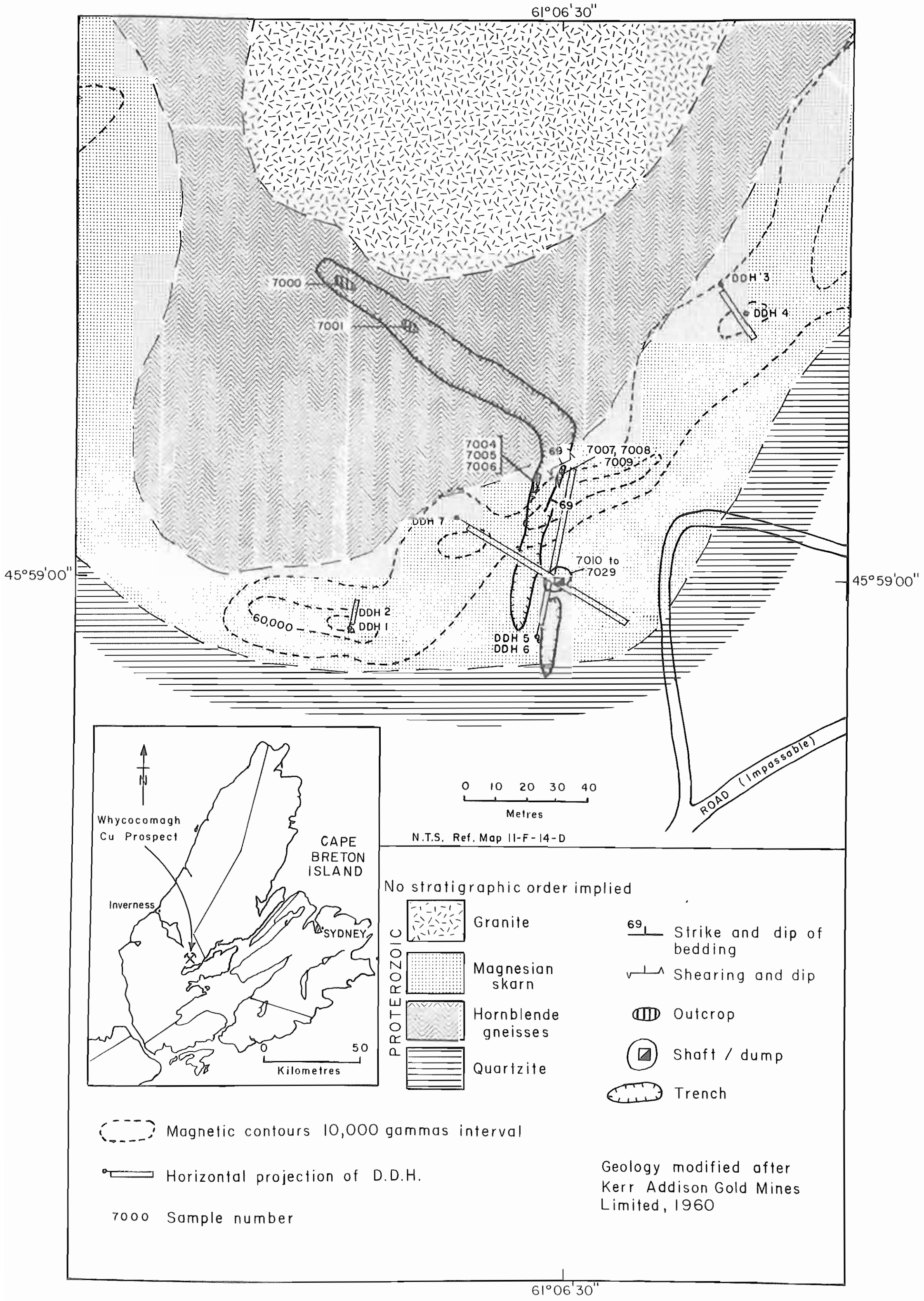


Figure 4-1 Surface plan, Whycocomagh copper prospect

halo characterized by talc and antigorite [6(2)-layer orthosilicate].

Description of Lithological Units

Hornblende gneiss: Small amounts of hornblende gneiss are seen in the trench and the in diamond drill core. The rock is massive and shows irregular flow banding expressed by mafic streaks and lenticles, and by planar distribution of feldspar. The hornblende gneiss is porphyroblastic with scattered, ovoid, potash-feldspar porphyroblasts (up to 50 mm) and 50 to 75 mm patches rich in garnet. A few samples from the drill core show poikilitic porphyroblasts of sillimanite. In the drill core a gradation from finely banded gneiss to coarse-grained, porphyroblastic gneiss was observed (Amax drill hole). In thin section the fine-grained gneiss contains a granoblastic aggregate of quartz, potassium feldspar and plagioclase feldspar (Ab75). Hornblende and biotite occur in layers. Accessory amounts of garnet, sillimanite, sphene, zircon, epidote and apatite are generally present. Mineralogically the coarse-grained gneisses are similar, except that the texture is predominantly porphyroblastic. As seen in the drill core the gneisses grade into garnetiferous quartz-feldspar-biotite schist through amphibole-bearing psammite (amphibolite).

Amphibolite (amphibole-bearing psammite): This rock type is seen in only one drill hole as a 2 metre thick band of hornblende-rich rock. Mineralogically it is characterized by quartz, garnet, plagioclase feldspar and hornblende with accessory amounts of biotite epidote, sphene and magnetite. Traces of pyrite and pyrrhotite are also seen.

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* The location of the holes drilled by Amax is not shown on the map (confidential information). The study by Amax of the alteration halo and its application to regional exploration has been shared with the author freely. However, the information presented in this thesis does not represent their conclusions or their viewpoint.

Garnetiferous quartz-feldspar-biotite schist: Again, this rock type has only been encountered in drill holes as a transitional unit from the gneiss. It is characterized by a distinct mineralogy (relatively high proportions of biotite and muscovite). It is also found interbanded with the siliceous dolomitic limestone. Biotite porphyroblasts are typically 0.5 to 1 mm in diameter, constitute as much as 20 per cent of the rock, and are either uniformly strewn but oriented parallel to the foliation or are segregated into folia or planar clusters. Quartz and subordinate plagioclase feldspar dominate the groundmass mosaics and have an average grain size in the range 0.02 to 0.3 mm. Other sparse groundmass minerals are garnet, muscovite, chlorite, rare hornblende, epidote, sphene and calcite.

Garnetiferous quartzites: There are only a few outcrops of quartzites in the immediate area of the deposit. The two "outcrops" southwest of the shaft are of fine-grained, saccharoidal-textured, garnetiferous quartzites. It is uncertain whether these are outcrop or large glacial boulders. In the present work this unit has not been studied in any detail.

Siliceous dolomitic limestone: Most of the recent diamond drilling is concentrated on this limestone as being the chief host rock for the mineralization; hence it is described here in more detail than the other types. For descriptive purposes, it can be divided into four sub-units, based on the relative proportion of talc, antigorite, diopside, forsterite, tremolite and garnet. The first sub-unit is characterized by andradite-diopside-forsterite, and from it are derived three others with characteristic mineral assemblages: (1) talc-antigorite, (2) antigorite-tremolite and (3) tremolite-actinolite. As will be shown later, the recognition and the zonal arrangments of these sub-units with respect to the mineralization are highly diagnostic.

Andradite-diopside-forsterite sub-unit: The rocks of this sub-unit are usually granoblastic, and are made up predominantly of diopside, andradite and forsterite. Where measured directly in drill holes, this sub-unit is 5 to 16 metres thick. Diopside occurs as fine (0.01 mm) or medium (2-4 mm) or large (>2 cm) crystals in a tightly intergrown unit. This sub-unit could be further sub-divided into two types: (1) andradite-forsterite and (2) diopside-forsterite rocks, largely on the basis of the presence or absence of diopside. Minor accessory minerals most commonly are chondrodite, monticellite, sphene, dolomite and quartz. In thin section stringers of calcite are also seen.

*Tremolite-actinolite*sub-unit:* Generally this sub-unit is recognized by its softness, fibrous texture and dull grey-green colour. The rocks in this sub-unit are composed of tremolite-actinolite (up to 60 per cent by volume), calcite (10 to 15 per cent) and diopside (20 per cent); minor accessory minerals include garnet, sphene, pyrite, pyrrhotite, scheelite, chalcopyrite and magnetite.

Tremolite-antigorite sub-unit: The rocks of this sub-unit are distinctly bright green, generally with high amounts of calcite and dolomite. Actinolite has not been observed in this sub-unit. Generally, tremolite and antigorite constitute up to 50 per cent of the rock. In one drill hole (DDH7-183 feet) this unit contains abundant fluorapatite and a mica whose d-spacings are remarkably similar to those for fluorphlogopite, published by Borg and Smith (1969). Calcite, dolomite and manganoan dolomite form up to 30 per cent by volume. In addition, some epidote, magnetite, pyrite, chalcopyrite, scheelite and molybdenite are widely dispersed in this sub-unit.

*Both types of amphibole occur in the sub-unit. Limited study of these amphiboles with the electron microprobe reveals that some contain 10–11 molecular % of ferrotremolite - ($Ca_2Fe_2Si_8O_{22}(OH,F_2)$) end member - (tremolite) (Deer *et al.*, 1962) whereas others contain 41-45 molecular per cent ferrotremolite thus fall in actinolite - composition.

Talc-antigorite sub-unit: This sub-unit is in every case encountered near the mineralized zone, is generally soft and is grey-green with abundant silvery mica. Talc and antigorite together may constitute up to 70 per cent of the rock. Locally, mineralized veins cut this sub-unit. Minor accessory minerals are calcite, dolomite, tremolite, chlorite, magnetite, chalcopyrite, scheetite and molybdenite.

Porphyry: A porphyry dyke, approximately 5 metres thick, intrudes the siliceous dolomitic limestone and was intersected in DDH1 and 2 at a depth of 8 metres and 11 metres respectively. It is greyish-green and contains light-coloured euhedra of alkali feldspar. In thin section the porphyry consists of prominent phenocrysts of feldspars and quartz which form about half the rock. Potash feldspar (15 per cent) grains are euhedral and range in size from 2 to 10 mm. They are microperthitic microcline and are commonly corroded and embayed by the siliceous matrix. They usually contain small subhedral inclusions of plagioclase. Plagioclase (15 per cent) phenocrysts, 2 to 4 mm, are subhedral and commonly glomero-porphyritic. They show reversed as well as normal zoning; average composition is Ab58. Quartz (15 per cent) phenocrysts are augen-like and show granulated margins. Biotite (4-5 per cent) occurs as large, rounded or lenticular grains which are shredded near the margin. The matrix (50 per cent) is a granular aggregate of quartz, plagioclase, sericite, hornblende and biotite. The grain size is approximately 0.2 cm.

The chilled marginal phase contains potash feldspar, plagioclase and quartz phenocrysts, most of which are slightly smaller than those away from the contact. Biotite phenocrysts are rare. The plagioclase grains are noticeably glomero-porphyritic. The matrix contains biotite, quartz, plagioclase, decussate patches of pale-green hornblende and abundant epidote. The rocks are porphyritic microadamellites though the groundmass of each is granodiorite. Interesting amounts of molybdenite are seen in the porphyry as disseminated grains and as thin stringers filling fractures.

Granite: A tongue of granite intrudes from the north and is a typical coarse-grained, porphyritic leucocratic biotite granite characterized by large feldspar phenocrysts, 10 to 30 mm across, set in a coarse- to medium-grained groundmass of quartz and feldspar with minor biotite.

Microcline phenocrysts (40 per cent) are microperthitic and in the matrix form small anhedral grains. Plagioclase (15 per cent) is oligoclase which forms distorted grains. Locally, medium-grained quartz (35 per cent) forms bands of interleaving mosaics, roughly parallel to biotite flakes. Biotite is partly altered to chlorite and commonly associated with minor muscovite. Plechroic haloes surround included zircon. Accessories include zircon, epidote, apatite and sphene. The groundmass is a mosaic of quartz, microcline and plagioclase of variable grain size.

Mineralogy: Descriptive Features

Magnetite is the major ore mineral in the Whycocomagh W-Mo-Cu prospect. The most common primary mineral assemblages are magnetite-pyrite-chalcopyrite-scheelite, magnetite-chalcopyrite-pyrrhotite-scheelite-pyrite, magnetite-pyrite-pyrrhotite-chalcopyrite-pyrrhotite-molybdenite-scheelite, magnetite-pyrite-chalcopyrite-pyrrhotite, magnetite-pyrite-chalcocite and magnetite alone. In general, the assemblages containing magnetite-pyrite-chalcopyrite-scheelite, pyrite-pyrrhotite-magnetite and magnetite alone are most widespread.

Magnetite:

Magnetite is characteristically fine to medium grained (1.0 to 5.0 mm) and poikiloblastic, and forms euhedral to anhedral, equant crystals. The crystals occur individually or, more typically, in a granoblastic mosaic. Magnetite grain boundaries are sharp in most places. One polished section showed euhedral crystals with serrated borders. Where magnetite is in contact with sulphides, the grain boundaries are so straight as to indicate that they are crystal faces. In general, magnetite masses show little or no structure and are irregularly distributed, and inclusions are almost exclusively gangue minerals.

Pyrite:

Pyrite is euhedral to subhedral and, in general, finer grained than magnetite, averaging 0.1 to 1.0 mm. In most places it contains inclusions of euhedral magnetite but is free of gangue. In places, it has replaced magnetite but not extensively. Pyrite typically is associated with, and replaces, carbonate minerals.

Chalcopyrite:

Chalcopyrite occurs as irregularly shaped stringers growing around and between the other sulphide minerals. It also occurs as blebs in pyrrhotite and as fracture filling in pyrite. Replacement of pyrite by chalcopyrite, in places, is controlled by fractures. Chalcopyrite also typically forms a partial rim on, and in some places replaces, pyrrhotite. Locally, chalcopyrite has inclusions of euhedral magnetite.

Bornite:

Bornite occurs chiefly as fracture fillings associated with chalcopyrite, but also is present in anhedral grains, some with blebs of chalcopyrite.

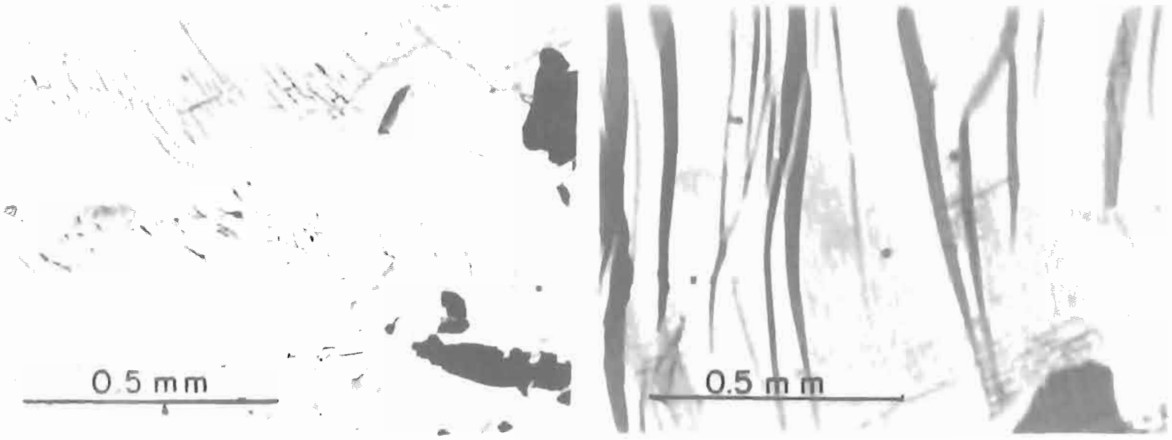
Chalcocite:

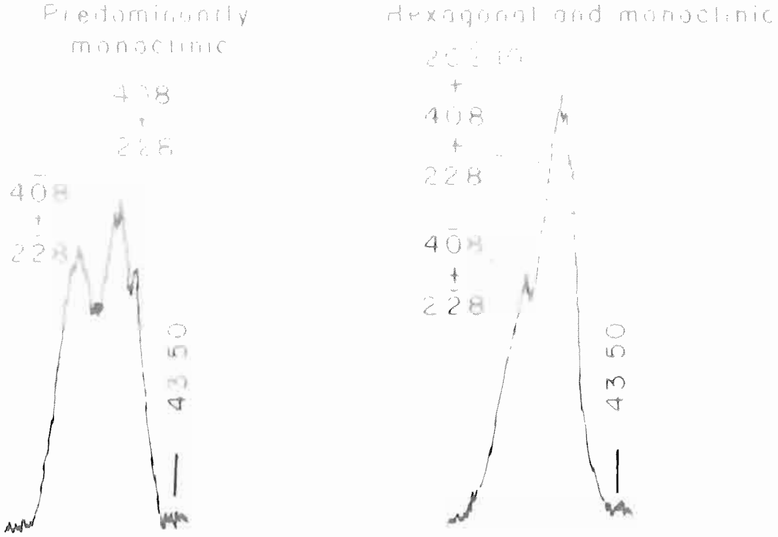
Chalcocite occurs as individual anhedral grains and as rims on some pyrrhotite grains that are associated with chalcopyrite. It also occurs as fracture filling in bornite.

Pyrrhotite:

Pyrrhotite is common at Whycocomagh copper prospect. Under the microscope, the pyrrhotite at Whycocomagh may be texturally classified as monoclinic-hexagonal intergrowths. The monoclinic and hexagonal pyrrhotite was distinguished by a combination of X-ray (Arnold, 1966), ammonium dichromate and hydriodic acid-etch methods (Cowan, 1968).

Under the microscope, the most common of the hexagonal-monoclinic intergrowths appear to be lamellar "flames" of the monoclinic phase in hexagonal pyrrhotite (Figure 4-2). The compositions of 6-hexagonal pyrrhotite and 4-hexagonal monoclinic pyrrhotites were estimated by the d "102" X-ray determinative technique of Arnold and Reichen (1962). However, as Carpenter and Desborough (1964) have noted, a typical monoclinic "202-$20\bar{2}$" reflection is made up of four peaks - 408, $\bar{4}08$, 228, and $\bar{2}28$ - and a "102" natural hexagonal reflection probably is more properly indexed as $20\bar{2}.10$. Although low 2θ superlattice reflections were not determined by powder camera studies, the natural hexagonal pyrrhotites at Whycocomagh probably belong to 2A, 5C hexagonal type of Carpenter and Desborough (1964). All measurements were made on a Phillips diffractometer, with Ni-filtered, CuKα radiation, and the mounts were scanned at 1/8° per minute 2θ scan speed. The compositions were then calculated using an equation derived by Yund and Hall (1969). The average composition of 6-hexagonal pyrrhotites is 47.32 atom per cent Fe, and the average of 4-hexagonal monoclinic pyrrhotite mixtures is about 46.90 atomic per cent Fe.





Diffractometer traces of selected monoclinic and hexagonal pyrrhotite peaks. Copper Kα radiation, 1/8° 2θ/minute scan rate.

X-ray diffration data and composition of six hexagonal pyrrhotites.

	1	2	3	4	5	6
dÅ 20̄2.10	2.0662	2.0659	2.0665	2.0655	2.0658	2.0665
Atom percent Fe	47.33	47.31	47.36	47.27	47.30	47.36

Figure 4-2
X-ray Diffraction Data and Composition of Pyrrhotites

Molybdenite:

Molybdenite generally occurs as a fine (0.1 to 1.0 mm) dissemination and is always associated with scheelite II, pyrite and pyrrhotite in siliceous dolomitic limestone. Molybdenite also occurs with pyrite and pyrrhotite in quartz veins cutting the porphyry, hornblende gneiss and garnetiferous quartzite.

Scheelite:

Scheelite occurs in two distinct modes. Scheelite I forms coarse, idiomorphic crystals which measure up to 8 mm in diameter. It also occurs interstitial to magnetite and shows a poikilobastic texture. Scheelite II is generally of much finer grain (<1 mm in diameter) and occurs in finely disseminated form. Molybdenite is generally associated with scheelite II.

The chemical compositions of scheelite I and II are markedly different, and mole per cent $CaMoO_4$ ranges from 0.1 to 18.50. The lower range is given by scheelite II whereas the higher values are given by large crystals. The present finding is in close agreement with data on compositional variations of the scheelite-powellite series of minerals given by Hsu and Galli (1973). Hsu (1977) also indicated that very pure scheelite of contact metasomatic origin tends to be associated with molybdenite.

Calcite:

Calcite is anhedral and may have inclusions of other minerals; locally it may crystallize in open fractures as small scalenohedral crystals. A notable characteristic is the presence of manganese in nearly all samples of calcite that have been tested (Table 4-1). A little ferrous iron is also present in some. A very fine-grained, pink calcite that cuts the fibrous tremolite-antigorite rock contains appreciable manganese and iron; a calcite associated with diopside-andradite rock, on the other hand, is low in manganese.

Dolomite:

Dolomite typically is coarser grained than is the calcite. In the andradite-diopside-forsterite unit it is interstitial to granular andradite. Some of the dolomite is colourless, but most of it is cream coloured or light brown. Chemical analyses show that it contains variable amounts of manganese and ferrous iron, and an example, approaching manganoan ankerite in composition, is seen in tremolite, antigorite rock. Sample 8, with molecular ratios of Ca: Mg: Fe: Mn: = 52.09: 33.58: 4.06: 10.28, is a manganoan dolomite, according to Palache et al. (1951, p. 208-213), but it is a manganoan ankerite according to Deer, Howie and Zussman (1962, Vol. 5, p. 295-298). Table 4-1 gives the chemical analyses of two dolomite samples from Whycocowagh prospect, analyzed in the same series with calcite samples of the preceding section.

Tremolite:

Most of the tremolite is present as a fine- to medium-grained, fibrous assemblage of crystals in a highly altered, diopside rock with abundant mineralization. Most of the amphibole in these rocks is colourless under the microscope and presumably rich in tremolite molecular end members. The tremolite rocks show some evidence of fluorine metasomatism during their formation. In one drill hole (DDH #7-183) 0.5 mm thick veinlets composed of about 80 per cent apatite and a white mica cut the tremolite-rich zone. The apatite was studied by X-ray diffraction techniques (Silverman et al., 1952) and it was found that the difference between the d-spacings of the apatite 231 and 004 reflections coincided exactly with fluorapatite. The white mica's d-spacings are similar to those for synthetic fluorphlogopite published by Borg and Smith (1969).

TABLE 4-1

Chemical Analyses of Calcite and Dolomite from the Whycocomagh W-Mo-Cu Deposit

	1	2	3	4	5	6	7	8
CaO	56.33	52.94	52.00	51.30	37.00	42.5	31.93	30.5
MgO	-	0.16	0.61	0.30	0.55	0.7	18.00	14.5
FeO	0.32	0.40	0.39	0.10	0.50	0.4	2.26	3.0
MnO	0.40	3.70	5.8	6.85	20.38	15.16	2.80	7.6
CO_2	42.94	42.9	40.4	42.00	42.00	42.00	45.01	44.3

1. Coarsely crystalline calcite; occurs as a pocket in massive diopside-andradite rock DDH #1.

2. Rhombohedral calcite, light brownish yellow, DDH #2-50 feet.

3. Coarse, crystalline, pink calcite in tremolite-actinolite rock DDH #2-88 feet.

4. Thin, white, stringer filling grain boundaries. Mineralized zone DDH #7-79 feet.

5. Pink calcite, fluorescent bright orange, as thin vein-cutting tremolite-antigorite rock, DDH #7-47 feet.

6. Grey calcite associated with the scheelite mineralization; dump, adjacent to the shaft sample 11F7021.

7. Colourless dolomite with chalcopyrite-scheelite-magnetite mineralization.

8. Light brown dolomite in antigorite-rich rock DDH #2-93 feet.

Andradite:

Andradite is a common and widely distributed mineral, occurring in scattered patches and in bands with forsterite and diopside. The varying proportion and grain size of andradite, diopside and forsterite are probably an expression of the relic bedding in dolomitic limestone. Some garnet crystals contain small (0.02 to 0.05 mm) inclusions of pyroxene. These inclusions are concentrated in the core of the garnet crystal, suggesting that pyroxene was no longer forming during the final stages of garnet growth.

Microprobe analyses, structural formulas and molecular composition of selected assemblages from four samples of the garnet are listed in Table 4-2. The garnets are relatively homogeneous in composition $Ad_{59.17-36.68}$ to $Ad_{65.37}$-$Gr_{33.54}$ and are characterized by rather high titanium content.

Diopside-hedenbergite:

The pyroxene is coarse, dark green in colour, and is closely associated with forsterite and andradite. In DDh #7 228,236, it is associated with andradite, quartz and wollastonite. The mineralization at Whycocomagh is confined to this unit, and in DDH #7 it can be demonstrated that the mineralization has a zoned alteration halo. The critical minerals which formed during the alteration are tremolite, antigorite, talc and chlorite. The dominant mode of occurrence of these phases is as pseudomorphs.

Pyroxenes from the dolomitic limestone show about 10 molecular per cent variation in composition, mostly in the diopside to hedenbergite series (Table 4-3). This variation is from about Di_{95}-Hd_4 to Di_{85}-Hd_{14}. All of the grains analyzed are associated at the millimetre scale with garnet, forsterite, magnetite and wollastonite, and they appear to be coexisting stable with them.

Epidote, Antigorite and Talc:

Epidote is rare, generally fine grained, and is always seen associated with antigorite and talc. Talc and antigorite are always in

Table 4-2.-Electron microprobe analyses and Structural formulas of garnets from Whycocomagh W-Mo-Cu deposit

		1				2				3				4			
		C		R		C		R		C		R		C		R	
Major Oxides (weight per cent)																	
SiO_2		36.47		36.53		36.33		36.26		36.07		36.08		35.76		36.14	
TiO_2		.93		.68		1.00		1.12		1.45		.86		.67		.63	
Al_2O_3		8.23		9.20		8.82		9.27		8.88		8.25		8.20		7.80	
Cr_2O_3		.06		0.00		0.00		.09		0.00		.08		0.00		0.00	
Fe_2O_3		19.90		18.73		19.21		18.48		18.59		19.88		19.60		20.56	
FeO		.98		.74		.84		.93		.91		.84		.69		.58	
MnO		.35		.24		.20		.14		.19		.11		.15		.14	
MgO		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
CaO		34.44		34.50		34.53		34.47		34.51		34.33		33.97		34.46	
Na_2O		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
K_2O		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
Sum		99.36		98.75		99.01		98.91		98.74		98.44		97.08		98.25	
Structural Formulas*																	
Si		6.166	*	6.164	*	6.137	*	6.110	*	6.100	*	6.155	*	6.180	*	6.195	*
Al $\boxed{IV}$	Z	0.000	6.166	0.000	6.166	0.000	6.137	0.000	6.110	0.000	6.100	0.000	6.155	0.000	6.180	0.000	6.195
Al $\boxed{VI}$		1.640	*	1.829	*	1.756	*	1.841	*	1.770	*	1.659	*	1.670	*	1.575	*
Ti		.118	*	.086	*	.127	*	.142	*	.184	*	.110	*	.087	*	.081	*
Cr		.008	*	0.000	*	0.000	*	.012	*	0.000	*	.011	*	0.000	*	0.000	*
Fe^{3+}	Y	2.531	4.297	2.379	4.294	2.442	4.325	2.343	4.338	2.366	4.320	2.552	4.332	2.549	4.306	2.651	4.308
Fe		.138	*	.105	*	.119	*	.131	*	.129	*	.120	*	.100	*	.084	*
Mn		.050	*	.034	*	.029	*	.020	*	.027	*	.016	*	.002	*	.020	*
Mg		0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*
Ca		6.239	*	6.237	*	6.249	*	6.223	*	6.253	*	6.275	*	6.290	*	6.329	*
Na	X	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*
K		0.000	6.427	0.000	6.376	0.000	6.396	0.000	6.374	0.000	6.409	0.000	6.411	0.000	6.412	0.000	6.433
O		24.000	*	24.000	*	24.000	*	24.000	*	24.000	*	24.000	*	24.000	*	24.000	*
Component		Proportion ⊕															
Andradite		63.71		59.62		61.33		59.17		59.37		63.97		63.40		65.37	
$Ca_3Ti_2Al_2SiO_{12}$		2.82		2.06		3.04		3.41		4.39		2.63		2.08		1.94	
Spessartine		.80		.54		.46		.32		.43		.26		.35		.32	
Uvarovite		.19		0.00		0.00		.29		0.00		.26		0.00		0.00	
Grossular		32.57		38.11		35.39		36.68		35.75		33.29		34.88		33.54	
Knorringite		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
Pyrope		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
Almandine		0.00		0.00		0.00		.13		.06		0.00		0.00		0.00	

C - core of the garnet grain
R - rim of the garnet grain
* - calculated on the basis of 24 oxygen atoms per forumla unit using the computer program of Rucklidge (1974)
⊕ - stoichiometry assumed

Table 4-3 . - Electron microprobe analyses of pyroxene from Whycocomagh W-Mo-Cu deposit

	1		2		3		4		5		6		7		8		9		10		11	
Major Oxides (weight per cent)																						
SiO_2	53.91		54.41		54.35		54.11		53.92		49.14		52.51		50.59		53.85		53.88		53.78	
TiO_2	0.00		0.00		0.00		0.00		0.00		1.69		.41		1.23		0.00		.12		0.00	
Al_2O_3	.72		.90		.50		.61		.50		3.92		2.24		3.33		1.18		.91		.96	
Cr_2O_3	0.00		.08		.05		0.00		.05		.05		.25		0.00		.06		0.00		.05	
Fe_2O_3	0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00		0.00	
FeO	3.43		3.23		2.90		2.67		3.65		10.41		6.09		9.86		2.59		2.81		2.54	
MnO	.29		.27		.30		.30		.38		.25		.11		.26		.23		.22		.16	
MgO	16.48		16.45		16.60		16.83		16.12		14.32		16.63		14.25		16.89		17.04		16.77	
CaO	26.03		25.91		26.06		25.90		25.76		20.42		21.09		20.89		25.84		25.62		25.66	
Na_2O	0.00		0.00		.11		0.00		0.00		.54		.28		.34		.22		0.00		0.00	
K_2O	.13		.14		.12		.09		.11		.11		0.00		.10		.18		.09		.05	
Sum	100.99		101.39		100.99		100.51		100.49		100.85		99.61		100 .85		101.05		100.69		99.97	
Structural Formulas*																						
Si	1.963	*	1.969	*	1.974	*	1.971	*	1.974	*	1.836	*	1.936	*	1.881	*	1.953	*	1.959	*	1.966	*
Al IV	.031	1.994	.031	2.000	.021	1.996	.026	1.998	.022	1.996	.164	2.000	.064	2.000	.119	2.000	.047	2.000	.039	1.998	.034	2.000
Al VI	0.000	*	.007	*	0.000	*	0.000	*	0.000	*	.009	*	.033	*	.027	*	.004	*	0.000	*	.008	*
Ti	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	.047	*	.011	*	.034	*	0.000	*	.003	*	0.000	*
Cr	0.000	*	.002	*	.001	*	0.000	*	.001	*	.001	*	.007	*	0.000	*	.002	*	0.000	*	.001	*
Fe^{3+}	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*
Fe	.104	*	.098	*	.088	*	.081	*	.112	*	.325	*	.188	*	.307	*	.079	*	.085	*	.078	*
Mn	.009	*	.008	*	.009	*	.009	*	.012	*	.008	*	.003	*	.008	*	.007	*	.007	*	.005	*
Mg	.895	1.008	.887	1.003	.899	.998	.914	1.005	.880	1.005	.798	1.189	.914	1.157	.790	1.165	.913	1.004	.924	1.019	.914	1.006
Ca	1.016	*	1.005	*	1.014	*	1.011	*	1.011	*	.818	*	.833	*	.832	*	1.004	*	.998	*	1.005	*
Na	0.000	*	0.000	*	.008	*	0.000	*	0.000	*	.039	*	.020	*	.025	*	.015	*	0.000	*	0.000	*
K	.006	1.022	.006	1.011	.006	1.028	.004	1.015	.005	1.016	.005	.862	0.000	.853	.005	.861	.008	1.028	.004	1.002	.002	1.008
O	6.000	*	6.000	*	6.000	*	6.000	*	6.000	*	6.000	*	6.000	*	6.000	*	6.000	*	6.000	*	6.000	*
Component			Proportion θ																			
WO	50.413		50.491		50.684		50.392		50.476		42.132		43.060		43.152		50.313		49.730		50.341	
EN	44.402		44.596		44.914		45.553		43.942		41.103		47.235		40.950		45.751		46.013		45.769	
FS	5.185		4.913		4.402		4.055		5.582		16.765		9.705		15.898		3.936		4.257		3.890	
WO	50.190		50.282		50.257		50.160		50.180		41.135		42.544		42.433		49.751		49.562		50.216	
HYP	49.810		49.718		49.359		49.840		49.820		56.897		56.434		56.318		49.482		50.438		49.784	
JD	0.000		0.000		.384		0.000		0.000		1.968		1.022		1.250		.767		0.000		0.000	

* - calculated on the basis of 6 oxygen atoms per forumla unit using the computer program of Rucklidge (1974)
θ - stoichiometry assumed

contact with each other and also in close association with the metallization. The relationship of these three minerals to the pre-existing minerals and metallization is fully described in a later section on wall rock alteration.

Wall Rock Alteration

The alteration of siliceous dolomitic limestone into zones showing a sequence of mineralogical changes is characteristic at Whycocomagh. The fresh rock zone 4 grades veinwards through tremolite-actinolite rock, zone 3, to moderately altered tremolite-antigorite rock, zone 2, to strongly altered talc-antigorite rock, zone 1. This zonal sequence has been designated on the basis of relative proportions of minerals in various alteration zones.

Zone 4. - The unaltered wall rock is characterized by diopside, forsterite, wollastonite and andradite. Diopside ranging in size from 0.01 to 2.4 mm occurs in a tightly intergrown mat. It also occurs as thin (<1 m) diopside-rich, almost monomineralic (Plate 4-1, Figure A) rock. Typically, forsterite and monticellite form a granoblastic fabric (Plate 4-1, Figure B) and the average grain size is generally 0.2 to 1.0 mm. A small volume of rocks is composed entirely of forsterite. Wollastonite is generally found in close association with calcite and diopside (Plate 4-1, Figure C). Closely packed arrays of subhedral to euhedral dodecahedron of andradite (Plate 4-1, Figure D) compose close to 95 volume per cent of some small domains. Modal composition of garnet varies highly. Some 0.25 to 1 m clots of almost pure garnet grade into roughly equal proportions of garnet and diopside across about a 2 m interval. The garnets range from 0.5 to 1.5 mm in size. Minor accessory minerals are sphene, magnetite and chondrodite.

Plate 4-1

Photomicrographs showing the textural relationships of diopside, forsterite and monticellite, wollastonite and calcite; diopside and garnet. Figure A, monomineralic diopside-rich unaltered wall rock. Figure B, forsterite and monticellite showing granoblastic fabric. Figure C, wollastonite, calcite and diopside showing interlocking texture. Figure D, closely packed arrays of subhedral to euhedral dodecahedron of anhydrite.

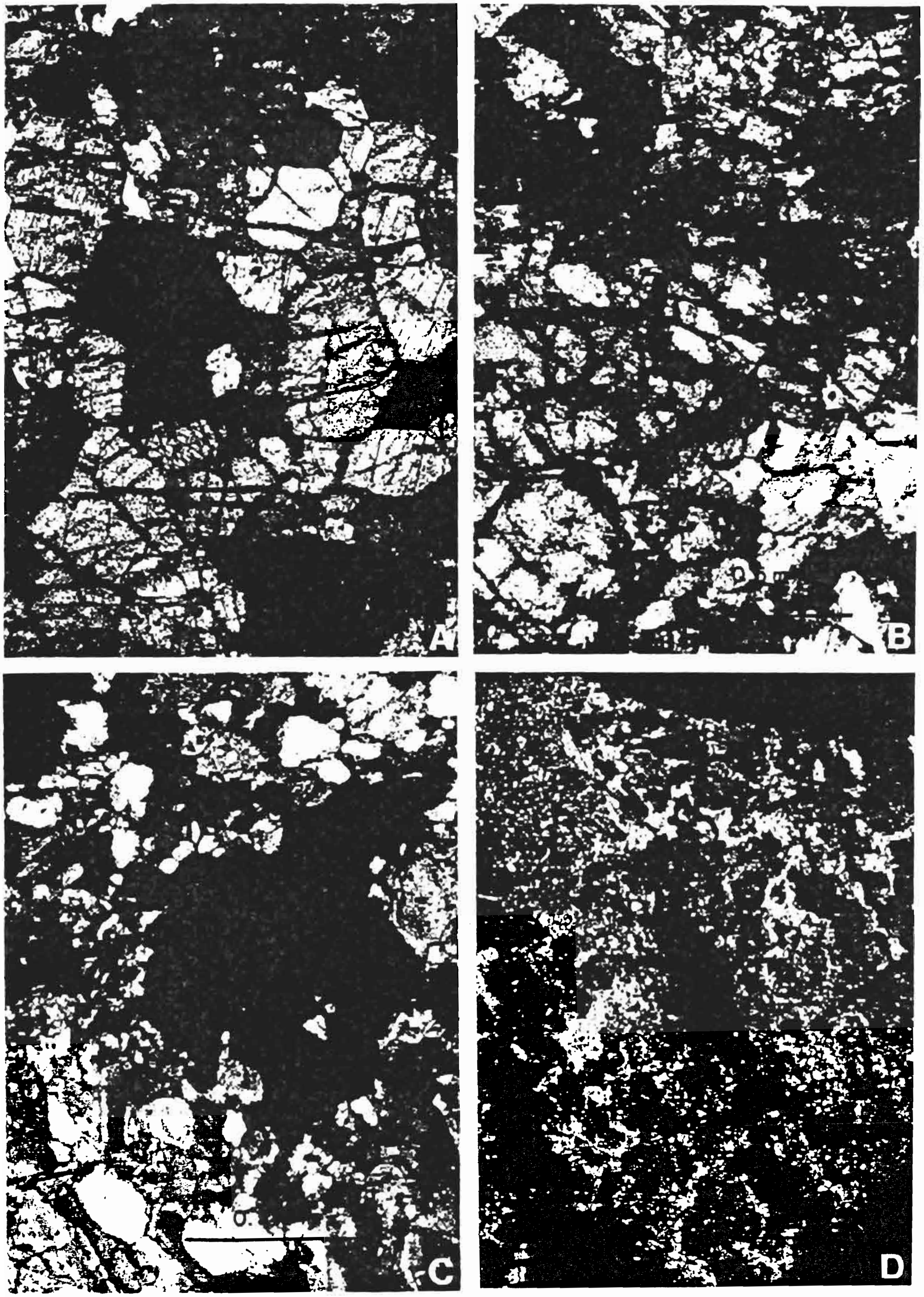


Plate 4-1

Zone 3. - This zone is grey-green in colour and is characterized by a preponderance of fibrous amphibole. Most of the amphibole in this rock is colourless under the microscope, and microprobe analyses (Table 4-4) have shown that it is rich in tremolite molecular end member. Rocks of this zone are widely distributed in the Whycocomagh Mountain area. Tremolite also occurs along microfractures and cleavage planes of diopside grains. Relict diopside, with conformable optical orientation, is observed within tremolite. It appears that most of the rocks in this zone have formed from a partial consumption of the unaltered wall rock as evidenced by apparently relict forsterite, garnet, diopside and sphene. A few grains of chalcopyrite, pyrite and pyrrhotite are also seen in this zone.

Zone 2. - The rocks of zone 2 are generally olive-green and are characterized by abundant development of antigorite and tremolite (Plate 4-2, Figures A and B). This zone is formed by nearly complete corrosion of forsterite, diopside and garnet (?). Minor accessory minerals that are present in the zone are magnetite, molybdenite, chalcopyrite, scheelite, pyrite and pyrrhotite.

Zone 1. - The rocks of zone 1 show abundant development of talc (Plate 4-2, Figure C) and are in immediate contact with the mineralized zone. Locally, granoblastic aggregates of epidote and antigorite are also seen in this zone. Talc is the diagnostic mineral of this zone and is also present in the mineralized zones.

Major Oxides (weight per cent)

	1	2	3	4	5	6	7	8	9	10
SiO_2	53.70	55.21	54.74	53.41	54.07	53.87	53.83	54.64	53.09	54.11
TiO_2	0.00	0.00	.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Al_2O_3	3.01	1.72	2.62	3.00	3.17	3.18	3.67	4.18	3.99	3.10
Cr_2O_3	0.00	0.00	0.00	0.00	.05	0.00	.04	0.00	0.00	0.00
Fe_2O_3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FeO	10.17	9.22	9.90	10.07	9.01	10.90	9.14	7.84	10.08	9.50
MnO	.26	.29	.36	.11	.23	.22	.17	.20	.22	.09
MgO	17.40	18.60	18.20	17.63	18.47	17.23	18.21	19.18	17.65	18.44
CaO	13.02	13.11	12.98	12.88	12.82	13.00	13.44	13.69	13.01	13.23
Na_2O	.55	.11	.32	0.00	.24	.38	.54	.58	.51	.46
K_2O	.13	0.00	.23	.11	.16	.16	.22	.24	.21	.16
H_2O	2.11	2.13	2.14	2.09	2.12	2.12	2.14	2.18	2.12	2.14
Sum	100.35	100.39	101.56	99.30	100.34	101.06	101.40	102.73	100.88	101.23

Structural Formulas*

	1		2		3		4		5		6		7		8		9		10	
Si	7.627	*	7.776	*	7.663	*	7.640	*	7.623	*	7.613	*	7.541	*	7.509	*	7.504	*	7.592	*
Al IV	.373	8.000	.224	8.000	.337	8.000	.360	8.000	.377	8.000	.387	8.000	.459	8.000	.491	8.000	.496	8.000	.408	8.000
Al VI	.130	*	.062	*	.095	*	.146	*	.150	*	.143	*	.146	*	.186	*	.168	*	.104	*
Ti	0.000	*	0.000	*	.007	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*
Cr	0.000	*	0.000	*	0.000	*	0.000	*	.006	*	0.000	*	.004	*	0.000	*	0.000	*	0.000	*
Fe^{3+}	0.000	*	0.000	*	0.099	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*	0.000	*
Mg	3.683	*	3.905	*	3.798	*	3.759	*	3.881	*	3.629	*	3.802	*	3.929	*	3.718	*	3.856	*
Fe	1.208	*	1.086	*	1.159	*	1.205	*	1.062	*	1.288	*	1.071	*	.901	*	1.191	*	1.115	*
Mn	.031	5.053	.035	5.087	.043	5.102	.013	5.123	.027	5.127	.026	5.087	.020	5.044	.023	5.039	.026	5.105	.011	5.086
Ca	1.981	*	1.978	*	1.947	*	1.974	*	1.937	*	1.968	*	2.017	*	2.016	*	1.970	*	1.989	*
Na	.151	*	.030	*	.087	*	0.000	*	.066	*	.104	*	.147	*	.155	*	.140	*	.125	*
K	.024	2.156	0.000	2.008	.041	2.075	.020	1.994	.029	2.031	.029	2.101	.039	2.203	.042	2.212	.038	2.148	.029	2.143
H	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
O	24.000	*	24.000	*	24.000	*	24.000	*	24.000	*	24.000	*	24.000	*	24.000	*	24.000	*	24.000	*

Component	Proportion ●									
Mg	53.596	56.029	55.010	54.182	56.413	52.707	55.183	57.392	54.046	55.408
Fe	17.576	15.583	16.789	17.364	15.440	18.708	15.540	13.162	17.318	16.016
Ca	28.828	28.388	28.201	28.454	28.146	28.586	29.276	29.446	28.636	28.576
Ca	91.884	98.504	93.834	98.994	95.353	93.673	91.559	91.113	91.730	92.823
Na	7.024	1.496	4.186	0.000	3.230	4.955	6.657	6.985	6.507	5.840
K	1.092	0.000	1.979	1.006	1.417	1.372	1.784	1.902	1.763	1.336

* - calculated on the basis of 24 oxygen atoms per formula unit using the computer program of Rucklidge (1974)

● - stoichiometry assumed

Table 4-4 - Electron microprobe analyses of amphiboles from tremolite alteration zone Whycocomagh W-Mo-Cu deposit. Analyses 1 to 5 from sample number DDH7-198, 6 to 9 from sample number DDH7-211 and analysis number 10 is of a partially corroded grain from antigorite-tremolite zone (DDH7-183).

Plate 4-2

Photomicrographs showing the relationships of antigorite, tremolite and talc in the altered zones. Figure A, partial to complete pseudomorphic alteration of forsterite to antigorite. Figure B, newly formed tremolite by the alteration of diopside. Figure C, intense talc alteration adjacent to the mineralized zone.

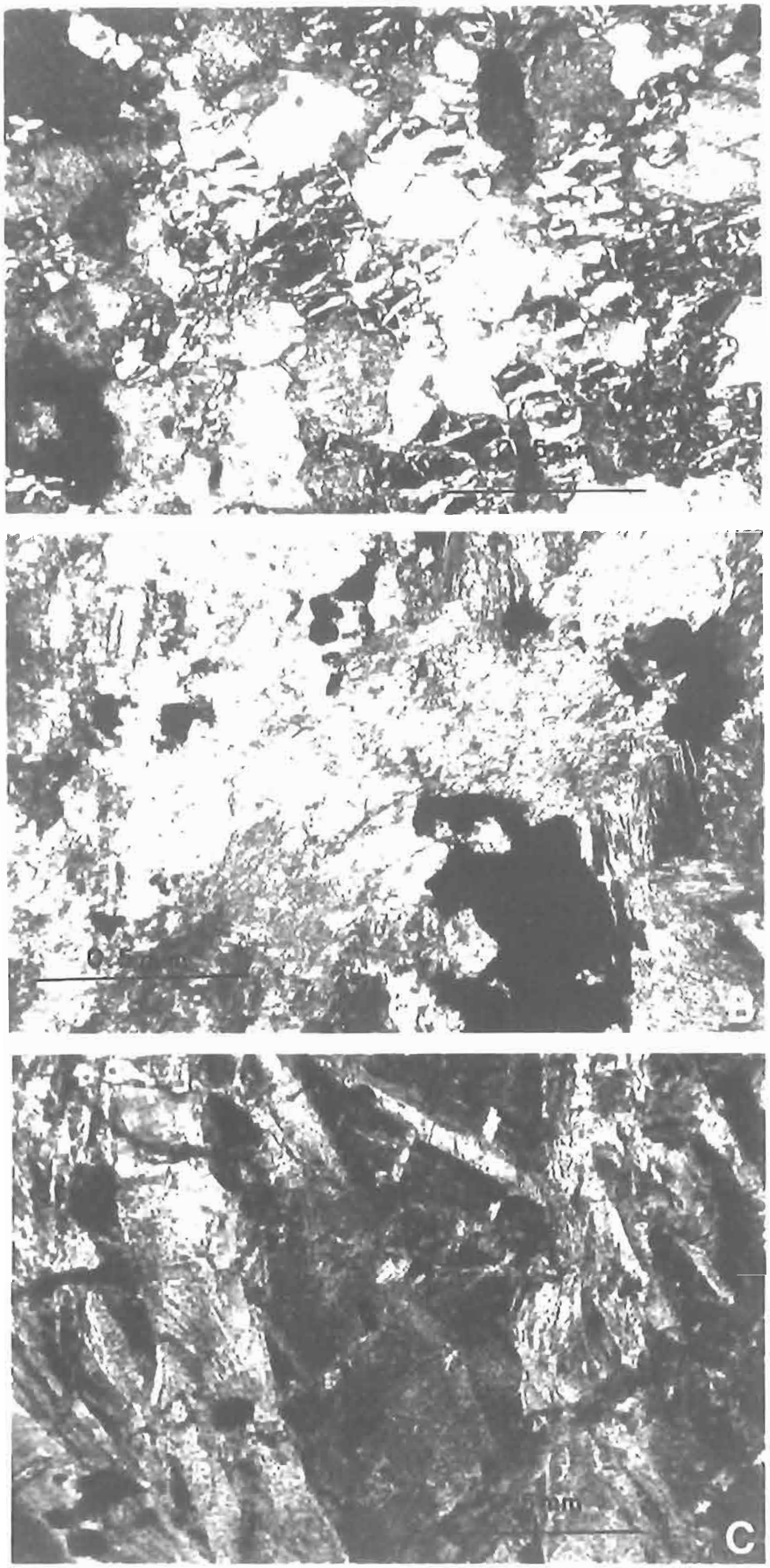


Plate 4-2

CHAPTER 5

BOISDALE HILLS

Introduction

The section exposed at Boisdale Hills shows considerable variety in the composition of the carbonate rocks, which are here considered to be typical of those of the George River Group that have undergone contact metamorphism.

The carbonate rocks of the Boisdale Hills cover an area of approximately 80 square kilometres. The area was mapped by Milligan (1970) and, except for the area near Steele's crossing (Figure 5-1), the samples for the present study were obtained from his collection.

Geological Setting

The country rock forms a sequence of interbedded limestone, dolomitic limestone and micaceous quartzites. These were intruded by granite, syenite and diorite. Later diabase, lamprophyre and pegmatite dykes cut the entire sequence. The regional strike appears to be north-northeast and the dip varies from 45° to 80°NW. The description of the lithological units and their relations with other units has been given by Milligan (*op. cit.*, pp. 11 to 53). The structural setting appears to be rather complicated and various alternative interpretations have been suggested by Milligan. Metamorphism of the carbonate rocks has produced several different skarns.

Mineralization

In the Boisdale Hills, mineralization is of two types, (a) veins of calcite-pyrite-pyrrhotite-chalcopyrite-sphalerite in magnesian

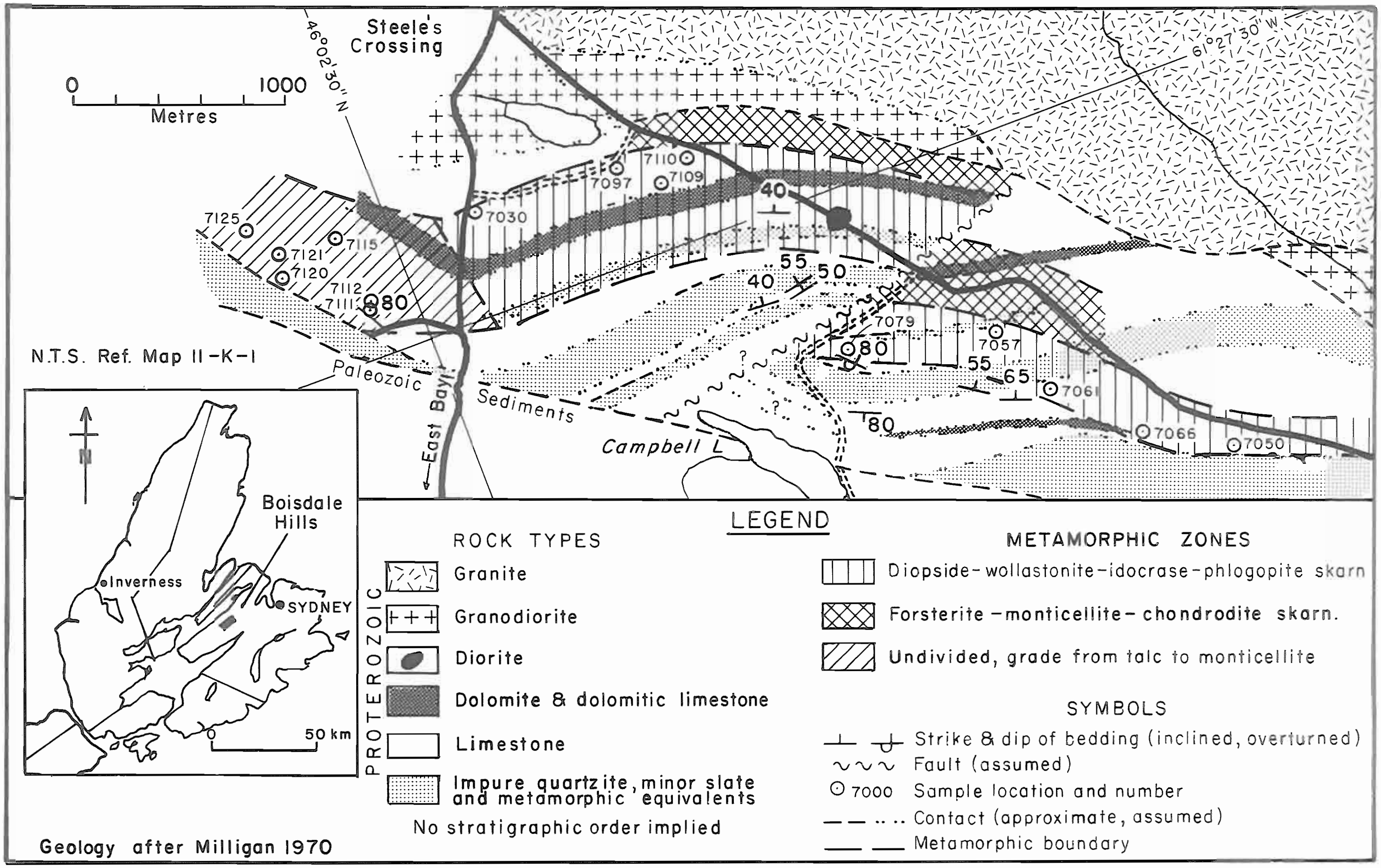


Figure 5-1 - General Geology and Metamorphic zones at Boisdale Hills skarn and (b) disseminated scheelite and rare molybdenite in impure siliceous and magnesian limestone, and is restricted to a metamorphic zone within these units (Figure 5-1). This metamorphic zone is characterized by wollastonite, diopside-andradite, diopside-wollastonite and clinozoisite-idocrase-phlogopite mineral assemblages. This zone has been traced for approximately 4.5 kilometres, clearly cross-cutting the strike of the lithological units and paralleling the contact between the metasedimentary and the intrusive rocks.

Pyrite generally occurs as small euhedral grains scattered randomly in the carbonate rocks, but it is also seen as thin films along the fractures. Pyrrhotite is rare but is associated with pyrite in fracture fillings. Small amounts of sphalerite, galena and chalcopyrite are commonly present with calcite stringers. In polished section, sphalerite commonly contains anhedral or euhedral grains of pyrite and small linear or irregular vermiform and discontinuous inclusions of galena or chalcopyrite, or both, varying in thickness and suggesting lenticular veinlets.

Scheelite occurs as fine disseminated (<1 mm) or large, rather equidimensional grains, as thin layers (<2mm) following the compositional banding and as cross-cutting veinlets. In transmitted light, it is colourless and a few grains exhibit weak anomalous birefringence. The indices of refraction are $N_e \approx 1.935$ and $N_s \approx 1.910$; the mineral is uniaxial and optically positive. The X-ray powder diffraction data for scheelite are given in Table 5-1. Because the diffraction pattern of scheelite is similar to that of powellite, confirmatory tests were performed by microprobe analysis. Chemical analyses of the variety that fluoresces golden yellow reveal 8.78 per cent MoO_3

TABLE 5-1

Powder X-ray Data for Scheelite ($CaWO_4$) from Boisdale Hills. for comparison the data for powellite ($CaMoO_4$) are also included.

Camera Diameter 114.6 mm, CuKα_1 radiation

	Scheelite NSDM 11K/7108		Scheelite ASTM 7-210 and 8-145		Powellite Berry & Thompson (1962) No. 292, p. 226	
θ	d	I/Io	d	I	d	I
9.3	4.77	m	4.76	53	4.80	60
14.45	3.09	vs	3.10	100	3.11	100
15.8	2.83	w	2.844	14	2.87	40
17.1	2.61	w	2.622	23	2.62	40
19.6	2.29	w	2.296	19	2.29	30
23.55	1.92	s	1.92	28	1.937	90
24.55	1.85	w	1.853	12	1.855	40
25.95	1.76	vw	1.727	5	1.701	50
27.15	1.609	m	1.68	16		
28.15	1.63	w	1.633	10	1.64	10
29.0	1.59	s	1.59	30	1.593	80
29.7	1.55	w	1.55	14	1.558	40
32.25	1.445	vw	1.442	6	1.439	10
∿						
∿						
∿						
∿						
38.0	1.252	s	1.251	80	1.256	70
39.55	1.211	vw	1.22	2	1.209	20
40.3	1.192	w	1.19	4	1.193	20

θ = the measured value of the glancing angle
I = intensity
d = the interplanar spacing between regularly spaced identical planes measured in Angstrom units
I/Io = visual estimate of intensities
vs = very strong; s = strong; m = medium; w = weak;
vw = very weak

and 69.2 per cent WO_3, whereas the bluish-white variety contains 0.78 per cent MoO_3 and 79.6 per cent WO_3, which is very close to the theoretical tungsten content of scheelite (80.5 per cent WO_3).

Molybdenite occurs in small flakes disseminated in siliceous limestone. It is commonly associated with scheelite. The molybdenite is negligible in quantity compared with the scheelite.

Mineral Composition of the Skarns

The rocks of the Boisdale skarn series (magnesian skarn, limy skarn, argillaceous skarn) range widely in composition. These skarns are dominantly calcite and/or dolomite, containing abundant Ca-Mg-Al-bearing silicates. In many cases, the complete range of compositions (i.e. magnesian, limy and argillaceous skarns) is visible within a single thin section. In spite of variations from one place to another, which make them almost impossible to map as separate lithological units, on the basis of certain common mineral assemblages, they may be classified.

Magnesian skarns are recrystallized, carbonate rocks containing high-temperature magnesian minerals. Typical minerals are merwinite, chondrodite, monticellite, forsterite, diopside and quartz. Depending on the availability of alumina, minerals such as spinel and anorthite may also develop. The observed mineral associations are listed in Table 5-2.

TABLE 5-2

Magnesian Skarn: Mineral Associations

Boisdale Hills

(Individual associations here listed have each been seen within the limits of a single thin section. There is no implication that these are equilibrium associations.)

Quartz-dolomite-talc
Quartz-dolomite-talc-antigorite
Quartz-dolomite-talc-antigorite-tremolite
Quartz-dolomite-talc-antigorite -diopside
Quartz-dolomite -tremolite-diopside
Quartz-dolomite

Dolomite-talc
Dolomite-talc-antigorite
Dolomite-talc-antigorite-tremolite
Dolomite-talc-antigorite-tremolite-diopside
Dolomite-talc -tremolite-diopside
Dolomite-talc -tremolite-diopside-forsterite
Dolomite -tremolite-diopside-forsterite
Dolomite-talc -diopside-forsterite
Dolomite-talc -forsterite
Dolomite-talc-antigorite-tremolite
Dolomite -antigorite-tremolite-diopside
Dolomite -antigorite-tremolite-diopside-forsterite

Dolomite-antigorite-forsterite-monticellite-chondrodite
Dolomite forsterite-monticellite-chondrodite
Dolomite -forsterite-monticellite

Dolomite-diopside-chondrodite
Dolomite-diopside-chondrodite-forsterite-monticellite
Dolomite-diopside -forsterite-monticellite
Dolomite -chondrodite-forsterite-monticellite-spinel

Dolomite-tremolite-diopside-forsterite-chondrodite
Dolomite-tremolite -forsterite-chondrodite
Dolomite -forsterite-chondrodite

Dolomite-talc-antigorite-forsterite-monticellite
Dolomite-talc -forsterite-monticellite

Dolomite-anigorite-diopside
Dolomite-antigorite-diopside-talc-chondrodite
Dolomite -diopside-talc

Dolomite-tremolite-diopside-monticellite-chondrodite
Dolomite-tremolite -monticellite-chondrodite

Argillaceous skarns are recrystallized rocks containing high-temperature lime-magnesia-potassium-iron silicates and alumino-silicates. Typical minerals in this group are scapolite, K-feldspar, plagioclase, zoisite, muscovite, phlogopite and quartz. Minerals such as diopside and tremolite may also appear in this type under certain pressure-temperature conditions. The observed mineral associations are tabulated in Table 5-3.

TABLE 5-3

Argillaceous Skarn: Mineral Associations

Boisdale Hills

(Individual assemblages here listed have each been seen within the limits of a single thin section.)

Quartz-muscovite-plagioclase-phlogopite-tremolite
Quartz   -plagioclase   -tremolite-K-feldspar-diopside
Quartz-muscovite-plagioclase
Quartz-muscovite-plagioclase-phlogopite

Dolomite-tremolite-plagioclase-muscovite-quartz
Dolomite-tremolite   -muscovite-quartz-phlogopite
Dolomite-tremolite-plagioclase   -quartz-phlogopite
Dolomite   -plagioclase-muscovite-quartz-phlogopite
Dolomite   -muscovite-quartz
Dolomite-tremolite   -muscovite
Dolomite-tremolite   -muscovite-quartz
Dolomite-tremolite   -muscovite   -phlogopite

Dolomite-muscovite-quartz-scapolite
Dolomite-muscovite   -scapolite-diopside

Calcite-quartz-biotite-plagioclase-tremolite-zoisite
Calcite-quartz-biotite-plagioclase-tremolite-zoisite-K-feldspar

Calcite-quartz-diopside-wollastonite

Quartz-muscovite-zoisite-tremolite-plagioclase
Quartz-muscovite-zoisite   -plagioclase

Quartz-muscovite-zoisite-plagioclase-wollastonite

Quartz-tremolite-zoisite-diopside-K-feldspar

Limy skarns are also recrystallized rocks containing high-temperature, lime-magnesia-iron silicates and alumino-silicates. The typical minerals are akermanite, idocrase, wollastonite, andradite and scapolite. The following mineral associations are the only ones found:

Diopside-wollastonite
Diopside-wollastonite-merwinite
Diopside-wollastonite -monticellite
Diopside-wollastonite -akermanite

Diopside-scapolite-wollastonite-idocrase

Diopside-wollastonite-idocrase-phlogopite

Diopside-andradite-tremolite

The individual mineral assemblages listed above and in Tables 5-2 and 5-3, though they have been found within a single thin section, do not imply equilibrium assemblages.

Host Rock Alteration

Talc and antigorite are the most prominent products of alteration. Microscopic examination of more than fifty thin sections and X-ray diffraction analyses of fifteen antigorite samples indicate that in every case the antigorite is derived from pre-existing minerals such as forsterite, diopside, tremolite and dolomite. Some of the pertinent data concerning the relationship between antigorite and the pre-existing minerals are described below.

(a) Mesh serpentine: Mesh serpentine is generally fine grained and forms an approximate prismatic arrangement of cross-fibre veinlets cutting through the earlier mineral. In different specimens, the outline may be rectangular, equidimensional, lensoid or highly asymmetrical. Different stages of alteration may be seen in Plate 5-1, Figure A. From the rhombohedral array pattern it appears that this variety of antigorite has been derived from dolomite. The X-ray diffraction data are shown in Table 5-4.

TABLE 5-4

Powder X-ray Data for Antigorite Derived from Dolomite (A), and Antigorite Derived from Diopside (B), Boisdale Hills
Camera Diameter 114.6 mm, CuKα_1 radiation

NSDM Film Nos. 8931, 8932, 8934		A ASTM 9-444 Antigorite**		ASTM 5-0586 Calcite		B NSDM Film Nos. 8934, 8935, 8936, 8945*		ASTM 9-444 Antigorite**		ASTM 24-705 ASTM 11-654 Diopside	
d	I/Io	d	I	d	I	d	I/Io	d	I	d	I
7.37	vs	7.33	100	-	-	7.31	vs	7.33	100		
4.60	m	4.60	60	-	-	4.60	m	4.60	60		
3.86	w	-	-	3.86	12	3.62	vs	3.66	100		
3.63	s	3.66	100	-	-	3.21	m			3.25	50
3.04	vs	-	-	3.035	100	3.01	s			2.99	80
2.50	s	2.502	100			2.91	s			2.90	70
2.28	m	-	-	2.285	18	2.521	s			2.53	60
2.09	m	-	-	2.095	18	2.309	s	2.335	70		
1.911	s	-	-	3 Refl.	22	2.227	m			2.22	30
1.86	s	1.791	10	1.875	17	2.127	s	2.149	60	2.11	
1.603	m	-	-	1.604	8	2.014	m				
1.521	m	1.53	80	3 Refl.	12	1.827	w	1.791	10		
1.469	w	-	-	1.473	2	1.756	w	1.739	10		
1.443	m	-	-	1.440	5	1.669	f				
1.420	w	1.41	20	1.422	3	1.623	s	1.626	40	1.62	40
						1.535	s	1.535	80		
						1.508	vs	1.501	70	1.51	70
						1.428	m	1.415	20		

* These four films are visually identical, but some of the weaker lines are not measurable for film 8936 and 8945. Distinctive are the two lines d = 3.01A and 2.521A which appear on each film with equal intensity. It must, therefore, be concluded that they belong to one and the same mineral. Only the calcium-magnesium silicate (diopside) of ASTM No. 24-705 and 11-654 fulfills this condition. The diopside also accounts for the splitting of the 2.91 from the 3.01A line in film No. 8935.

** The X-ray pattern of antigorite matches very closely with the 6(2)-layer orthosilicate described by Brindley and van Knorring (1954) and experimentally produced hydrothermally by Roy and Roy (1956).

d = the interplanar spacing between regularly spaced identical planes measured in Angstrom units
I = intensity
vs = very strong; s = strong; m = medium; w = weak; f = broad very weak reflection
I/Io = visual estimate of intensities

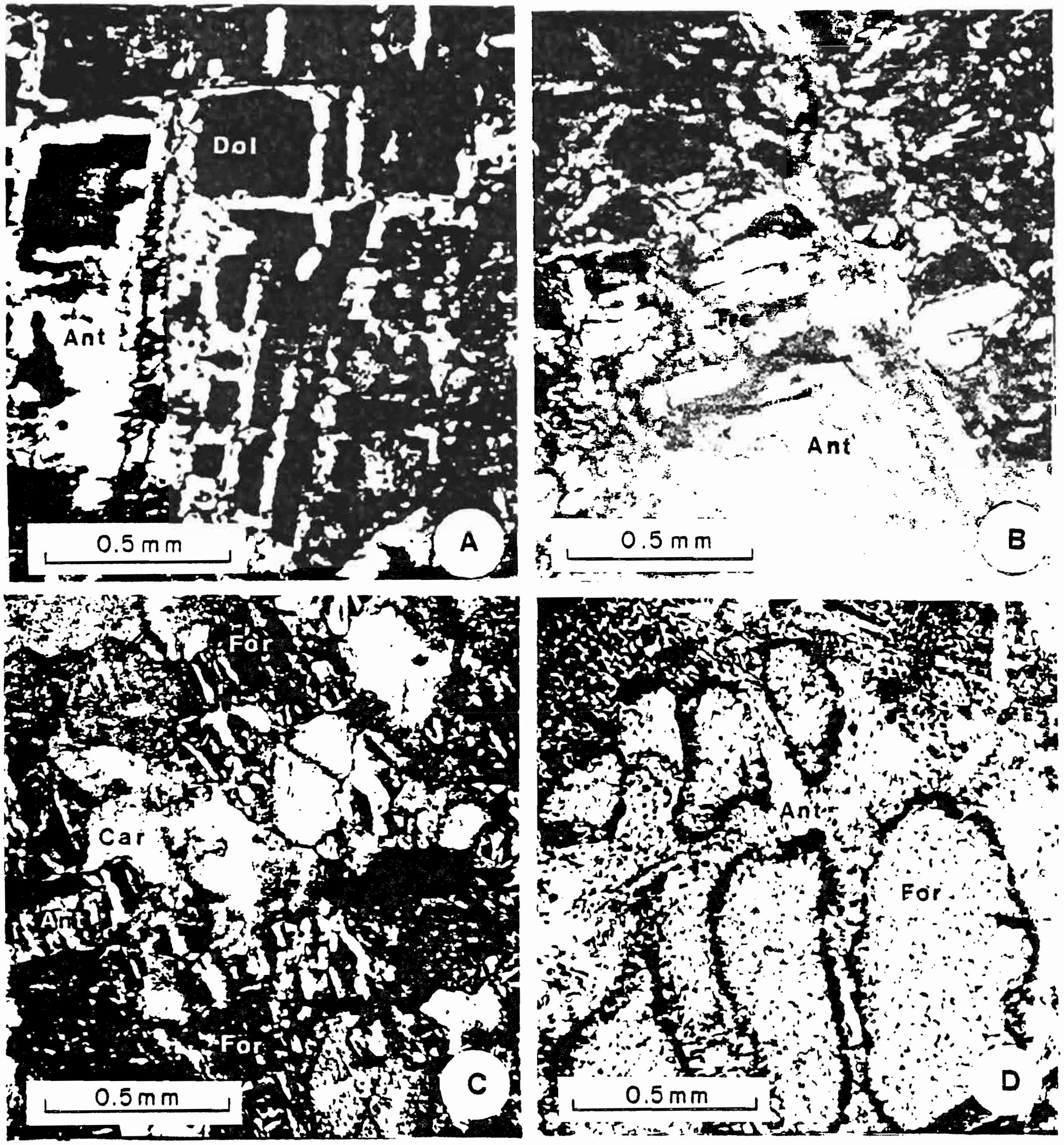


Plate 5-1

Photomicrographs showing the textural patterns of antigorite. A, Mesh serpentine showing the pseudo-rectangular arrangement of cross fibre veinlets. This variety of antigorite has been derived from dolomite. B, elongated fibrolamellar flakes of antigorite developed from tremolite and diopside. C and D, Poikilitic pseudomorphs of antigorite after forsterite. Ant, antigorite; Dol, dolomite; For, forsterite; Tre, tremolite; Car, carbonates.

(b) Fibrolamellar serpentine: This variety of antigorite has developed from tremolite and diopside (Table 5-4) and it occurs as a tightly compacted matte of elongated fibrolamellar flakes of antigorite (Plate 5-1, Fig. B). In four x-ray analyses, all the lines could only be accounted for by a mixture of diopside and antigorite. Many small areas show a preferred alignment of flakes associated with magnetite particles.

(c) Antigorite as poikilitic pseudomorphs: This variety of antigorite occurs as elongated sub-rectangular flakes, and exhibits rather ragged and feathery terminations. Poikilitic pseudomorphs after forsterite (Plate 5-1, Figures C and D) are preserved in well-developed textural patterns. These are composed of rounded to oval-shaped granules of fine antigorite flakes set in a matrix of antigorite and carbonate.

Talc is also an important product. Forsterite, diopside, tremolite, and antigorite are seen partly altered to talc. It is an alteration product near veins but is also developed in units of appropriate composition of some distance from the intrusive granite contact. Both antigorite and talc alteration characterize the alteration around late calcite and sulphide veins.

CHAPTER 6

FARIBAULT BROOK AREA

"Silver Cliff" Showing: Dauphinee Brook

"Core Shack" and "Galena Mine" Showings: Faribault Brook

Introduction

The "Silver Cliff", "Core Shack" and "Galena Mine" mineral deposits are about 8 km from Petit Etang and are on opposite sides of a ridge, between Faribault Brook and Dauphinee Brook, both tributary to Cheticamp River (Figure 6-1).

Previous Work

The first recorded work in the area was carried out by Hugh Fletcher for the Geological and Natural History Survey of Canada during the period 1882 to 1884.

In 1953 the Government of Nova Scotia granted a mineral concession termed "closure No. 1" to the Mineral Exploration Corporation Limited (Minex) covering 3200 square kilometres of northern Cape Breton Island. Minex conducted geological, geophysical and geochemical investigations, discovered base-metal mineralization in the bed of Dauphinee Brook and drilled holes in the vicinity of what is known as the "Silver Cliff" Deposit.

In 1954 MacLaren of the Geological Survey of Canada mapped the Cheticamp area (Geol. Surv. Can. Map 55-36) on a Scale of 1"= 1 mile.

From 1963 to 1967 Noranda carried out an exploration program and did some 1000 metres of drilling in 16 holes. From 1965 to 1968 Barrington Exploration Limited conducted a field program and outlined a second area of mineralization, approximately 480 metres west-southwest

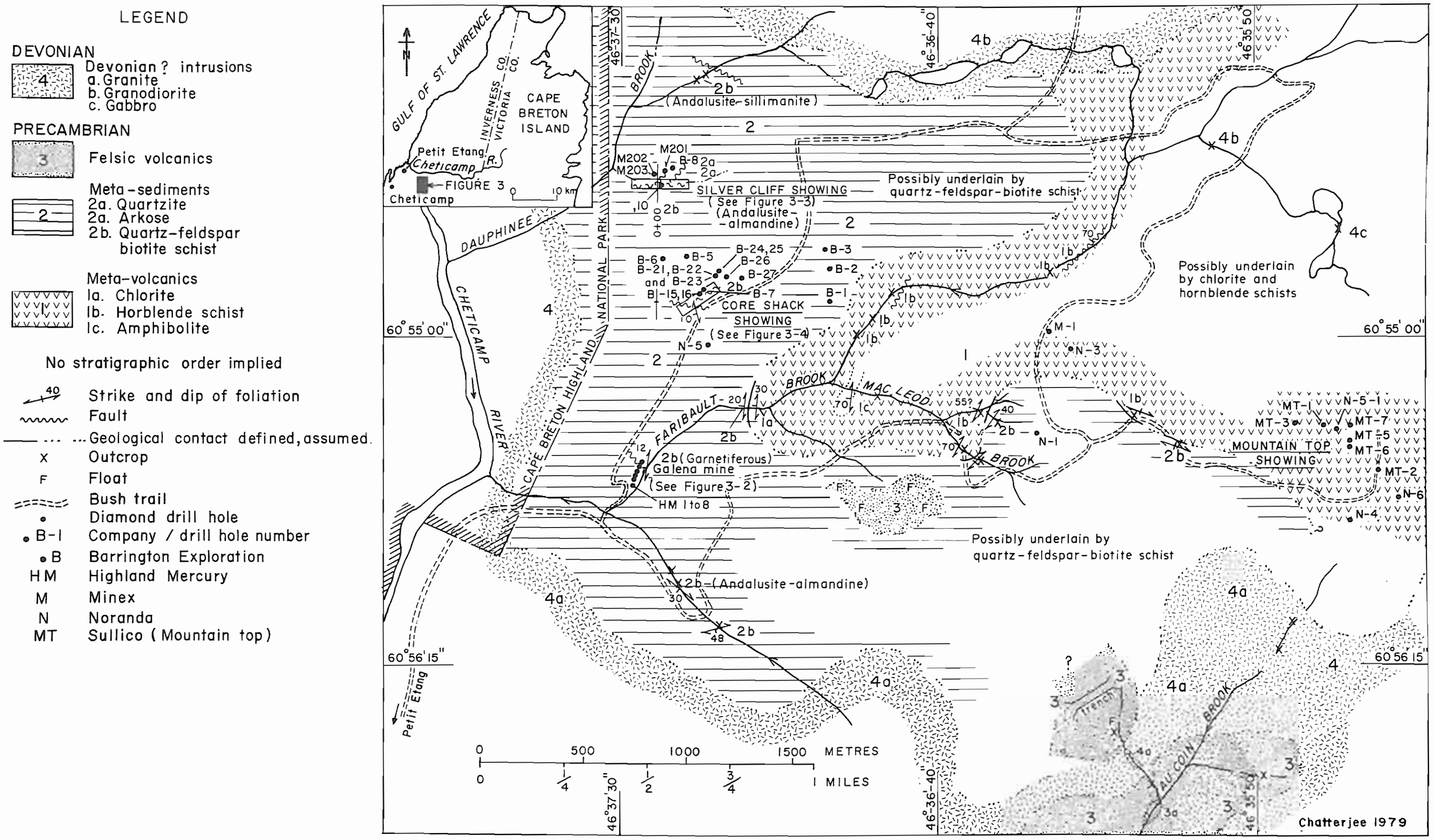


Figure 6-1. General geology, Faribault Brook area.

of the "Silver Cliff" occurrence; this was termed the "Core Shack" occurrence. Twenty-four holes, totalling approximately 2280 metres, were drilled.

In 1966, Canadian Aero Mineral Surveys Limited conducted airborne EM and magnetic surveys over the entire area. This survey was conducted jointly for Sullico Mines ltd., Cominco Limited, Bunker Hill Mines Limited and Kennco Exploration Limited. Sullico and Cominco drilled six holes on an electromagnetic anomaly and encountered Zn-Cu-Ag-Au mineralization in meta-volcanic rocks. This mineralization (though unexposed) was termed the "Mountain Top" showing.

During the summers of 1967 and 1968 the Silver Cliff and Core Shack occurrences were mapped in detail by Milligan and Chatterjee for the Nova Scotia Department of Mines. During 1967 and 1968, Chatterjee logged and sampled in detail approximately 1200 metres of core from Silver Cliff, Core Shack and Mountain Top occurrences. Preliminary results of this work were summarized by Milligan (1970).

During the summer of 1975, an exposure of base-metals, now known as the Galena Mine occurrence, was found in the bottom of Faribault Brook. It was revealed by the abnormally low water levels resulting from the extremely dry summer of 1975. Highland Mercury Mines Limited drilled eight holes, but concluded that the mineralized zone was "erratic and lenticular" and so dropped its option on the property.

In 1976 and 1977 Chatterjee again examined all the mineral deposits and logged the core resulting from the recent diamond drilling. Also, during this period a compilation of all the existing data on assay values for Cu, Pb, Zn, Ag and Au was made from the assessment files of the Nova Scotia Department of Mines. The purpose was to determine the abundance relationships between metals and, from them, possible relationships between the mineralization and the environment in which it was formed. It was intended that this objective method should complement the field and microscopic studies relating to the likely origin of the mineralization in the George River rocks.

Geological Setting

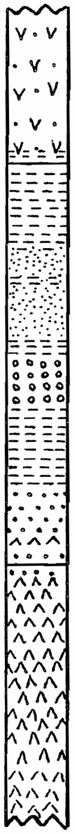
The Faribault Brook area is underlain by a sequence of interbedded sedimentary and volcanic rocks (Table 6-1). The minimum thickness of this sequence is approximately 350 metres. The lower mafic volcanic part consists of meta-basalt, meta-andesites and meta-porphyrites. These are now represented by andalusite-sillimanite schists, almandine-andalusite schists and garnetiferous quartz-feldspar-biotite schists. In this part, minor meta-arkose is also found. The upper intermediate and felsic volcanic portion originally consisted of acid tuffs and rhyolites, but is now represented by quartz-porphyries and meta-rhyolites. In the vicinity of Faribault Brook the above sequence of rocks has been involved in a large anticline, on the northern limb of which the mineralization occurs. Most of the mineralization (except the Mountain Top deposit) is found in the intermediate shale-sandstone sequence.

The base-metal mineralization occurs in three zones, designated as Galena Mine, Silver Cliff and Core Shack showings. The Core Shack showing is highest stratigraphically (in its present position), the Galena Mine lowest. The host rock in all three cases is garnetiferous quartz-feldspar-biotite schists and the mineralization is accompanied by a low-grade alteration halo. The mineralization is largely undeformed.

At the Galena Mine (Figure 6-2) the sulphides - principally sphalerite, galena, pyrite, arsenopyrite with small to accessory amounts

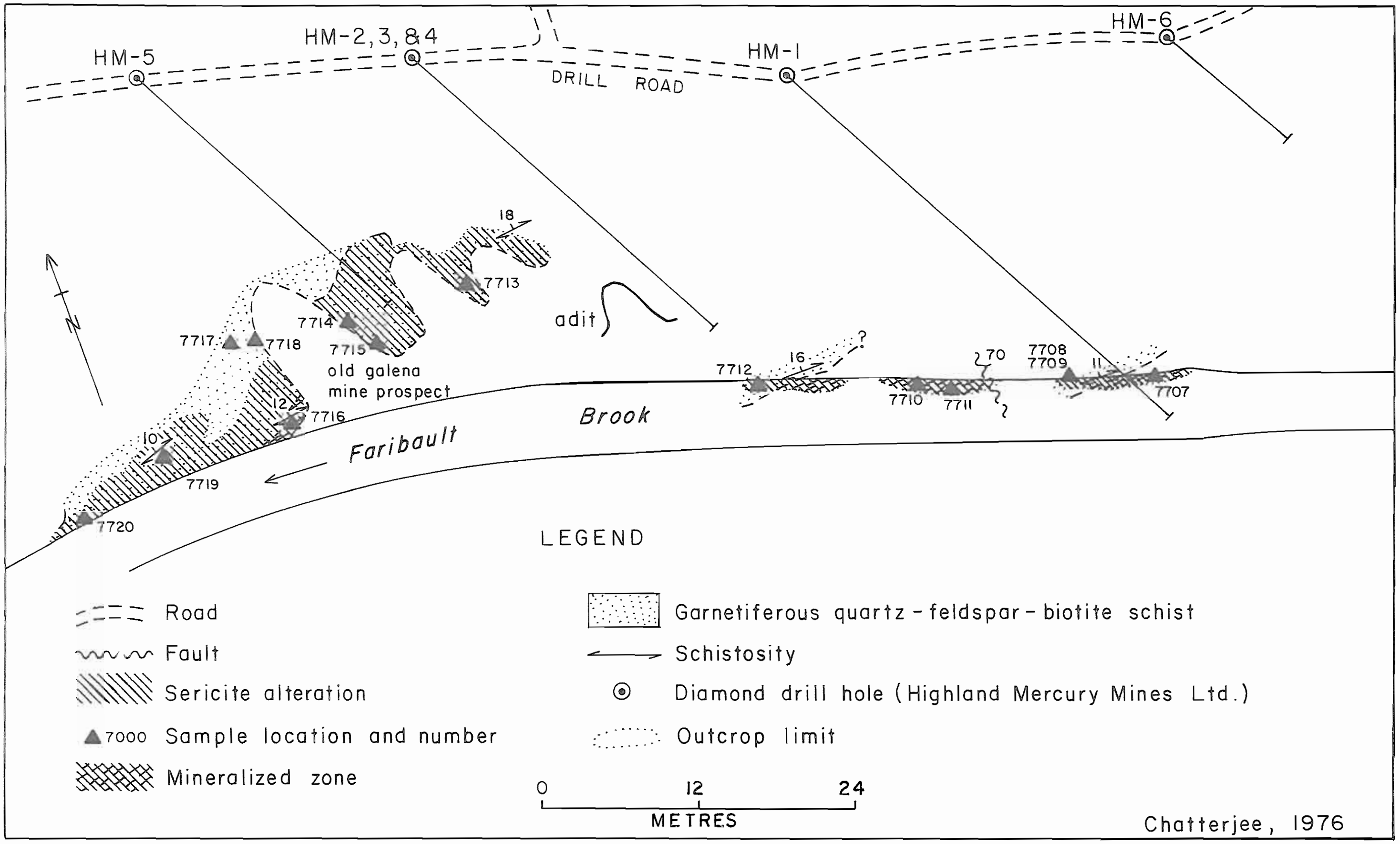
TABLE 6-1

Idealized Lithological Sequence of the George River Rocks: Cheticamp Area*



Estimated Thickness	Map Unit	Rock Types/Area of Exposure	Igneous Activity	Mineralization
∿ 70 metres	Intermediate to felsic volcanics	Quartz-porphyries, meta-rhyolites, Exposed: upper reaches Au Coin Brook		
∿ 140 metres	Interbedded shale and sandstone (Meta-sedimentary)	Sillimanite schist, almandine-andalusite schist, garnetiferous quartz-feldspar-biotite schist, sericite schist. Exposed: Dauphinee Brook, Cheticamp River and LeBlanc Brook		As-Zn-Pb-Ag-Au ± Cu Core Shack showing Zn-Pb-Cu-As-Ag-Au ± Bi Silver Cliff showing Zn-Pb-As-Sb-Bi Galena Mine showing.
∿ 125 metres	Mafic volcanics	Chlorite schist, hornblende schist, amphibolites. Exposed: upper reaches of Faribault Brook, Intersected in DDH MT5,6,7		Zn-Cu-Ag-Au Mountain Top showing.

* It is not known whether this sequence is stratigraphic or tectonic nor is it known which direction is stratigraphically upward.



Chatterjee, 1976

Figure6-2 Surface plan, Galena Mine Deposit, Faribault Brook.

of stibnite and bismuthinite - follow the layering (stratification?) of the enclosing schists faithfully and as a result show a beautifully bedded form, giving the mineralization the appearance of simple sulphide-bearing beds. The gangue minerals are calcite, quartz, sericite and chlorite.

At Silver Cliff (Figure 6-3) the mineralization is exposed over a length of 45 metres and the width varies between 2 and 8 metres. The sulphides at Silver Cliff are in the form of folded lenses of sulphide-rich,, meta-sediments and are concordant as well as discordant with the layering (bedding?) of the enclosing garnetiferous quartz-feldspar-biotite schists. Within the schists there are interbeds of arkose, forming a gradation to the arkose member. Similarly, there are also interbeds of schistose material within the more massive quartz-feldspar-biotite schist. The strike of these is roughly north-south and the dip 45°E. Detailed examination of the mineralized horizon shows that the sulphide concentration has developed not simply in one layer, but in several layers. The sulphide mineral association is complex, comprising principally sphalerite, galena, pyrite, arsenopyrite, chalcopyrite, tetrahedrite, argentite and bismuthinite, but with small to accessory amounts of pyrrhotite and lollingite. The gangue minerals are quartz, calcite, sericite and chlorite. The mineralization is accompanied by pronounced sericitic and chloritic alteration.

At Core Shack (Figure 6-4) there are a number of sulphide layers in quartz-feldspar-biotite schist. The strike of the host rock is north-south and the dip 2 to 5° to the east. Detailed examination reveals that along the sulphide layers, the sulphide mineralogy changes substantially. For example, it is common that a layer of arsenopyrite

Figure 6-3 Surface plan, Silver Cliff deposit, Faribault Brook

(In pocket at back of thesis)

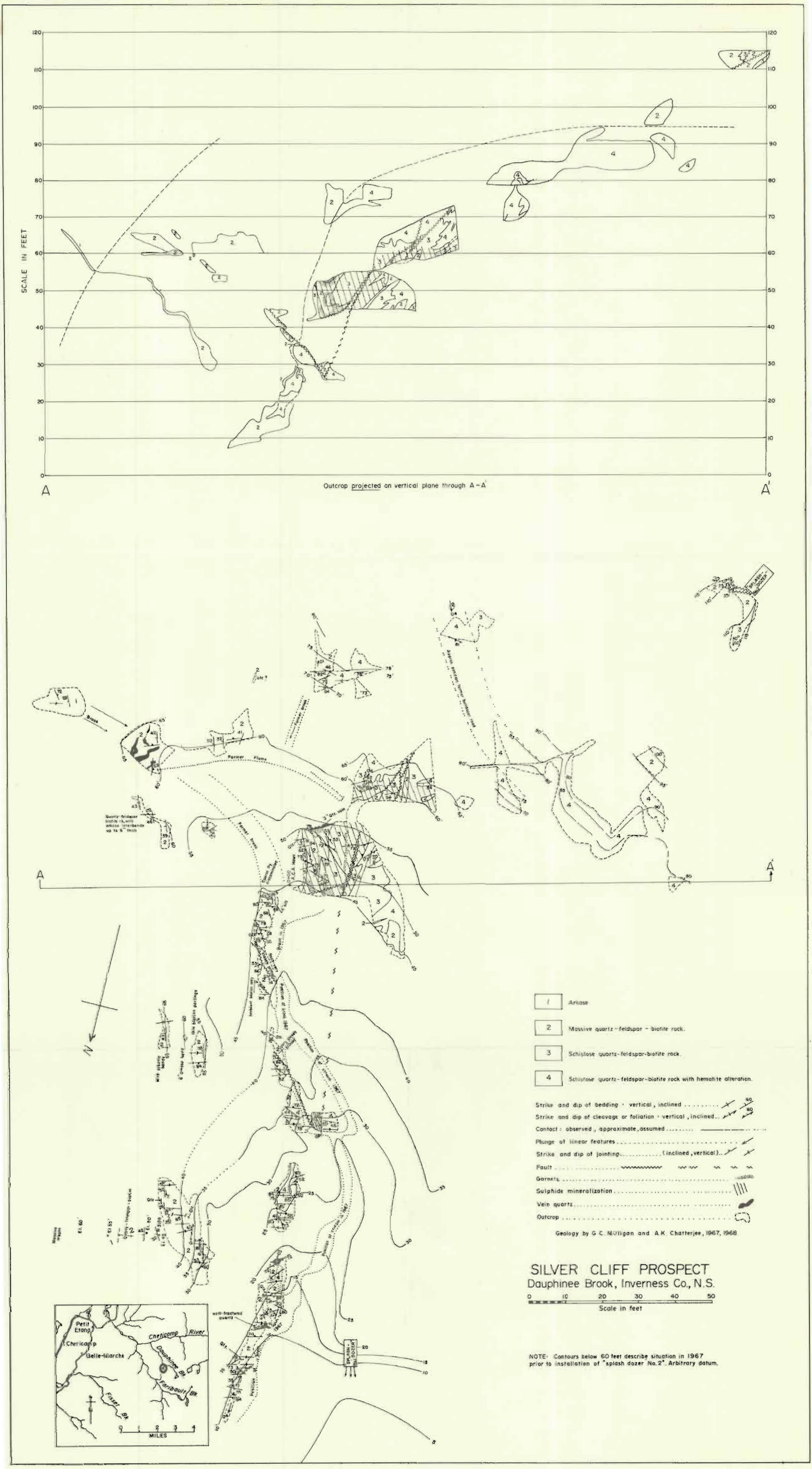


Figure 6-3
Surface Plan, Silver Cliff Deposit, Faribault Brook

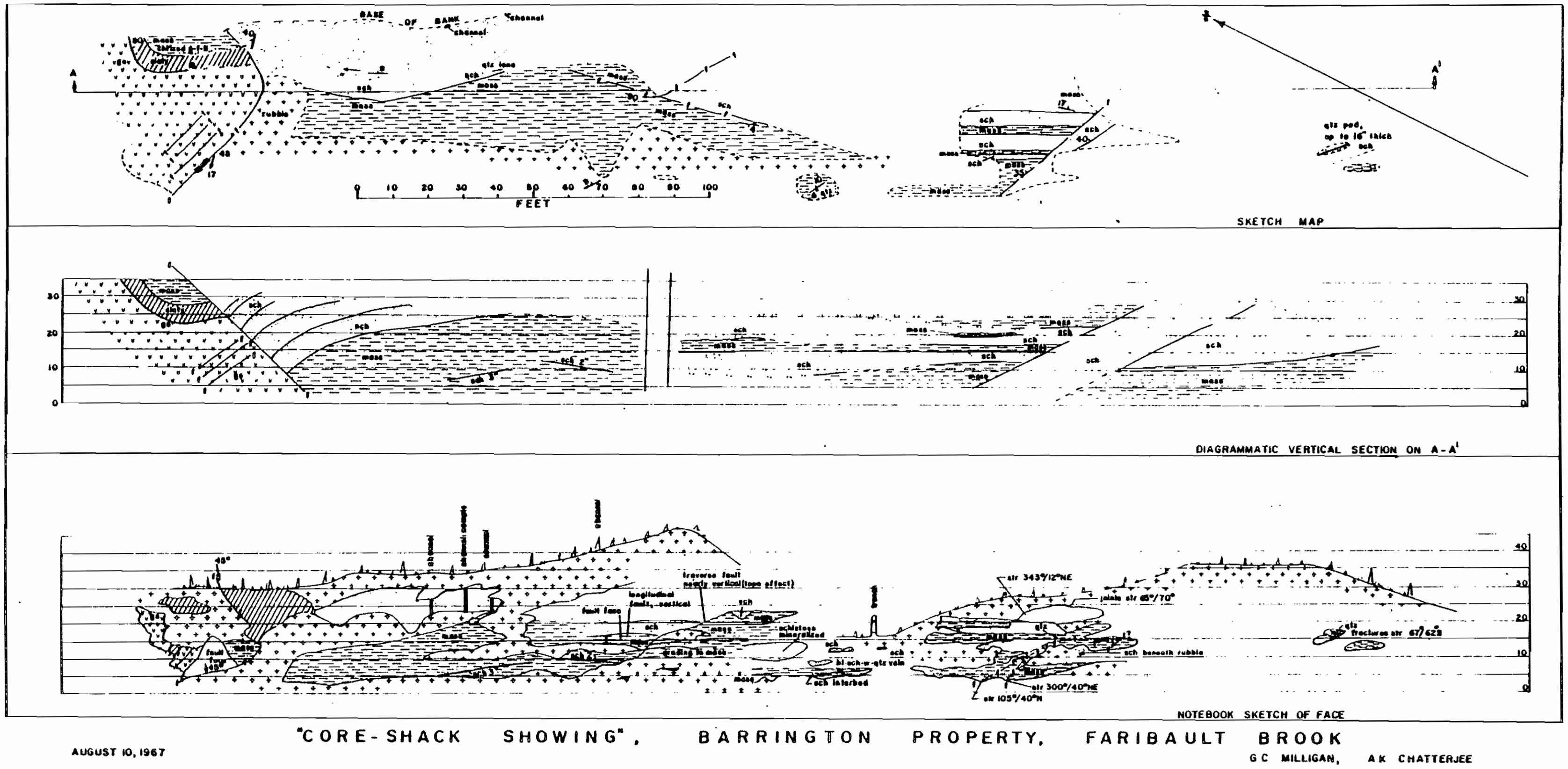


Figure 6-4

Surface Plan and Vertical Section, Core Shack Showing, Barrington Property grades into massive sphalerite and then into disseminated pyrite and pyrrhotite and finally into galena. The principal sulphides are arsenopyrite, sphalerite, pyrite, pyrrhotite, galena, argentite and minor chalcopyrite. These generally occur as discontinuous layers and as irregular splashes and veins. The gangue minerals are quartz, sericite, chlorite and calcite.

The Mountain Top showing was encountered as Zn-Cu-Ag-Au mineralization in meta-volcanics in DDH MT-5. In the vicinity of this diamond drill hole there are no surface exposures. The drill hole intersected chloritized, garnetiferous hornblende schist from 48 to 183 feet; from 183 to 227 feet sericitized, garnetiferous quartz-feldspar-biotite schist; from 227 to 318 feet interbedded biotite schist and hornblende schists; from 318 to 359 feet mineralized, hornblende schist and 400 feet quartz-feldspar-biotite schist. A ten-foot section (319-329) was assayed by Sullico Mines Limited and returned 0.28 per cent copper, 1.39 per cent zinc, 0.28 oz. of gold per ton and 1.42 oz. of silver per ton. Sphalerite-chalcopyrite-arsenopyrite-pyrite-pyrrhotite mineralization occurs as thin bands parallel to the foliation, as thin stringers cutting the foliation and as fine disseminations throughout the entire length of the mineralized zone. All the wall rock surrounding the mineralized zone is heavily chloritized.

Description of Lithological Units

The George River rocks in the Faribault Brook area are composed of three mappable units and a variety of metamorphic equivalents. As has been mentioned previously, these three units are (a) meta-volcanic unit, including such rock types as chlorite schists, hornblende schists and amphibolites; (b) meta-sedimentary unit, including such rock types as andalusite-sillimanite schists, almandine-andalusite schists, and garnetiferous quartz-feldspar-biotite schists and (c) intermediate and felsic volcanic unit. In the following description, only the first two units are fully described because all the known mineralization in the Cheticamp area is confined to these two units.

Meta-volcanic Unit

The rocks assigned to the meta-volcanic unit are medium to dark grey schists and are composed largely of hornblende, biotite, zoned calcic plagioclase, garnet, chlorite and quartz in widely differing proportions. Epidote and sphene are common accessories. Hornblende is commonly very poikilitic and strongly pleochloric, its maximum colour being a deep, almost bluish green. Biotite is well oriented and its maximum absorption colour is dark green. Prochlorite is a minor component and occurs as radial clusters that are clearly secondary after garnet, hornblende and biotite.

<u>Chlorite Schists</u>: Chlorite schist is by far the most characteristic rock in DDH MT-5 where it surrounds the mineralized hornblende schist. In this drill hole several layers, a few centimetres thick and composed almost entirely of chlorite, are interclated with the hornblende-rich schist. Hand specimens superficially resemble fragments of single large crystals of chlorite. The chlorite is dull green in hand specimen and makes up 10 to 40 per cent of the rock. Flakes range in average size from 0.05 to 0.20 mm and are well oriented along the cleavage direction; porphyroblasts, lacking in most rocks, include both concordant and cross-cutting grains. Albite as granules and porphyroblasts is the common feldspar. With the albite is quartz that is in part similar in

habit and appearance and in part segregated into tiny lenses of coarser grained material. Quartz and feldspar together total 45 to 85 per cent of the rock. Small granules of epidote make up as much as 15 per cent in some chlorite schists, and, in these, hornblende is also present as tiny corroded and altered prisms.

Hornblende Schist: Conspicuous porphyroblastic prisms of black hornblende characterize this rock type. The average length of the thin prisms ranges from 2 mm to 5 cm. Prisms are generally sub-parallel to the foliation; alignment is crude, however, and as seen in thin section, the prisms cut across the foliation. Calcic plagioclase, garnet, biotite, epidote or clinozoisite and opaque minerals are present in different proportions. Hornblende schist is layered with, and grades into, garnetiferous quartz-feldspar-biotite schist.

Amphibolite: Schistose amphibolite, approximately 70 metres thick, forms a conspicuous outcrop in the upper reaches of Faribault Brook, at the junction with McLeod Brook. The amphibolite consists of laminae alternating in small needles or larger prisms of actinolitic hornblende and in calcic plagioclase and subordinate quartz. Hornblende needles are subhedral and well aligned whereas the larger, stubbier prisms are anhedral and poorly oriented. Calcic-oligoclase occurs as a mosaic of equant anhedra about 0.2 mm in diameter and shows smooth zoning. In one outcrop on the east bank of MacLeod Brook, the amphibolite cuts across the hornblende schist. Probably the amphibolite was a diabase dyke.

Meta-sedimentary Unit

The meta-sedimentary unit consists predominantly of grey and buff-coloured schists, micaceous quartzites and feldspathic quartzites.

In these rocks laminations and compositional layering are conspicuous. All the rock types are fine or medium grained, and have a moderate to well-developed schistosity, which is crenulated in places. The distinction between various rock types cannot be made satisfactorily without microscopic examination. Generally, in sillimanite and andalusite schists, muscovite predominates over biotite, and with an increase in quartz content the schist grades into quartzites.

Andalusite-sillimanite Schist: It is grey to buff in colour and commonly iron stained. The schist contains small porphyroblasts of andalusite, which are generally partly altered to sericite. The porphyroblasts are 0.5 to 2 cm long and are aligned parallel to the schistosity. Fibrolite is found in quartz and muscovite, and occasionally in biotite. Some of the rocks contain aggregates of fibrolite which are generally replaced by sericite, and many of the small lenses of sericite may have been formed by the alteration of the fibrolite aggregates. A few thin sections also show idioblastic garnet.

Almandine-andalusite Schist: It is greyish green to buff in colour and is a common rock type at Silver Cliff and Core Shack. At these localities it is highly altered and appears as quartz-sericite schist. Pale pink porphyroblasts of almandine garnet are generally present in small amounts, but in places they form up to 70 per cent of the rock. The altered rock contains up to 60 per cent sericite plus a quartz component.

Garnetiferous quartz-feldspar-biotite Schist: These schists occur widely and are the host rock for mineralization at Silver Cliff, Core Shack and Galena Mine. The schist is generally of dark colour, and the foliation planes are crinkled. Folia consist of aligned flakes of micas separated by seams of quartz and feldspar. Some samples have a micro-augen structure, in which blades of mica wrap around quartz grains, garnet grains and quartz-feldspar aggregates. The mineralogical characteristics of this rock type are discussed in detail in a later section on wall rock alteration.

Meta-arkose: It is speckled light to dark grey, weakly schistose, and generally has a sugary texture. It is seen only at Dauphinee Brook overlying the mineralized garnetiferous schist. Garnetiferous amphibole schist was encountered in DDH B-26 at a depth of 78 feet interbanded with the quartz-feldspar-biotite schist. Both the meta-arkose and amphibole schist are considered as minor rock types.

Mineralogy: Description

As described above, the George River rocks of the Cheticamp area are composed of three mappable units and a variety of metamorphic rocks. The mineralogy of these rocks varies more significantly with the metamorphic grade than it does with the stratigraphy and it is accordingly appropriate to consider the characteristics of the mineralogy for the entire sequence of rock in the Cheticamp area.

Quartz:

Quartz is a very abundant and widespread mineral formed at different times and by different processes. It commonly constitutes about 35 per cent of the rock and is everywhere anhedral. It occurs as small crystals in the groundmass of the rock, as larger grains in segregated lenses or as augen with or without other minerals. Quartz forms mosaics of generally even-sized grains that are commonly equant, but which may have a dimensional elongation of as much as 2:1 in some rocks.

Quartz is the main constituent of many veins, formed mostly by the filling of open fissures but partly by replacement. The intersection of one vein by another indicates several stages of vein formation.

Quartz is the most common gangue mineral in the sulphides. Individual veins are not large, seldom exceeding 1/2 metre in width, but stringer zones and stockworks locally form conspicuous outcrops.

Fine-grained quartz masses in fault zones appear to have been formed by silicification of broken and sheared rocks.

Quartz is altered only in the sense that some of it is recrystallized, with a loss of undulatory extinction and the formation of smaller, complexly interlocking grains. It is generally clear, but some contains inclusions of clay (?), chlorite, sericite and bubbles of gas or liquid.

Plagioclase:

Plagioclase, generally of composition within the range Ab 95-70, makes up as much as 35 per cent of the host rock. The plagioclase of the lower grade rocks is albite, whereas that of the middle or high-grade rocks is generally in the more calcic part of the range just quoted.

Orthoclase and microcline:

Potassium feldspar generally constitutes less than 10 per cent of the rock. It is chiefly microcline in gneisses, and is orthoclase or cryptoperthite in schists. In general, the K-feldspar occurs as white to pink, subhedral to anhedral, tabular, well-twinned porphyroblasts ranging in size from 0.02 to 1.5 mm. Microcline also occurs in blebs in antiperthite crystals.

Prochlorite:

Most of the schists in the vicinity of sulphide mineralization contain prochlorite in various amounts. Several varieties of chlorite may occur in the same specimen, and some are not readily distinguishable from green biotite. In schists, in which it is a minor component, prochlorite is primarily a groundmass mineral occurring in tiny flakes, sub-parallel to the cleavage direction and either concentrated in folia or strewn throughout the rocks. Where it is a major component, prochlorite occurs characteristically as thick, subhedral porphyroblasts, as much as 0.5 to 4.0 mm long, randomly oriented and cut across the foliation at all angles. It is also found in sheaves in many places. Many thin sections have both oriented flakes and random porphyroblasts.

The common chlorite is aluminian prochlorite. It is green in hand specimen, colourless to faintly pleochroic, light yellowish green in thin section, and displays anomalous yellowish grey to greyish green interference colours.

Ferroan prochlorite is found in many of the altered rocks. This chlorite, also green in hand specimen, is strongly pleochroic and has a bright brown to reddish brown anomalous interference colour. A few other specimens have prochlorite that is markedly pleochroic, like the ferroan variety, but it has yellowish or greenish grey interference colours, more like the aluminian variety; presumably this is an intermediate type.

The main varieties of chlorite noted above occur in veinlets that cut biotite and carbonate minerals, and also have developed from, or might be considered to be alteration products of, garnet, biotite and amphiboles. The optical properties of some samples of chlorite are shown in Table 3-2.

TABLE 6-2

Optical Properties of Chlorite (2V estimated)

No.	Indices of Refraction	2V		Comments
1	Y variable, 1.560 - 1.590 ± 0.006	0°	(-)	Birefringence 0.006 (?); yellow-green. Range for several grains.
2	Z = Y = 1.656 - 1.658 ± 0.005	0°	(-)	Birefringence = 0.004 - 0.008; grass-green. Range for several grains.
3	Z = 1.641 - 1.610 ± 0.006	0 - 5°	(-)	Range for several grains; green.
4	Y = Z = 1.587 ± 0.003; X = 1.560		(-)	X = nearly colourless; Y = Z = medium green.
5	X = 1.651; Y = Z = 1.653 - 1.654 ± 0.003	0°	(-)	X = light yellow brown; Y = Z = deep green.
6	Y = Z = 1.649 ± 0.003	0°	(-)	Birefringence 0.006.

Biotite:

Biotite is typically larger, more irregularly shaped and not as well oriented as is muscovite. In the fine-grained schists it occurs chiefly as prophyroblasts that are commonly oriented, anhedral and poikilitic. The present study has shown that three kinds of biotite are present.

There is a green biotite which has a distinctive plate-like shape. The grains usually range from 0.01 to 0.05 mm in diameter. Optical properties of six samples of green biotite are shown in Table 6-3.

The brown biotite of the quartz-feldspar-biotite shist occurs in shred-like habit and ranges in grain size from 0.05 to 1.5 mm. It is strongly pleochroic, with X = light yellow-brown and Z = very dark brown, almost black. Optical properties of some brown biotite samples are shown in Table 6-3.

A third type of biotite, possibly related to brown biotite described above, can be recognized in thin sections of sulphide-carbonate veins. The mica is shred-like in habit and occurs either in veinlets that cut carbonate or as individual shreds that lie in the carbonate groundmass near the sulphides. The colour of this mica has considerable range, even in the same thin section, but X is generally colourless and Z may range from a very faint yellow to a rather weak brown.

Garnet:

Red-brown garnet is a common component of the schist. Although generally including less than 5 per cent, rocks with as much as 10 per cent garnet are common, and a few have as much as 50 per cent.

The garnet is reddish brown or, less commonly, brown or light to moderate red in hand specimen. Most is greyish orange-pink in thin

TABLE 6-3

Optical Properties of Biotite (2V estimated)

GREEN BIOTITE

No.	Indices of Refraction	2V		Comments
1	1.658 ± 0.004	small	(-)	Y = Z dark green to greenish brown.
2	1.657 ± 0.003	0 - 4°	(-)	X = light greenish yellow, Y = Z = dark green.
3	1.620 - 1.625 ± 0.008	5 - 20°	(-)	Range for several grains.
4	1.620 - 1.625 ± 0.004	0 - 5°	(-)	X = yellowish brown, Y = Z = dark brown. Range for several grains.
5	1.590 - 1.600 ± 0.010	-		Range for several grains. Y and Z in individual = dark brown or olive brown.
6	1.653 - 1.658 ± 0.005	-		Range for several grains. X = light olive green, Z = Y = dark greenish olive.
BROWN BIOTITE				
1	1.588 - 1.593 ± 0.005	0° (?)	(-)	Range of several grains. In one grain 2V = 10° (-) X = yellow brown, Y = Z = very dark brown.
2	1.663 - 1.665 ± 0.004	0 - 5°	(-)	Range of several grains. X = light brown, Y = Z = dark brown.
3	1.660 ± 0.005	0 - 10°	(-)	Y = Z dark yellowish brown.
4	1.675 ± 0.005	small	(-)	X = pale yellow, Y = Z dark brown or greenish brown.

section. None shows anomalous birefringence. Habit varies widely (Figure 6-5); euhedral, subhedral, anhedral and extremely irregular crystals are all abundant. Garnet crystals average as small as 0.5 mm in some schists and as large as 5 mm in others; in most the grains are near 1 mm. Some garnets partly cut across and partly shoulder aside folia of the schists. In other places, garnets are elongate along the cleavage. Clear evidence of rolling (shearing after crystallization) was seen in only a few specimens.

Hornblende:

Hornblende generally forms prisms that are short to acicular, ragged to euhedral or poikiloblastic to compact. The prisms are commonly crudely aligned.

The amphibole of arkose is black in hand specimen but pleochroic in light colours (X = pale greenish yellow to light yellowish-grey, to Z = pale greyish yellow). The sparse amphibole of massive quartz-feldspar-biotite schist is also black, but it is darker in thin section (X = greenish yellow, Y = yellow green, Z = greyish, bluish or dark green). In the plicated schistose member, the amphibole is greyish green in hand specimen and pleochroic from X = pale greenish yellow to Z = greyish yellow green. These differences must partly reflect compositional differences among the strata, but they are due chiefly to different grades of metamorphism. Black hornblende is in rocks of higher grade than green hornblende or actinolite; and within the black, the more darkly pleochroic hornblende is of the higher grade assemblage.

Epidote minerals:

The epidote makes up less than 10 per cent of most of the rocks in which it occurs, although a few specimens have as much as 30

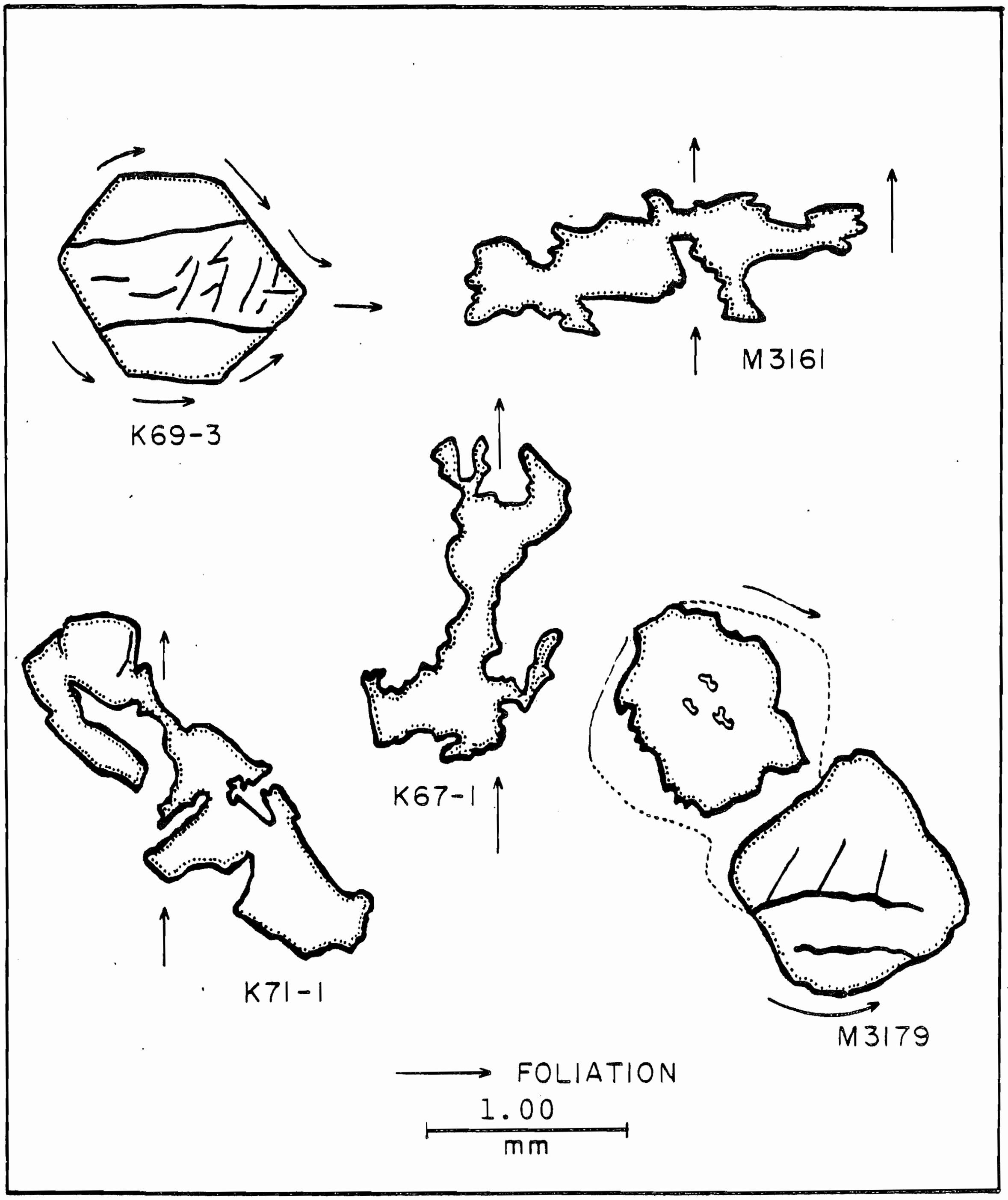


Figure 6-5

Habit and textural patterns of some garnet from "Silver Cliff" and "Core Shack" prospects, Faribault Brook.

per cent. Both orthorhombic and monoclinic epidotes are common, but they are not observed together. These occur as granules, small anhedra and small domes. Clinozoisite is more commonly microporphyroblastic than are the others (Figure 6-6).

Clinozoisite is colourless but shows bright to dark blue interference colours. Aluminian epidote is also colourless in thin section but has a moderate birefringence, near 0.015 to 0.025, and is either grey or green in hand specimen. Iron-rich epidote is pleochroic in yellowish green, has a birefringence higher than 0.03, and is green. Clinozoisite and aluminian epidote intergrade with each other, or are present in adjacent laminae, in some of the schists.

A few schists carry porphyroblasts of zoisite - euhedral domes as large as 0.5 by 1 by 15 mm that have a superficial resemblance to prisms of hornblende (Figure 6-6#E and F). The zoisite is colourless in thin section and glassy greenish grey in hand specimen. The crystals are bounded by the [101] faces, with lesser development of the [100] pinacoids. The domes have strong [100] cleavage and [010] parting and conspicuous striations parallel to <u>b</u>. Extinction is straight and symmetrical, and sections perpendicular to Bxa show blue colour for 25° of rotation on one side of extinction. The zoisite has a 2V of 15°, $n_x = 1.692$, $n_y = 1.693$, $n_z = 1.701$, and $n_z - n_x = 0.009$.

<u>Andalusite:</u>

Small prismatic prophyroblasts of andalusite accompanied by muscovite can be recognized under the microscope. In these rocks the andalusite forms anhedral spongy porphyroblasts that enclose minerals of the groundmass and it is partly altered to matted aggregates of sericite.

Figure 6-6 A and B

ANHEDRA AND DOMES OF CLINOZOISITE

A: Anhedron twinned on 100 showing strong 001 cleavage.
B: Two domes and an anhedron.

Figure 6-6 C and D

MICROGRAPHIC CLINOZOISITE PROPHYROBLASTS

C: Three (?) subparallel crystals, cut to parallel to b.
D: Cross section of similar group.

Figure 6-6 E

E: Cross sections of porphyroblastic zoisite domes.

Figure 6-6 F

F: Section cut parallel to b and
Section cut perpendicular to b.

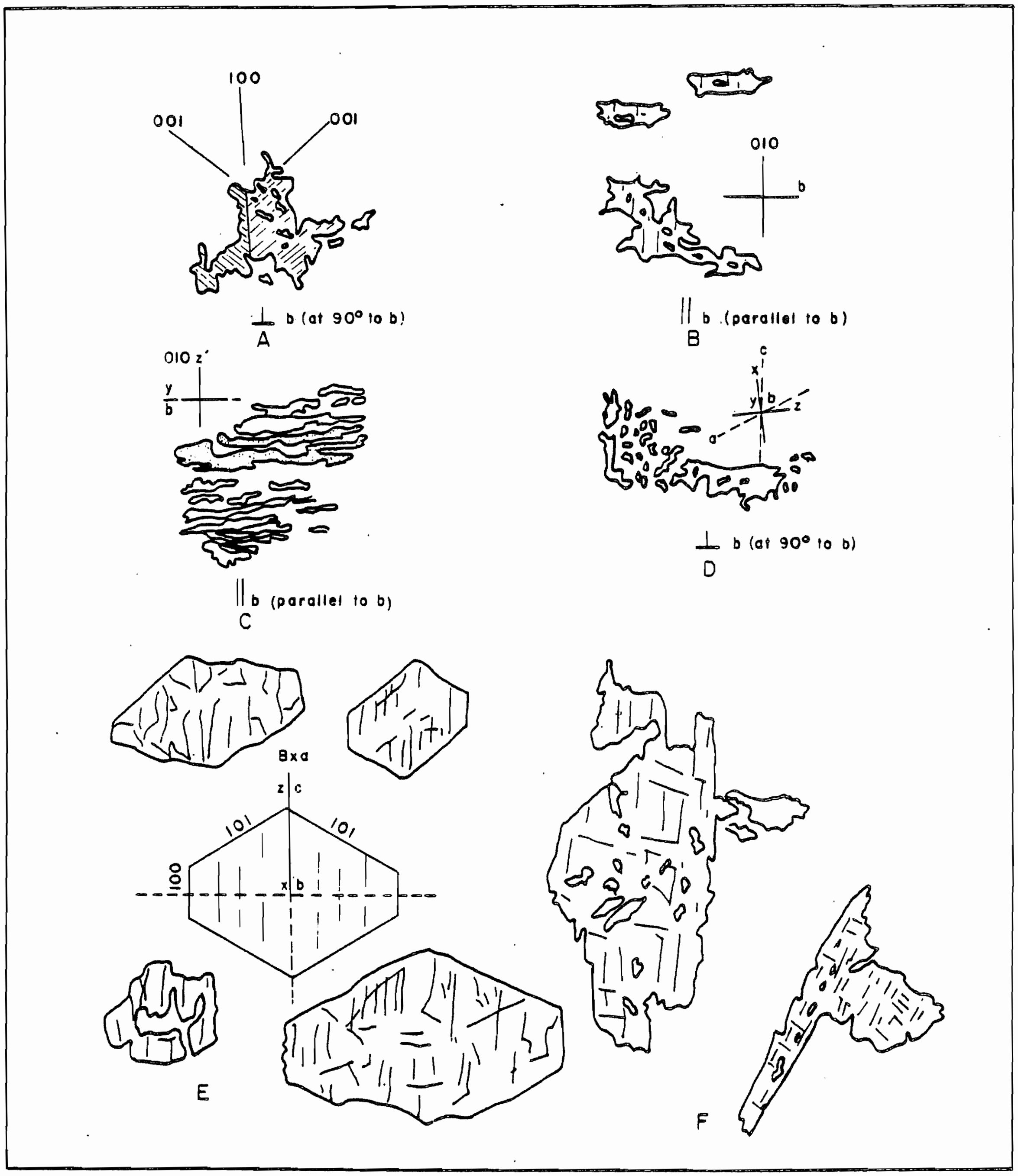


Figure 6-6
Sketches Showing Granules, Anhedra
and Domes of Epidote From Faribault Brook

Muscovite:

Muscovite is widely distributed in the schists. It is also common in veins. Secondary muscovite (sericite) is abundant in the wall rock adjacent to the mineralized veins. The alteration muscovite has the same optical properties as that in the schists. Tests in immersion oils indicate that n_y ranges from 1.590 to 1.605 and that 2V ranges from 30° to 40°. Muscovite is associated with chlorite, biotite, K-feldspar, plagioclase, andalusite and sulphides.

Other minerals:

Most of the schists contain from a trace to 5 per cent sillimanite, sphene, graphite, actinolite, calcite, apatite, tourmaline, magnetite and zircon.

The observed mineral associations are listed in Table 6-4.

Descriptive Features of Sulphide Minerals

Pyrite:

Pyrite has been introduced throughout the process of mineralization and is probably a constituent of all the veins. Two varieties of pyrite have been noted: one is an early, massive pyrite (pyrite I), and the other is late, finely crystalline pyrite (pyrite II).

The most common mode of occurrence of pyrite I is in disseminated, euhedral to subhedral grains that range in size from 2.0 to 3.0 mm. The replacement of silicates by pyrite I produces irregular masses in many places. Poikilitic and skeletal crystals are very common, and much that might be called corroded or partially replaced pyrite is actually younger than its groundmass. The poikilitic character of the pyrite is best recognized where the pyrite has partially replaced

TABLE 6-4

Observed Minerals Association

Pelitic Rocks of Faribault Brook Area

(Individual associations here listed have each been seen within the limits of a single thin section. There is no implication that these are all equilibrium assemblages.)

Quartz-muscovite-biotite-K-feldspar-plagioclase-calcite
Quartz-muscovite-biotite-chlorite-garnet-epidote
Quartz-muscovite-biotite-chloritoid-chlorite
Quartz-muscovite-garnet-biotite-chlorite-sericite
Quartz-muscovite-garnet-K-feldspar-sericite-calcite

Quartz-K-feldspar-plagioclase-garnet-biotite-chlorite-sericite
Quartz-muscovite-garnet-plagioclase-sericite-epidote
Quartz-garnet-K-feldspar-sericite-epidote

Quartz-muscovite-K-feldspar-garnet-andalusite-kyanite
Quartz-muscovite-plagioclase-biotite-chlorite-sericite-kyanite-garnet
Quartz-muscovite-plagioclase-biotite-chlorite-sericite-kyanite-garnet-K-feldspar
Quartz-muscovite-biotite-chlorite
Quartz-muscovite-biotite-andalusite
Quartz-muscovite-biotite-andalusite-K-feldspar-plagioclase
Quartz-muscovite-sillimanite
Quartz-muscovite-oligoclase-biotite-andalusite-garnet
Quartz-muscovite-albite-epidotes

Quartz-muscovite-chlorite-albite
Quartz-muscovite-chlorite-magnetite
Quartz-muscovite-chlorite-chloritoid
Quartz-muscovite-magnetite-chloritoid-epidote
Quartz-albite-muscovite-biotite-chlorite-clinozoisite
Chlorite-muscovite-kyanite-quartz-albite
Chlorite-chloritoid-muscovite-quartz-epidote-calcite-tourmaline
Quartz-muscovite-biotite-almandine-K-feldspar
Quartz-muscovite-biotite-almandine-sillimanite
Quartz-muscovite-oligoclase-biotite-almandine
Quartz-muscovite-oligoclase-biotite-almandine-sillimanite
Quartz-plagioclase-biotite-almandine-sillmanite-K-feldspar
Quartz-plagioclase-biotite-almandine-sillmanite
Quartz-plagioclase-biotite-sillimanite

country rock in a vein. Similar textures also result where pyrite has replaced the older minerals. It is not always possible to tell whether the shape of a crystal results from corrosion, and thus represents an older mineral, or whether it is a skeletal crystal and thus probably indicates a younger mineral. Pyrite I is closely associated with arsenopyrite.

The late, finely crystalline pyrite occurs in veinlets and as porous masses within the sulphide zone, where it is generally associated with sphalerite, chalcopyrite and galena.

Pyrrhotite:

Most pyrrhotite grains are from 0.01 to 1.0 mm; grains larger than 1.0 mm are rare. Much of the pyrrhotite is not homogeneous and in polished surfaces clearly shows two phases. The intergrowths are in general parallel and there is no development of grating textures. One phase is darker, but both have the same crystallographic orientation as shown by parallel extinction of the two phases. The distribution of two-phase pyrrhotite is erratic and it is not characteristic of any vein or group of veins.

Marcasite:

It has been observed that pyrrhotite has been altered to a mixture of marcasite and pyrite. Aggregates of fine-grained granular marcasite form as the first stage in the alteration of pyrrhotite. In some areas alteration started along pyrrhotite grain boundaries; in other areas, alteration started in the centre of the grain, where there is no visible fracture. A second stage in the alteration process appears to be the recrystallization of granular to bladed or lamellar marcasite.

Edwards (1954) considered that such alteration could be hypogene and that it was the result of a change in the acidity and temperature of residual mineralizing solution. The partial replacement of marcasite blades by galena shows that the alteration of pyrrhotite was hypogene, and that it dates such alteration as at least pre-galena in age.

Arsenopyrite:

Arsenopyrite is one of the early sulphides and generally occurs as euhedral crystals. The crystals are as much as 5.0 mm long and characteristically show wedge-shaped forms having short prism faces and domes. Lollingite is almost invariably associated with coarse-grained arsenopyrite. It has almost the same reflectivity as that of arsenopyrite but a microchemical test with HgCl quickly differentiates it from arsenopyrite.

Sphalerite:

Sphalerite is the predominant sulphide mineral and is dark brown to nearly black. It is generally associated with arsenopyrite, pyrite and pyrrhotite. The grain size is generally less than 1.0 mm and most grains are in the 0.1 to 0.5 mm range. Textural and cross-cutting relations suggest that sphalerite is younger than pyrrhotite and older than tetrahedrite, chalcopyrite and galena.

Chalcopyrite:

Chalcopyrite is the principal copper mineral but is a minor constituent of the sulphides. It occurs as scattered grains intergrown with sphalerite, galena and pyrite. Some of it was formed at the same time as sphalerite but most is younger, as is indicated by numerous chalcopyrite stingers cutting the sphalerite. A little chalcopyrite is also associated with sphalerite, galena and bornite in the quartz veins of the area.

Galena:

Galena, associated with sphalerite, chalcopyrite, pyrite and tetrahedrite, is a late-formed mineral in the sulphide veins. Study of polished sections of galena has not revealed any silver-bearing minerals; however. the silver may be present in the form of sulfosalts in exsolved blebs.

Enargite:

Enargite is a less common mineral than chalcopyrite but is found associated with it. Thus, whereas it always has chalcopyrite with it, the reverse is not true.

Enargite forms tabular, lath-shaped or, rarely, prismatic crystals that are usually bright. They may be scattered singly, or several crystals may be clustered on chalcopyrite or sphalerite; rarely, the enargite crystals may be included in an outer zone in garnet crystals (Plate 6-3, Figure A). There is no fine lamellar twinning characteristic of luzonite (Ramdohr, 1950; Gaines, 1957).

Chalcocite and covellite:

The chalcocite occurs as veinlets, pods and irregular masses that coat and replace pyrite, chalcopyrite and, to a lesser extent, pyrrhotite and arsenopyrite. It is usually associated with covellite.

Magnetite:

Magnetite is associated with the early sulphide minerals, where it occurs as finely crystalline grains.

Hematite:

The hematite was derived from the original iron sulphides. It is generally in irregularly shaped, red, earthy masses - associated with clay minerals and other iron oxides.

Tetrahedrite:

Grains of tetrahedrite are rarely larger than 1 mm and most are less than 0.5 mm in diameter. They are anhedral and corroded. The grain boundaries in polished surfaces cannot be recognized without etching with HNO_3 and KCN.

According to Palache and others (1944, p. 375), there is a complete series from tetrahedrite (antimony dominant) to tennantite (arsenic dominant); however, tennantite has not been recognized in this area.

The observed sulphide mineral associations from Faribault Brook area are tabulated below.

Wall Rock Alteration

The alteration of rocks into zones surrounding sulphide mineralization may differ in response to the type and proportion of rock minerals (i.e., the chemistry of the wall rocks) as well as to the physical and chemical character of the mineralizing solution. Wall rocks adjacent to the mineralized zones in the Faribault Brook area characteristically have a sequence of mineralogical zones. The fresh rock, zone 4, grades vein-ward through weakly argillized rock, zone 3, to strongly argillized rock, zone 2, to sericitized rock, zone 1. Exceptions to this zonal sequence have not yet been found. The metasedimentary rocks of the Faribault Brook area contain quartz, K-feldspar, plagioclase and biotite as essential minerals (i.e., they have the bulk composition of a granite or granodiorite). These rocks nearly everywhere alter to a softer outer zone in which clay minerals are dominant, and a hard, bleached, sheared

TABLE 6-5

Sulphide Associations at Faribault Brook Area

(Individual associations here listed have each been seen within the limits of a single polished section.)

Pyrite-pyrrhotite-arsenopyrite±magnetite
Pyrite-pyrrhotite-arsenopyrite-lollingite
Pyrite-pyrrhotite-arsenopyrite-lollingite-marcasite
Pyrite-pyrrhotite-arsenopyrite -marcasite-sphalerite

Pyrite-pyrrhotite-sphalerite-chalcopyrite-bornite
Pyrite-pyrrhotite-sphalerite-chalcopyrite
Pyrite-pyrrhotite-sphalerite-chalcopyrite -galena

Pyrite-pyrrhotite-sphalerite-chalcopyrite-bornite-covellite

Pyrite-pyrrhotite-sphalerite-chalcopyrite-chalcocite-covellite

Pyrite-pyrrhotite-sphalerite-enargite-chalcopyrite

Pyrite-pyrrhotite-sphalerite-chalcopyrite-bornite-chalcocite-covellite-enargite

Pyrite-pyrrhotite-galena-chalcopyrite-bornite
Pyrite-pyrrhotite-sphalerite-tetrahedrite-galena-chalcopyrite
Pyrite-pyrrhotite-sphalerite-tetrahedrite-galena

sericite-quartz zone adjacent to the mineralization. The meta-volcanic rocks, which contain an abundance of iron-bearing minerals and plagioclase, alter instead to a soft rock containing sericite and chlorite near the mineralization. In the host rocks, where plagioclase and biotite are absent, montmorillonite-chlorite and aphrosiderite-chlorite are the predominant alteration products (i.e., they occupy the position of the sericite zone in other rocks).

Wall Rock Alteration

in

Garnetiferous-quartz-feldspar-biotite Schist

The relationship between the mineralization and the altered wall rock encountered in DDH HM-2 and DDH HM-4 is shown in Figure 6-7. Based on the relative proportion of minerals and their associations, the altered wall rock has been divided into four zones. This zonal division is based on the study of 101 thin and polished sections and 39 X-ray diffraction analyses and forms the basis for the following discussion.

Zone 4. Fresh garnetiferous quartz-feldspar-biotite schist : Fresh rock, as the term is used in the thesis, is characterized in hand specimen by the clear, reflective appearance of the constituent minerals, and in thin sections by the lack of observed alteration of plagioclase, biotite and garnet (Plate 6-1A). The biotite is triocthedral and occurs as elongated cleavage plates that are generally brown to black or, less commonly, a greenish brown. The garnet is typically almandine ($\bar{a}_0 = 11.52 \pm 0.04$). The transition from zone 4 into zone 3 is gradual, but the boundary is placed where "sericite-like" inclusions in feldspar definitely become megascopically recognizable.

Zone 3. Weakly argillized rock: In this zone the rock is hard, and the original structure and texture are preserved. The plagioclase grains, white to light grey, have a dull, chalky lustre that is due to incipient alteration on cleavage and fracture faces to patchy aggregates of clay. In the core logs these patches were called "sericite", but X-ray studies indicate that they are actually composed of a mixture of montmorillonite, illite and random mixed-layer montmorillonite clay minerals. Near the boundary with zone 2, plagioclase is altered to fine-grained aggregates

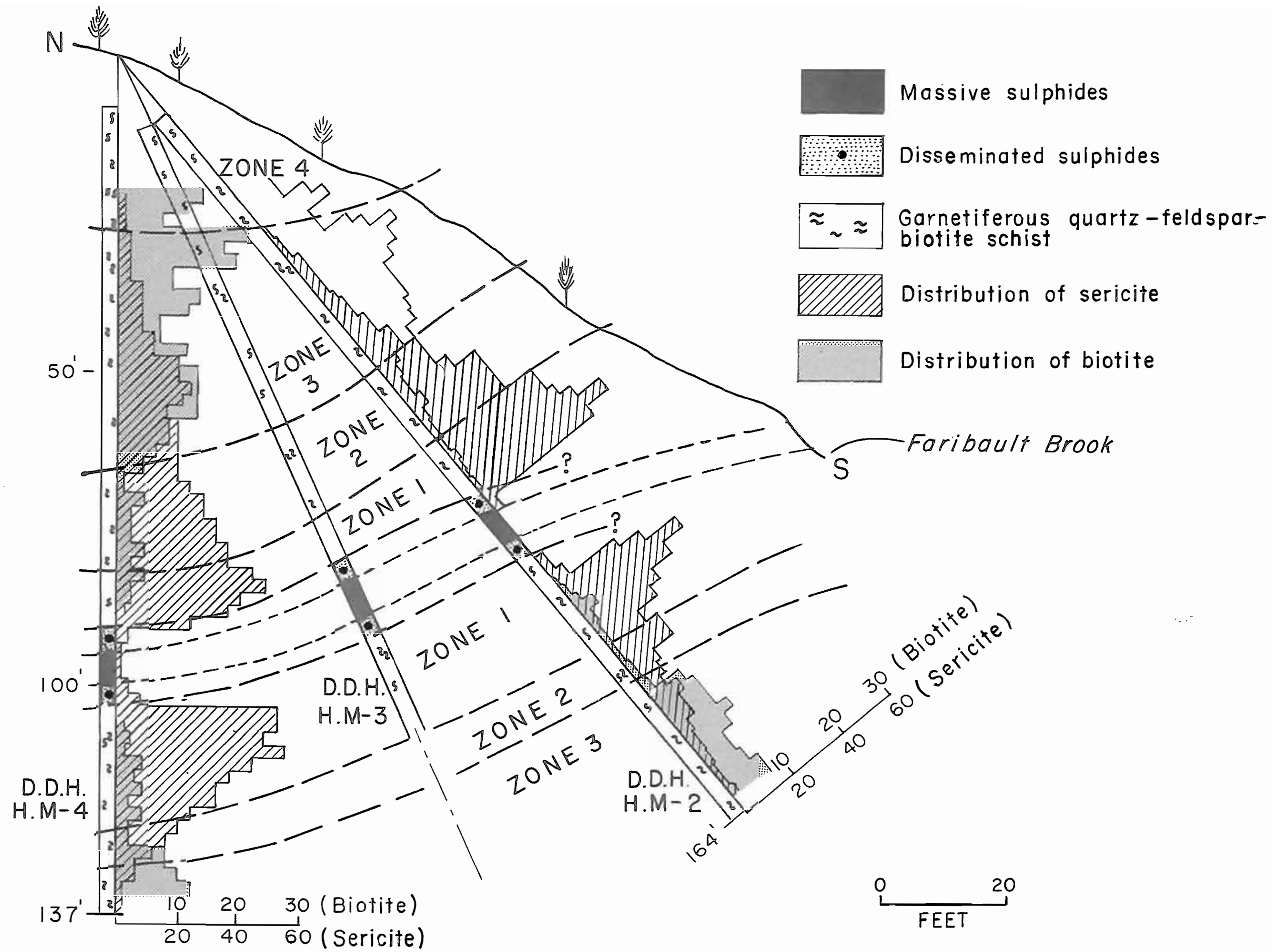


Figure 6-7 Rock types and distribution of sericite and biotite in D.D.H HM-2 and 4; Galena Mine Faribault Brook. For location of drill holes see Figure 6-2. Visual estimates of percentages are determined for 2-foot sections of core and plotted at depth of midpoints. Zone 4 = unaltered wall rock; zone 3 and 2 = argillized rock; zone 1 = sericitized rock.

of montmorillonite, other clay minerals and calcite. As observed in thin section, the clay minerals appear to be composed of several irregularly intermixed components that have variable optical properties (Plate 6-1B and C). Garnet, biotite and K-feldspar appear to remain unaltered, but X-ray examination of a hand-picked sample (HM2-52 feet) of K-feldspar revealed the presence of kaolinite and illite (or sericite).

Zone 2. Strongly argillized rock: In this zone the rock is soft, composed of light greyish green to white clay minerals, quartz, partially altered K-feldspar, biotite, almandine and nearly completely altered plagioclase. The boundary between zone 3 and 2 is rather sharp and easily diagnosed megascopically, being characterized by a sharp increase in "sericite" (megascopic identification) and a drop in biotite content. The clay minerals are most abundant in this zone and, because the particle size is below the effective resolution limit of the microscope, the image viewed usually is that of an aggregate of clay minerals. The methods of X-ray identification of clay minerals used in this study are described by Weaver (1958). On X-ray diffraction data, this zone may be divided into several sub-zones based on the predominant clay mineral within the mixed clay assemblage. The outermost sub-zone, 2c, is a montmorillonite-rich rock that grades into a less distinct sub-zone, 2b, of illite-rich rock, that in turn grades into the kaolinite-rich rock, sub-zone, 2a, adjacent to zone 1. The boundary between zones 2 and 1 is generally sharp, and is marked by distinct changes in texture and mineral content.

Within zone 2, biotite has a predominantly 1M trioctahedral structure (Table 6-6), and locally biotite flakes are replaced irregularly

Plate 6-1

Photomicrographs showing the minerals of the unaltered wall rock and alteration of plagioclase and biotite to clay minerals and chlorite. Figure A, unaltered plagioclase feldspar, biotite and garnet. Figures B and C, alteration of plagioclase to fine-grained aggregates of montmorillonite and calcite. Figure D, alteration of biotite to chlorite along cleavage planes.

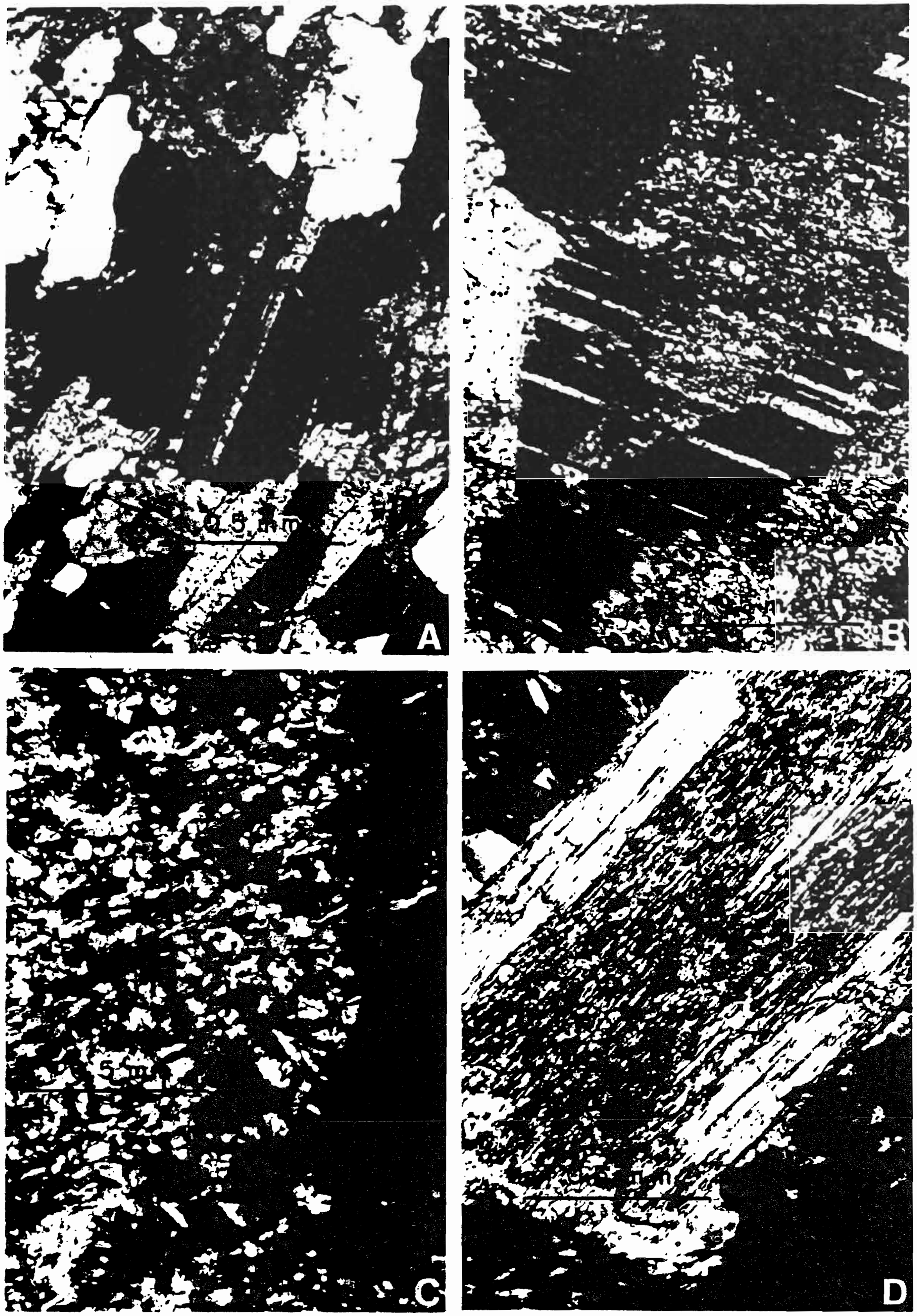


Plate 6-1

TABLE 6-6

X-ray data for biotite separates from zones of progressively more altered garnetiferous quartz-feldspar-biotite schist, Faribault Brook Area.

Fe/Mn Radiation: vs very strong, s strong, m medium, w weak, vw very weak, b broadlines, d diffuse lines

Sample	HM-4; HM-2	HM-4; HM-2	HM-4; HM-2	HM-4; HM-2	HM-4	HM-2
No/depth	17,23; 24	56, 113; 46	66, 74; 76	84,78; 125	90, 111	88, 118
NSDM Film No.	7913,7916,7920	7928,29;7934	7941,7942;7977	8010,8011;8037	8044,8055	8071,8072
Zone of alteration	4	3	2C	2a	1c	1a

dÅ	Index	dÅ	Index	dÅ	Index	dÅ	Index	IM#hKl	dÅ	Index	dÅ	Index	2M#hKl
10.01	s(b)	10.10	vs	10.10	vs	1.10	vs(b)	001	10.01	vs	10.01	vs	002
4.64	W	7.09	vw	4.64	w	4.62	w	020	7.13	vw	7.19	vw	-
3.96	vw	4.60	w(b)	3.93	vw	3.96	vw	-	6.55	vw	5.98	w	-
3.70	vw	3.69	w	3.68	vw	3.69	w	$11\bar{2}$	5.00	m	4.49	w(b,d)	110
3.37	vs(b)	3.54	vw	3.42	m				4.52	ms	3.76	w	023
3.17	w(d)	3.37	vs	3.35	vs	3.37	vs	003	4.24	m	3.66	w	-
3.05	vw	3.17	m	3.14	m	3.16	w	$11\bar{2}$	4.12	vw	3.51	m	$11\bar{4}$
2.94	w(d)	3.05	vw	2.93	mw	2.94	w	$11\bar{3}$	3.96	vw	3.36	vs(b)	006
										w	3.23	w	$11\bar{4}$
2.73	w	2.94	mw(d)	2.71	w	2.72	vw	023	3.67	w(d)	3.12	w	-
2.63	s	2.84	vw	2.63	s	2.64	s	$130,20\bar{1}$	3.48	w	3.00	vw	025
2.52	m(b)	2.79	vw	2.51	m	2.52	m	004,113	3.34	vs(b)	2.91	vw(d)	$11\bar{5}$
2.11	ms	2.63	s	2.44	m-s	2.45	m-s	132,201	3.23	m	2.81	m(d)	$11\bar{6}$
									3.07	vw			
2.01	ms(b)	2.53	m-w	2.31	vw	2.31	v-w	$22\bar{1}$	2.99	w	2.70	m-s	-
1.92	vw	2.45	m	2.25	vw	2.27	w(d)	$20\bar{3}$	2.91	w(b,d)	2.62	m-w	-
1.55	ms(b)	2.32	w	2.18	m	2.19	m-s	041	2.81	w	2.57	v-w	116
1.53	w	2.28	vw	2.02	m-s	2.02	s	005	2.77	vw	2.52	w(b)	008
1.48	vw	2.18	m	1.99	m	2.00	m	$20\bar{4},133$	2.68	w	2.42	w	$11\bar{3}$
1.44	vw(b,d)	2.05	m	1.91	vw	1.92	w	$13\bar{4},203$	2.63	w	2.22	w	041
1.36	mw	2.00	m	1.68	ms(b)	1.70	s-m	$13\bar{5},204$	2.57	mw(b)	2.18	vw	$22\bar{3}$
		1.92	w	1.54	s(b)	1.54	s	060	2.45	vw	2.02	w(d)	001
		1.68	m(b)	1.52	w	1.53	vw	061,330	2.39	vw	1.99	w	$13\bar{7}$
		1.54	m	1.43	w	1.44	w	-	2.28	vw	1.91	w	-
		1.53	w	1.36	m(d)	1.37	w(b)	-	2.26	vw	1.89	vw	-
		1.44	w						2.17	w	1.84	vw(d)	-
		1.37	w(b)						2.13	w	1.80	vw	-
									2.01	w-m	1.74	vw	139
									1.99	w-m	1.68	w(d)	150
									1.82	w	1.63	m	-
									1.50	w	1.54	mw	060
											1.45	vw	-

along certain cleavage planes by chlorite (Plate 6-1), which occurs either as discontinuous or patchy, randomly oriented aggregates of small flakes or as continuous thin plates. Under the microscope both the aggregates and the plates of chlorite are characterized by low relief, low birefringence and an index of refraction greater than balsam. The iron liberated by this chlorization may be fixed as magnetite, or other iron oxides, in irregular streaks that are also parallel to the cleavage planes.

The alteration of plagioclase is more pronounced; the centres of crystals are completely altered, whereas the rims are less altered. In zone 2, close to the mineralization, kaolinite and illite are more prominent alteration products of plagioclase.

Zone 1. Sericitized rock: In this zone the rock is hard and bleached to light grey or white. Original structures and textures are mostly obliterated. Parallelism of alteration minerals and recrystallization are common features on the mineralized side of the zone. The rock is composed chiefly of sericite and quartz, and contains scattered crystals of pyrite.

X-ray diffraction patterns (Table 6-6) of a series of progressively more bleached biotite grains indicate that in zone 1 the flakes contain spacings characteristic of both 2M dioctohedral and 1M trioctahedral structures. Kaolinite (or perhaps chlorite) and montmorillonite are also present. Chlorite and clay minerals are reconstituted to sericite. The sericite occurs as radial plumose aggregates, parallel bundles of flakes or, most commonly, as irregular matted aggregates (Plate 6-2A). Sericite in this zone is in part a replacement of plagioclase, K-feldspar and biotite following their alteration first to clay minerals. X-ray diffraction data for a typical sample of sericite

(Table 6-7) indicate that it is a dioctahedral 2M mica.

Wall Rock Alteration in Garnetiferous Hornblende Schist

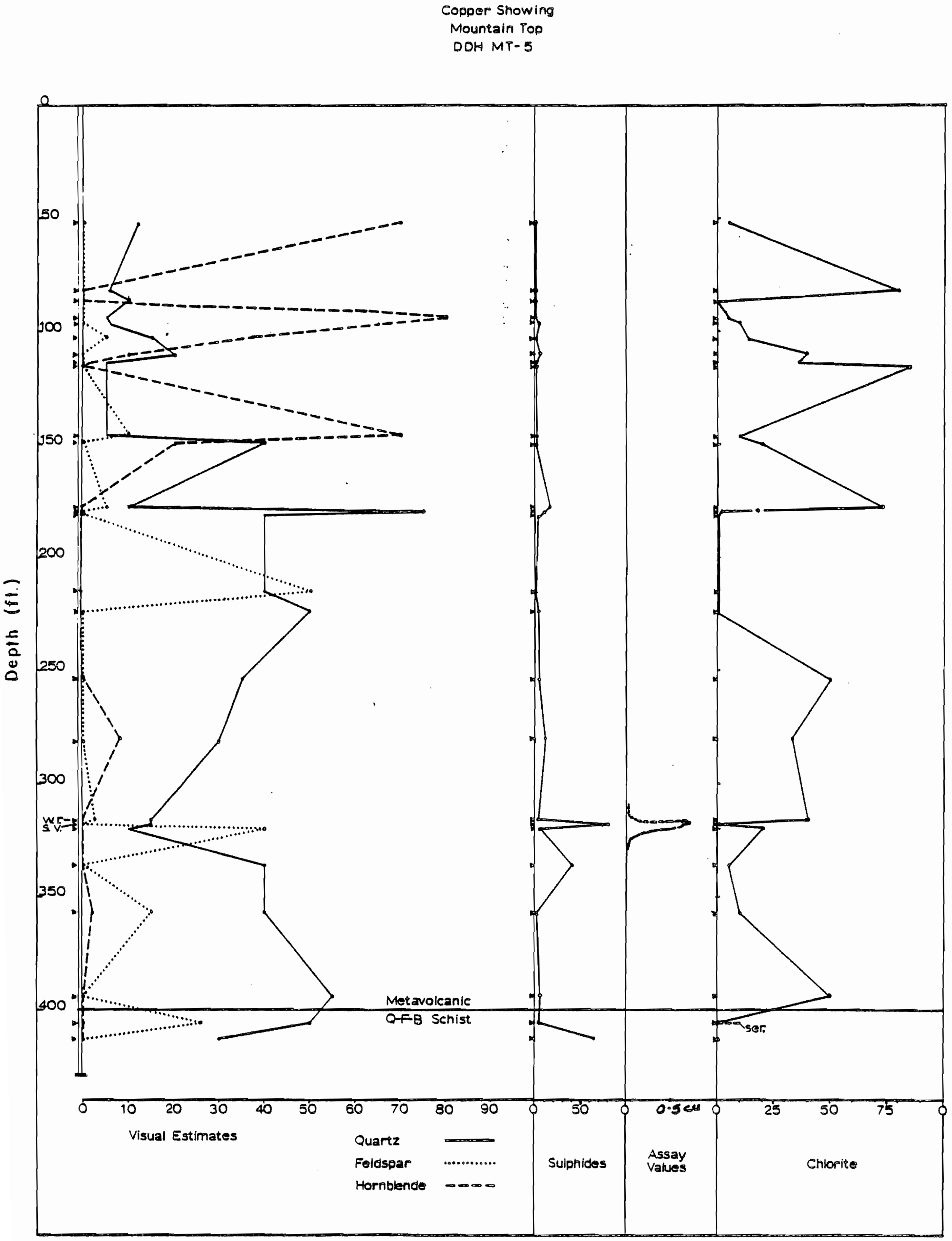
The relationship between the mineralization and the alteration adjacent to it in the hornblende schist is shown in Figure 6-8. Based on the relative mineral proportions, distribution and associations, this altered wall rock has also been divided into 4 zones.

Zone 4. In this zone the rock is characterized by large porphyroblastic prisms of hornblende, grossularite and calcic plagioclase. Apatite, magnetite, pyrite, sphene and epidote are present as minor constituents.

Zone 3. In this zone hornblende is altered to biotite and in certain hand specimens biotite forms up to 15 per cent of the rock. Biotite is quite fresh, i.e., with no interleaved chlorite. The centre of calcic-plagioclase crystals is altered to a mixture of epidote, calcite and montmorillonite (Plate 6-2B). Garnet is persistent in this zone and shows no signs of alteration.

Zone 2. In this zone plagioclase is completely altered to a mixture of calcite and montmorillonite, but hornblende persists, which would imply that hornblende is slightly more stable than plagioclase in this alteration zone. The biotite flakes show chloritic alteration about their edges and along cleavages and, in fact, chlorite is interleaved with biotite (Plate 6-2C). The centre of garnet crystals shows partial alteration to calcite and clay minerals (Plate 6-2D).

Zone 1. In this zone chlorite forms approximately 60 per cent of the rock; it was observed in thin section as an alteration product of hornblende and, in part, of biotite. In severely altered rocks near the mineralized zone, chlorite is, in turn, replaced by a mica-like clay



Copper Showing
Mountain Top
DDH MT-5

Figure 6-8.

Rock Types, Modal Proportions, and the Alteration Halo in DDH MT-5. Mountain Top Showing. Fairbault Brook.

Plate 6-2

Photomicrographs showing the intense sercite, epidote, calcite and clay alteration in the altered zones. Figure A, parallel matted aggregates of sericite in alteration zone No. 1. Figure B, alteration of calcic plagioclase to a mixture of epidote calcite and montmorillonite. Figure C, intercleaved biotite and chlorite in alteration zone No. 2. Figure D, alteration of garnet to clay minerals and calcite in alteration zone No. 2.

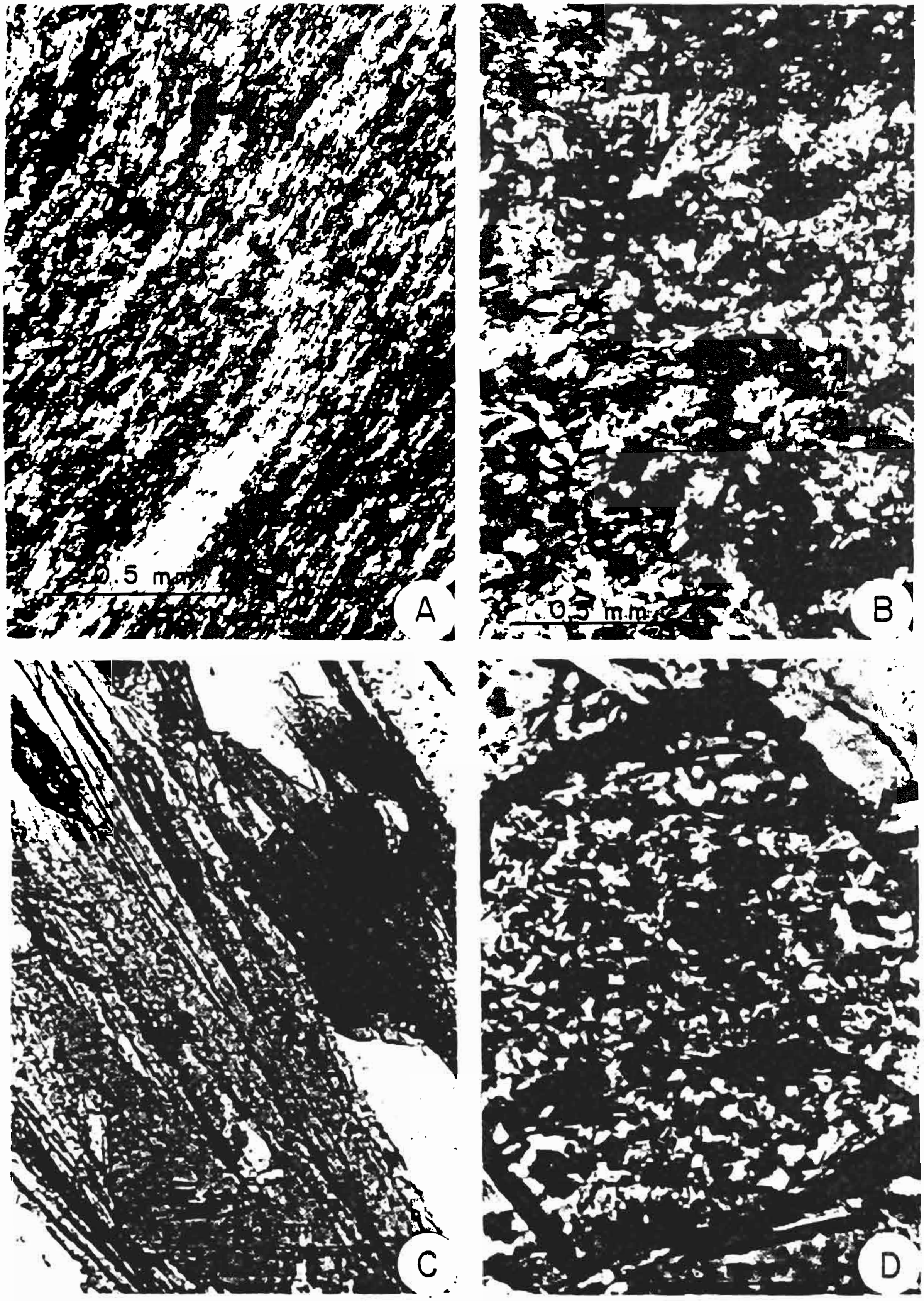


Plate 6-2

mineral. X-ray data (Table 6-7) reveal that it is a mixture of montmorillonite-chlorite and aphrosiderite-chlorite. The chlorite ultimately altered to sericite adjacent to the mineralized zone. Rounded aggregates composed of biotite, sericite, calcite and clay are also seen in this zone and they, in all probability, are pseudomorphs after garnet.

Summary:

From the above observations it may be concluded that a sequence of shale, sandstone and mafic volcanic of the George River Group in the Faribault Brook area was subjected to sillimanite grade of regional metamorphism. Minerals appropriate to the grade of metamorphism were produced in each, and the original sequence of rocks is now represented by rock types such as sillimanite schists, almandine-andalusite schists, garnetiferous quartz-feldspar-biotite schists, garnetiferous quartzites, hornblende schists, etc. The host rocks for massive, stratabound Cu-Pb-Zn (Ag, Au, Bi, As) mineralization are garnetiferous quartz-feldspar-biotite schist, and for Zn-Cu (Ag-Au) mineralization are hornblende schists. The wall rocks adjacent to the mineralized zones are altered and this alteration is zoned. The altered rock minerals are clay minerals (montmorillonite, illite, kaolinite), biotite, chlorite and sericite, and it has been shown that all these minerals are derived from metamorphic minerals formed earlier. It has also been shown that the alteration has a close spatial and regular zoning relation to the mineralization; no sulphide mineralization has been found without accompanying alteration. From this, it is clear that the alteration halo is due to some effects associated with the emplacement of the sulphides. The effects and the sulphide mineralization, therefore, have occurred after the development of the high-grade metamorphism. Thus, it is appropriate

TABLE 6-7

X-ray powder diffraction data for sericite (A) in zone 1, DDH HM 4-86' and Montmorillomite-chlorite (B) in zone 1, DDH M 5-1-; Faribault Brook area. Indices for "sericite" from Yoder and Eugster (1955, p. 247) correspond to similar d values. M = montmorillonite, K = Kaolinite impurities Cu/Ni radiation, NSDM film numbers 8920 and 8921.

(A)

dÅ	Index	Mica hkl
7.13	vvw	K
4.98	ms	004
4.57	w	$11\bar{1}$
4.37	vw	021
4.27	w	111
4.13	vw	022
3.90	vw	$11\bar{3}$
3.66	vw	023(?),K
3.32	vs	006,024
3.22	w(b)	114
3.07	m	M
3.01	w	025
2.94	vw	?
2.86	vw	115
2.80	vw	$11\bar{6}$
2.68	vw(b)	?
2.57	m	13T,M
2.49	w	008
2.47	w	$13\bar{3}$(?)
2.39	w	204,K
2.15	vw(b)	222
2.14		043,135
1.99	ms	0010
1.82	vw	K,M
1.66	w	$20\bar{1}0$
1.65	w	314?
1.64	w	?
1.54	vw	M
1.51	w	060

(B)

dÅ	Index	ASTM 12-231 Montmorillonite-chlorite d	I/IO	ASTM 12-243 Aphrosiderite-chlorite d	I/IO
5.00	ms	4.97	75		
4.50	vs	4.53	100		
3.50	vs			3.52	90
3.30	m	3.29	25		
3.185	w	3.16	12		
3.00	w	2.98	25		
2.818	m			2.83	40
		2.60	25		
2.578	m	2.54	50		
2.475	w(b)			2.49	50
2.380	w(b)	2.41	25		
2.142	w			2.14	40
1.993	vw	1.99	12		
1.652	vw	?		?	
1.506	ms	1.509	50	1.523	30
				1.347	5
1.344	vw			1.326	10

to design a sequence of the principal silicate and sulphide minerals found in the Faribault Brook area.

Paragenetic Sequence

The paragenesis of minerals has been considered in "stages". The use of the word "stage" as in "stage of deposition" and "stage of mineralization" is common in the literature of ore deposition (Lovering, 1949, p. 16; Kutina, 1957, p. 316) and is used here to mean a step, or a discrete interval of deposition, in the development of wall rock - mineralization relationship.

Metamorphic Stage: Following or accompanying the intrusion of granite, the argillaceous wall rocks were metamorphosed to schists. As would be expected, the metamorphism has caused the formation of a considerable variety of rock types, containing several metamorphic minerals whose variations in composition and distribution depend partly on the composition of the original rock and partly on the grade of metamorphism. Remnants of sillimanite, andalusite, garnet, hornblende, plagioclase, and K-feldspar in the schists suggest that these silicates were formed during the metamorphic stage. Some magnetite and pyrite may have been introduced during this stage.

Hydrothermal Stage: During the hydrothermal stage, sericite, biotite, chlorite, epidote and calcite were formed. The general age of the micas is younger than K-feldspar and older than pyrite I.

Sulphide Mineralization Stage: The stage is the final event of the main period of mineralization, except for the formation of minor quartz, quartz-carbonate veinlets, chlorite, sericite and possibly some biotite. The sulphides were formed by an extensive series of replacements.

Generally, the earlier sulphide minerals have replaced the quartz of the garnetiferous quartz-feldspar-biotite schists. An example of perhaps the simplest type of replacement is shown in Figure B (Plate 6-3). The grains of quartz are in contact with each other and show a sutured texture. The small amounts of pyrite, arsenopyrite and pyrrhotite seem to be about evenly divided between obvious veinlets and small masses that lie at the intersection of several quartz grains. At this stage in the replacement processes the influence of grain boundaries is marked; nevertheless, quartz has been attacked, as is most noticeable at the centre of the illustration.

The product of more complete replacement of garnet by sphalerite is shown in Figures C and D (Plate 6-3). Penetration of sphalerite along grain boundaries is seen in many polished sections, but the important feature is the texture of the sphalerite aggregates. The aggregate is composed of sphalerite and minor chalcopyrite grains that are subhedral to euhedral in shape, and all are of about the same size as the grains of garnet in the quartz-feldspar-biotite schist. Examples of most, if not all, of the sulphide minerals replacing minerals of the quartz-feldspar-biotite schist could be similarly shown.

As replacement continues along grain boundaries, grains may coalesce to form a network. The strands of the network then increase in width until only small remnants of the original grains remain, or until replacement is complete. All steps may be seen in the same polished surface.

During the later part of the hydrothermal stage, sulphide deposition continued with the formation of galena, tetrahedrite, chalcocite and covellite.

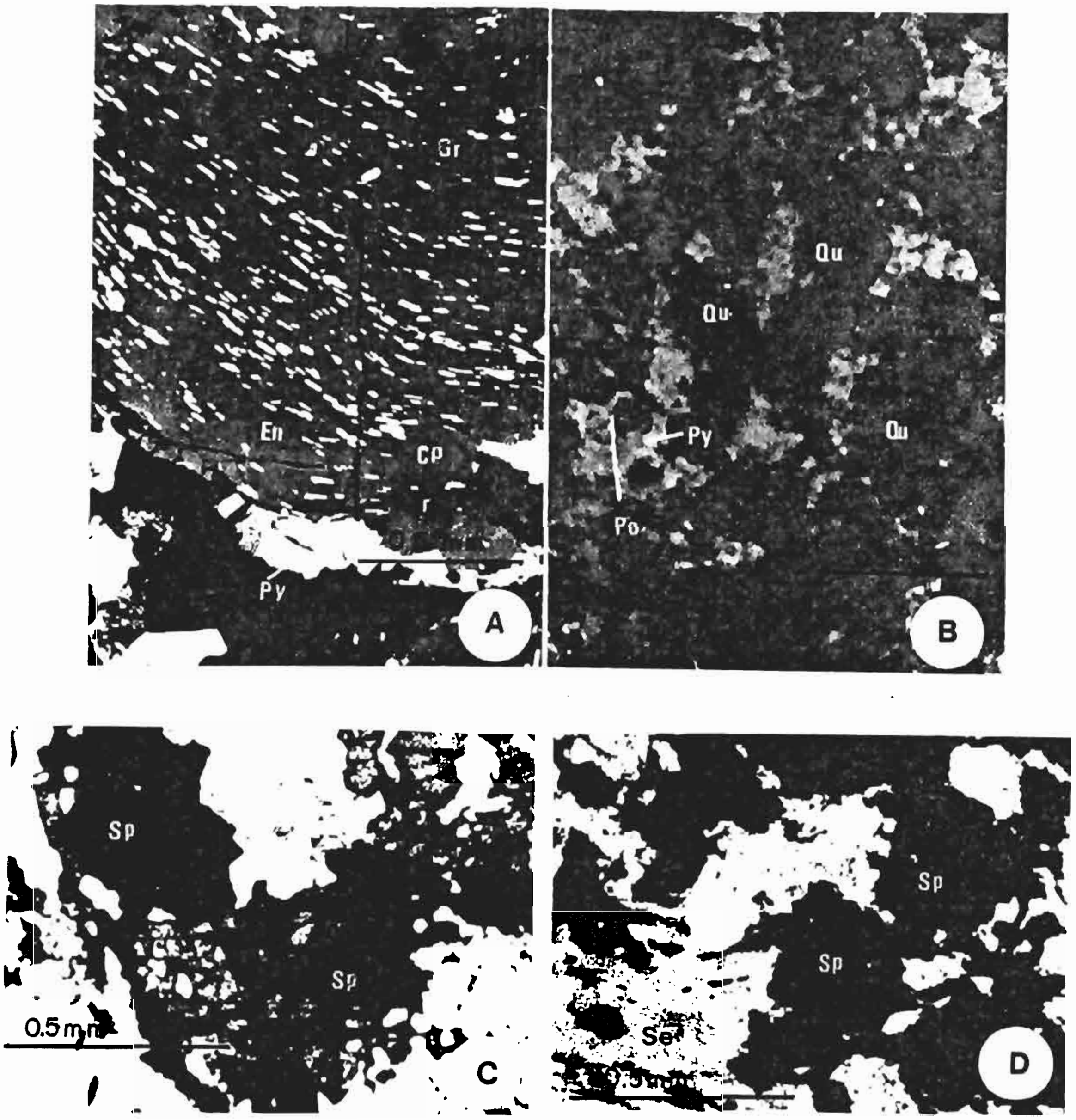


Plate 6-3

Figure A. Photomicrograph showing lath-shaped crystals of enargite and chalcopyrite in a rolled garnet grain. En, enargite; Cp, chalcopyrite; Gr, garnet; Py, pyrite.
Figure B. Photomicrograph showing the replacement of quartz grains along the grain boundaries by pyrite, arsenopyrite and pyrrhotite. Qu, quartz; Py, pyrite; Asp, arsenopyrite; Po, pyrrhotite.
Figure C and D. Photomicrograph showing partial and complete replacement of garnet by sphalerite. The aggregates of sphalerite grains are subhedral to euhedral in shape, and are all of about the same size as the grains of garnet. Gr, garnet; Sp, sphalerite; Se, sericite.

Late Gangue Stage: The deposition of sericite, calcite, chlorite and quartz probably continued from the hydrothermal stage to the late gangue stage.

Metal Abundances: Faribault Brook Area

There may have been investigations of metal abundances of mineral deposits which occur in volcanic-sedimentary (volcanogenic sulphides) and marine carbonate (Mississippi Valley type) sequences (Stanton, 1958, 1962; Stanton and Richards, 1961; and Sangster, 1968).

The detailed analysis of abundances and behaviour of Cu, Pb, Zn, Ag, Au* for the mineral deposits of the Faribault Brook area has been given by Chatterjee (1980b). In the present discussion, the results are briefly summarized and compared with similar data for the concordant Cu-Pb-Zn deposits. Such a comparison tests the possibility that metal abundance patterns of base metal deposits may be indicative of the mode of ore deposition.

Behaviour of Individual Elements

The metal values, with the exception of silver and gold (oz. per ton), are discussed in weight per cent.

Copper: The frequency distribution of values is positively skewed, 93.8 per cent of values fall in the range 0 to 6 per cent and the remainder extend up to a maximum of 23.8 per cent.

*The assays were obtained from various mining companies and the assessment files of Nova Scotia Department of Mines. Care was taken to use only assays from individual samplings - none of the analytical figures used are of bulk material or are averages of a number of assays.

Lead: The general pattern of frequency distribution is again positively skewed, but it is unimodal. Small peaks are developed at 19 to 21 per cent interval and between 78 to 82 per cent. The extreme values of lead represent almost monomineralic samples because galena contains 86.59 per cent lead. The range of values is 0 to 81.2 per cent, and the average is 7.38 per cent.

Zinc: The average zinc content (4.13) and its range of values (0 to 41.3) are higher than copper and lower than lead. The frequency distribution is positively skewed and more regularly J-shaped than that of copper.

Silver: The frequency distribution of silver is positively skewed and multimodal. Small peaks occur in the 25 to 35 oz. per ton interval and between 85 to 95 oz. per ton. The range of values is from 0 to 205 oz. per ton, and the average is 15.13 oz. per ton.

Gold: The average gold content is 0.03 oz. per ton and the frequency distribution is positively skewed and unimodal. The range of values is 0 to 0.58 oz. per ton.

Relation Between Pairs of Metals

Lead -Zinc relation: Atomic percentage, rather than weight percentages, is used when comparing zinc and lead, in order to allow for the effects caused by their markedly different atomic weights. Again, no apparent correlation exists between zinc and lead. However, as mentioned earlier, the general separation of sphalerite and galena has bands, and the fact that zinc and lead each have only one mineral representative, suggests that a series of inverse correlations might be expected. In fact, the outer boundary of the field of points is approximately parallel to a line joining the maximum of lead to the maximum of zinc (Figure 6-9).

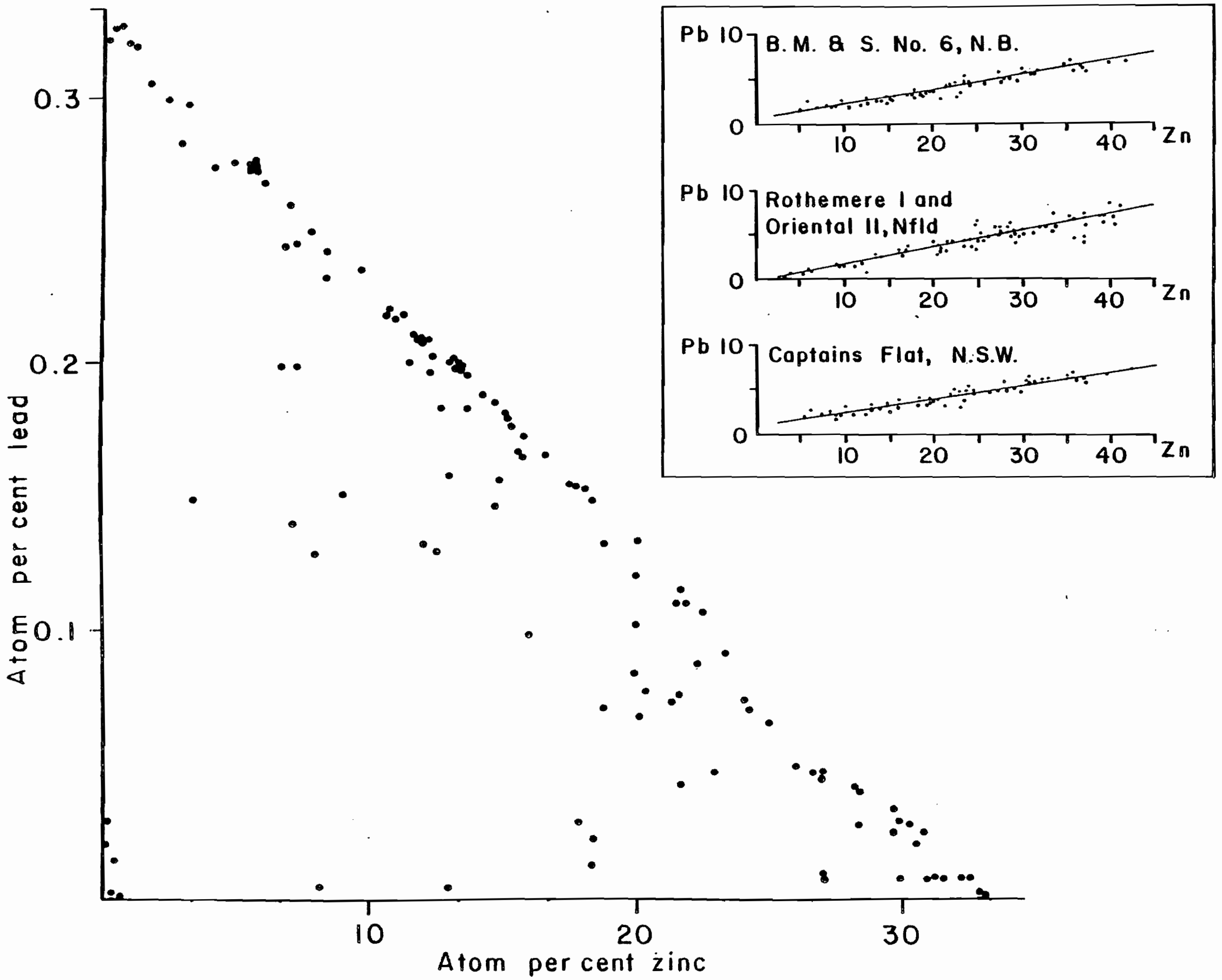


Figure 6-9 Atoms per cent lead against zinc. Data for Faribault Brook area. Scatter diagram in inset for comparison-concordant ore deposits.

Lead-Silver relation: There is a definite linear relationship between lead and silver (Chatterjee, 1980, Figure 7). The distribution of points may represent a series of inverse correlations.

Gold-arsenic relation: The relationship between arsenic and gold was not considered by the author earlier (Chatterjee, op. cit.) because of the availability of only a limited number of assay results. However, even with the limited number of points available, the scatter diagram (Figure 6-10) shows a very strong positive correlation. This relationship suggests that the gold mineralization is probably associated with the arsenopyrite.

Relations Between Ternary Groups of Metals

Copper-lead-zinc relationship: The ternary diagram for copper-lead-zinc shows no distinctive relationships (Figure 6-11). There is no marked concentration of points along the copper-zinc, zinc-lead or copper-lead boundaries; neither are there any linear relationships. Instead points are scattered throughout the diagram. This situation is supported by the observations that copper-zinc-lead, copper-lead, lead-zinc or copper-zinc minerals may coexist in individual polished sections.

Summary:

As already stated, the purpose of this study was to examine the abundance and relationship of Cu-Pb-Zn-Au-As mineralization of the Faribault Brook area, and to compare these with the abundances of the same elements in concordant sulphide deposits.

1. The frequency distributions of the individual elements are all positively skewed, and it is significant for comparison that both a wide range of values, and high values, of copper, lead, zinc and silver occur in one deposit. In individual concordant ore bodies (Stanton, 1958,

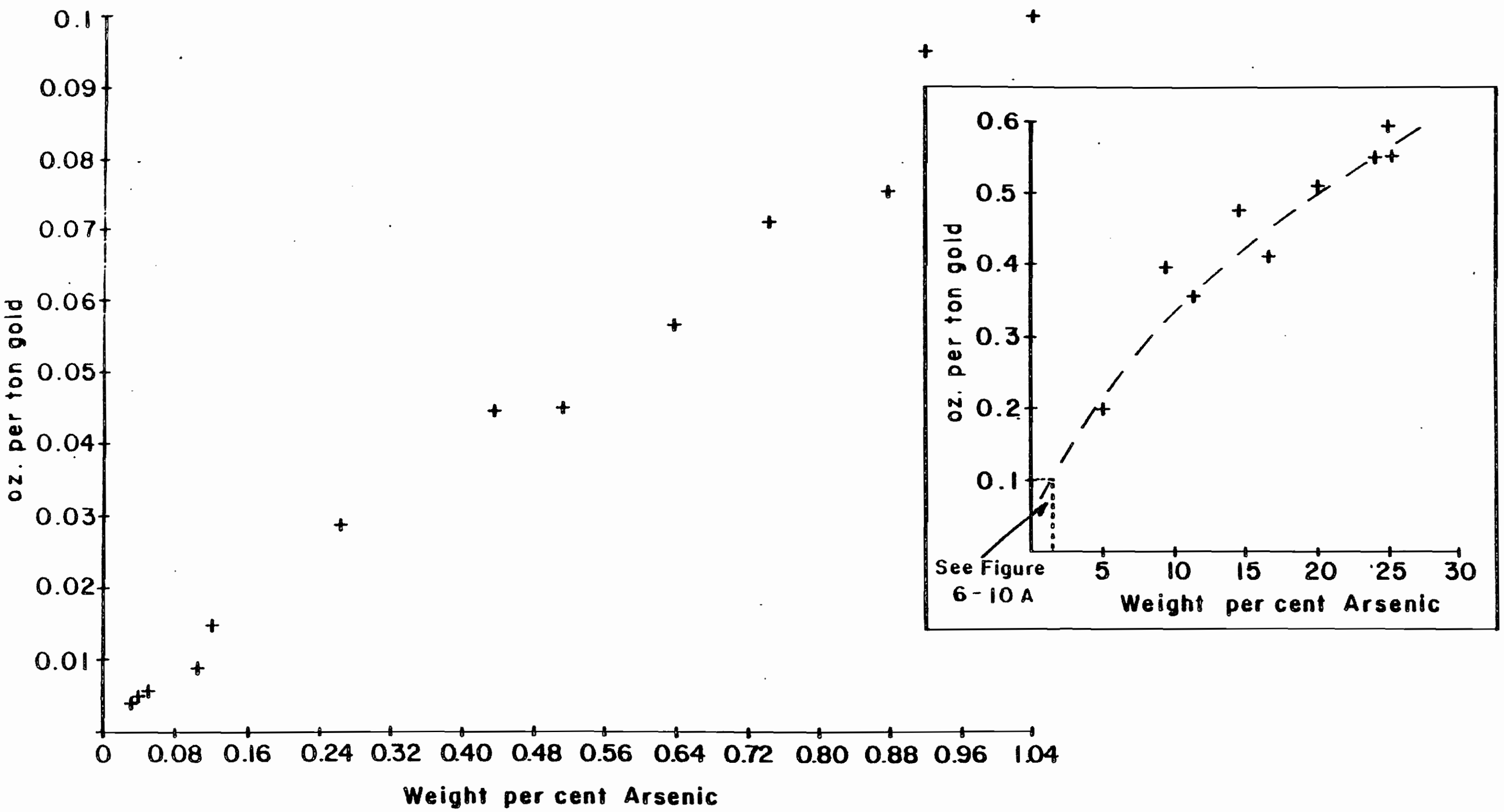
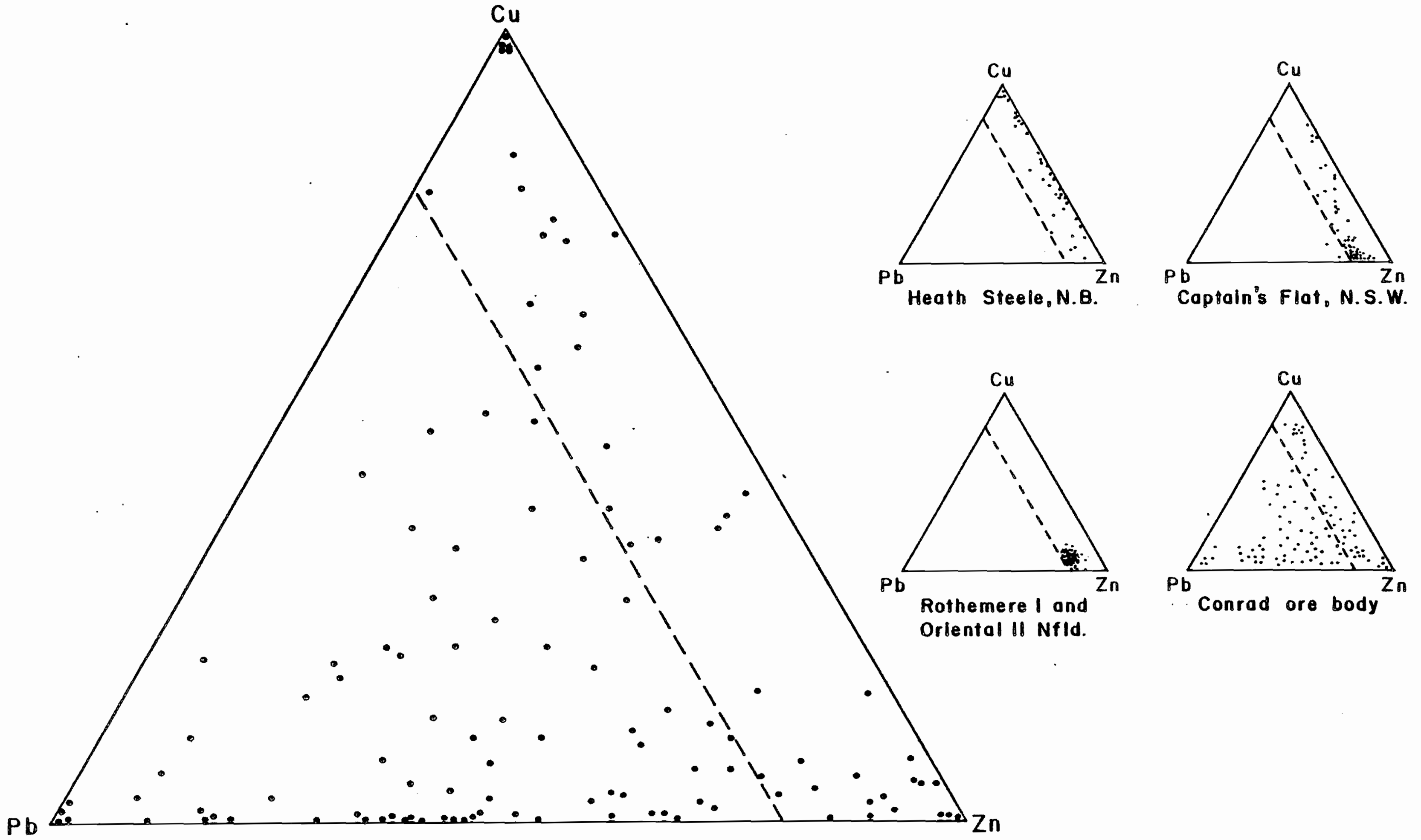


Figure 6-10A

Figure 6-10 Plot of oz. per ton gold against weight per cent arsenic. Data from Faribault Brook area



Heath Steele, N.B.

Captain's Flat, N.S.W.

Rothemere I and Oriental II Nfld.

Conrad ore body

Figure 6-11. Triangular diagrams illustrating relationships (atom per cent) of copper, lead and zinc for the mineral deposits in the Faribault Brook area. Triangular diagrams for Heath Steele, Captain's Flat and Rothemere I and Oriental II from Stanton (1958) and Conrad from Edwards and Wade (1953). Twenty mole per cent lead line shown for comparison

1962; Stanton and Richards, 1961), only one or two of these metals are abundant, i.e., the ore deposits are rich in copper, copper and zinc, or zinc and lead, but not all of copper, zinc, lead, silver and gold.

2. The positive correlation between arsenic and gold contents from Faribault Brook area is somewhat similar to many hydrothermal gold deposits described by Boyle (1974).

3. In the concordant deposits lead and zinc show a positive correlation whereas the same scatter plot shows a negative correlation from Faribault Brook area.

4. The relative abundance of Cu, Pb and Zn is quite unlike that shown by concordant ore bodies. The copper and lead content of a significant number of samples is high compared with the zinc content, a feature never exhibited by concordant ore bodies.

5. The relative abundances of copper, lead and zinc from Faribault Brook area and from the Conrad ore body - a hydrothermal discordant body (Edwards and Wade, 1953) are remarkably similar.

CHAPTER 7

MIDDLE RIVER (SECOND GOLD BROOK)

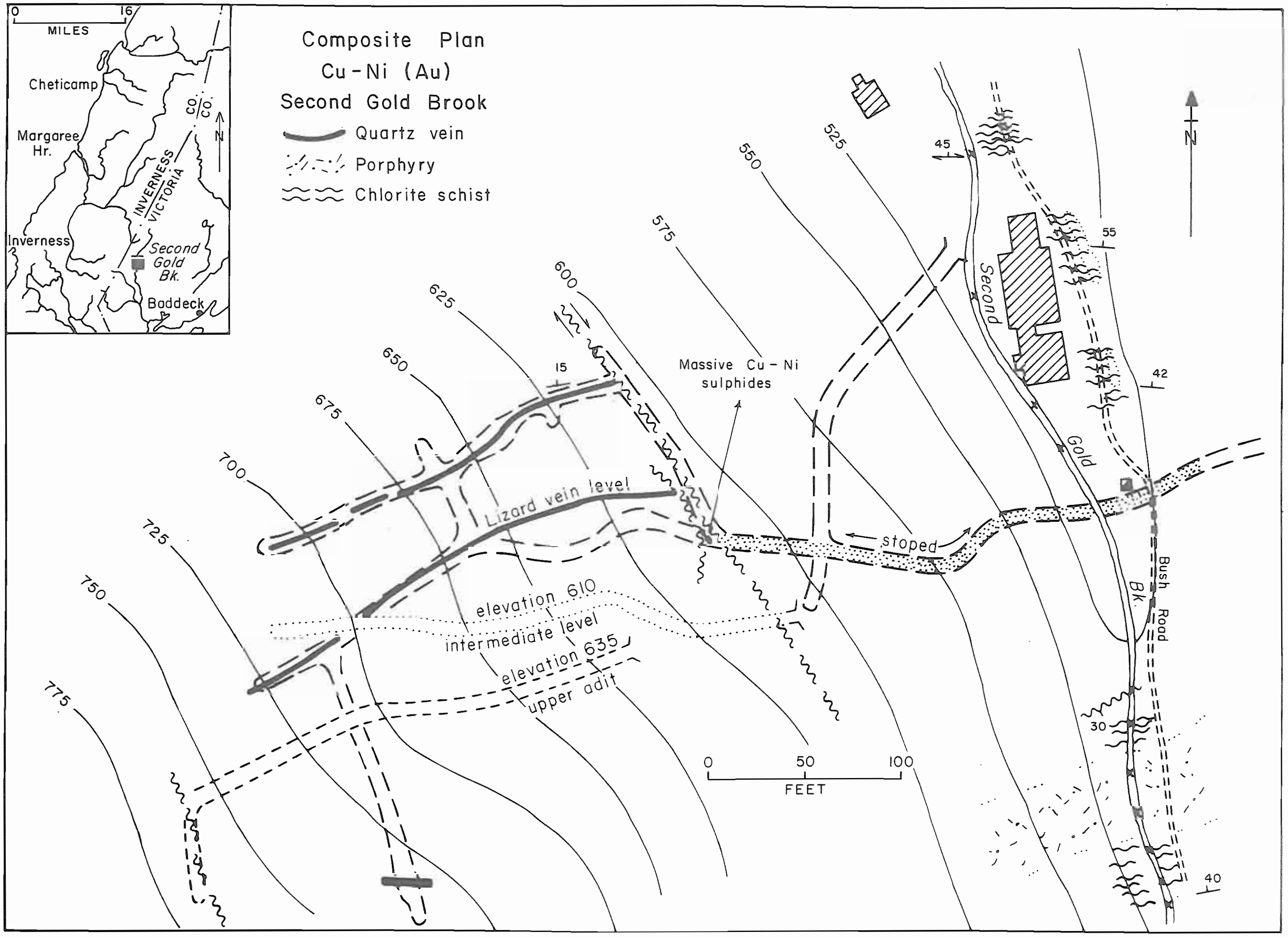
Introduction

This locality is a former gold mine in the central part of Cape Breton Island. According to Fletcher, gold had been found in the vicinity by 1877. A shaft was sunk and an adit driven into the hillside, but operations had ceased by 1915, with a total reported production of less than 2,000 ounces. Considerable exploration was undertaken by various mining companies during the late fifties and early sixties. The details of their findings are not available to the author, and it seems that encouraging results were not obtained.

Geological Setting

In the bed of the brook fairly continuous outcrops of metasedimentary rocks are exposed. They are predominantly argillites but also include conglomerates, quartzites and quartz-feldspar porphyry. Owing to regional metamorphism, the argillites now range from slate to fine-grained schist. The general strike is roughly east and the dip varies from 35° to 52° to the north (Figure 7-1).

Sulphide mineralization is principally confined to two types of quartz veins: a carbonate-pyrite-arsenopyrite vein and a nickeliferous pyrite-pyrrhotite-chalcopyrite vein. No gold was found in polished sections. Near the quartz veins, chlorite and sericite alteration is distinct but is noticeable only about 15 cm from the vein. However, in the adit, the wall rock is sericitized up to a distance of 5 metres from the sulphide vein.



Ref. map 11 K 7/W

Figure 7-1 Composite plan, Second Gold Brook.

Descriptive Features of Silicate Minerals

Chlorite:

Chlorite is nearly ubiquitous in the argillaceous rocks and has been found in association with every other mineral except tremolite-actinolite. It occurs in the bulk of the rock or as irregular vein fillings. Under the microscope chlorite appears either as tiny scales, about 0.01 mm in long dimension, or as randomly oriented microporphyroblasts up to 0.05 mm in size. As microporphyroblasts, it is commonly intergrown with muscovite and, in some cases, with biotite.

Chloritoid:

Chloritoid occurs in schist as metacrysts. Microscopically, it occurs as lath-shaped, euhedral, polysynthetically twinned crystals up to 3.0 mm in length. The crystals are randomly oriented in the rocks and commonly cluster in sheaves. The high relief, low birefringence and segmented appearance, coupled with pleochroism from indigo to greenish yellow, are diagnostic. It is commonly intergrown with muscovite, biotite, chlorite, quartz and iron oxides.

Muscovite:

Muscovite occurs in schist as microscopic flakes. They are distinguished from other platy minerals by relatively high birefringence and by lack of colour and pleochroism. Muscovite also occurs as microporphyroblasts, about 0.05 mm in size, cutting across the cleavage and commonly interleaved with chlorite. This textural feature demonstrates that the minerals are the result of recrystallization and are not detrital in origin.

Epidote:

Epidote occurs as colourless to yellowish-green, granular aggregates, and the mineral is slightly pleochroic with moderate birefringence. Associated minerals are chlorite, biotite, albite, muscovite and quartz.

Feldspars:

Albite and orthoclase, showing polysynthetic and Carlsbad twinning, are abundant. These are generally altered to a mixture of finely divided muscovite and aggregates of clay mineral.

Biotite:

Biotite is light brown, moderately pleochroic, and occurs in fibrous sheaves and small, generally equidimensional plates. The pleochroism is X = very light yellow, Y = light brown and Z = light greenish brown. The Y index of refraction is 1.605 ± 0.003, which suggests an iron content of about 11 per cent, based on comparison with biotite studies made by Anderson and Scholz (1955, p. 52).

Descriptive Features of Sulphide Minerals

Pyrite:

Two ages of pyrite have been recognized. The first of these makes up approximately 45 per cent of the total sulphides. It is massive, showing no outward crystalline form. Under the microscope the individual masses are composed of a mosaic of weakly anisotropic grains, apparently the result of brecciation. Veins and stringers of quartz and calcite crisscross the pyrite and in places fill the spaces between individual fragments. In some places, angular chips of pyrite completely enclosed by calcite can be traced back into corresponding re-entrants in the main mass of pyrite. The second age of pyrite is represented by veinlets of a fresher, non-brecciated type cutting the older brecciated pyrite. This pyrite marks the advent of the deposition of the nickel-bearing pyrrhotite.

Pyrrhotite:

Pyrrhotite is associated with pyrite and chalcopyrite in narrow quartz stringers, and it also appears in the form of closely spaced crystals up to 0.25 cm in diameter in seams of quartz and clayey carbonate material.

Chalcopyrite:

Chalcopyrite is the only copper-bearing mineral in the ore. It is present in the chlorite schist as tiny *en echelon* lenses and elongated, or irregular, replacement masses, and as disintegrated grains with projections along the planes of slaty cleavage. The bulk of the remainder of the chalcopyrite is intimately associated with the pyrite and pyrrhotite.

Wall Rock Alteration: Descriptive Features

The wall rock in the vicinity of the quartz veins has been altered to different degrees. As in the rocks of the Faribault Brook area, four sub-zones have been observed away from the vein in the altered zone.

Zone 4: This zone is farthest from the vein and in it porphyroblasts of quartz, orthoclase, plagioclase and chloritized biotite are seen embedded in the groundmass of quartz, muscovite and chlorite. The alteration is manifested in slight kaolinization of orthoclase, sericitization of plagioclase and chloritization of biotite. The sericite developed on plagioclase and is an aggregate of very thin scales. This

sericite is often accompanied by minute segregations of calcite, epidote and quartz.

Zone 3: In this zone the content of chloritized biotite has decreased and the zone is characterized by the development of chlorite which is a major constituent, in contrast to the previous zone. The sericite content has also increased noticeably and it is seen replacing the porphyroblasts.

Zone 2: In this zone a second generation of sericite appears, replacing potassium feldspar, chlorite, albite and the first generation sericite. It shows weak pleochroism and the flakes are considerably larger than the flakes observed in zone 4.

Zone 1: The sole constituent of this zone is a mixture of clays and is in immediate contact with the vein material (Plate 7-1). Trace amounts of corroded grains of quartz are also seen.

CHAPTER 8

NILE BROOK COPPER PROSPECT

Introduction

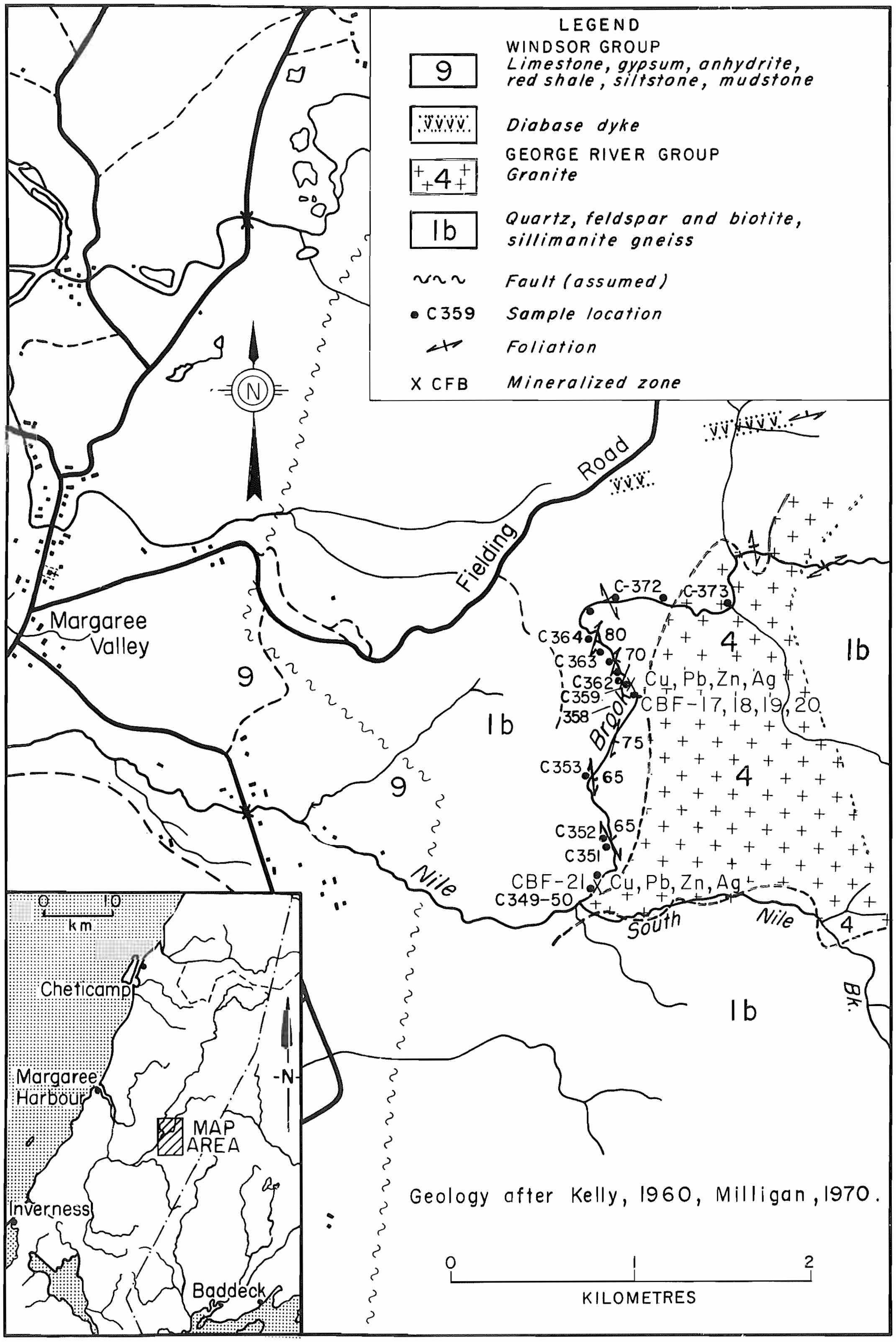
This showing is at the bottom of the deep valley of the north branch of Nile Brook (Figure 8-1). There is only a small surface exposure, on which some blasting and shallow drilling have been done. The distinctive surface feature of the mineralized zone is the presence of vuggy gossan which has resulted from the oxidation of the sulphides.

Geological Setting

The host rock is the quartz-feldspar-biotite gneiss, common all along Nile Brook; this is generally a strongly banded paragneiss, which has a granitoid texture in many places. It has been intruded by granite, and by lamprophyre dykes which probably followed shear zones. There are a number of faults and shear zones in the gneiss, and a substantial part of Nile Brook is probably controlled by such a zone.

Mineralization occurs in a shear zone, which is marked by biotite schist, strikes N10°W and dips 70 to 80 degrees easterly. The shear is exposed for a length of 5 metres and the width varies from 1 to 2 metres. The sulphides are confined to the shear zone and are essentially chalcopyrite, pyrite and pyrrhotite with minor amounts of sphalerite. Sericitic and chloritic alteration is distinct in the wall rock, and minor epidote also occurs as thin stringers.

The silicate mineralogy is essentially the same as that described for Faribault Brook.



Ref. Map 11-K-7-W

Figure 8-1 Surface Geology: Nile Brook Copper Prospect

Descriptive Features of Sulphide Minerals

Chalcopyrite:

Chalcopyrite makes up the bulk of sulphide minerals, and some polished sections consist almost wholly of it. It ranges in texture from extremely fine grained to coarse crystalline. Most of the chalcopyrite is interstitial to the pyrite grains and in places is partly replaced by sphalerite.

Pyrite:

Pyrite is an early mineral and occurs as tiny cubes, as corroded relics in chalcopyrite and as irregular masses along fractures.

Pyrrhotite:

Pyrrhotite has been identified in trace amounts. It forms anhedral grains filling cavities in pyrite; it also occurs as inclusions in sphalerite.

Sphalerite:

Sphalerite is not as widely distributed as chalcopyrite, although its mode of occurrence is similar. It forms masses or is interstitial to pyrite and chalcopyrite. Isolated islands of corroded chalcopyrite occur in sphalerite; the zinc sulphide also forms rims around chalcopyrite and fills cavities in it. These relations would suggest that sphalerite is later than chalcopyrite.

The observed sulphide mineral associations are listed below. Individual assemblages here listed have each been seen within the limits of a single polished section.

Pyrite-pyrrhotite-chalcopyrite±magnetite
Pyrite-pyrrhotite-chalcopyrite-sphalerite
Pyrite -chalcopyrite-sphalerite
Pyrite -chalcopyrite

Wall Rock Alteration: Descriptive Features

The alteration halo around the mineralized zone is shown diagrammatically in Figure 8-2. This diagram is based upon samples of the gossan, mineralized zone and wall rock. The mineralogy of the zones is shown in Table 8-1.

Zone 4: This zone is farthest from the mineralized zone and the gneiss shows typical granitoid texture. The alteration is very weak; there are only minor developments of flaky sericite aggregates on feldspar and chloritic alteration along the margins of the biotite. Typically the gneiss consists of quartz, potassium feldspar, plagioclase (An_{17}) feldspar, biotite, kyanite, garnet and minor amounts of chlorite and sericite. The mineralogy of Zone 4 extends at least 50 metres from the mineralized zone.

Zone 3: In this zone the quartz-feldspar-biotite gneiss retains much of the original structure and texture. The quartz and feldspar grains are lensoid and rather angular in nature, and a clay mixture forms the matrix. The boundary between zone 3 and zone 2 is sharp, and is marked by distinct changes in texture and mineral content.

Zone 2: The sericitized rock is the most intensely altered wall rock bordering the vein, original structures and textures are obliterated, and shearing and recrystallization are common features in quartz grains on the veinward side of the zone. The zone is composed chiefly of sericite and scattered flakes of chlorite.

Zone 1: Zone 1 is the shear zone, which is characterized by biotite and minor chlorite that has formed as an alteration of biotite.

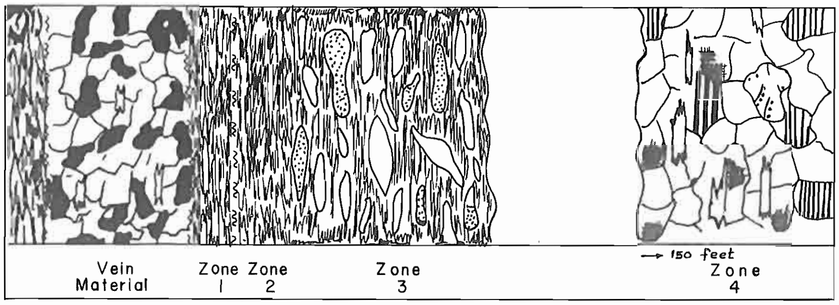
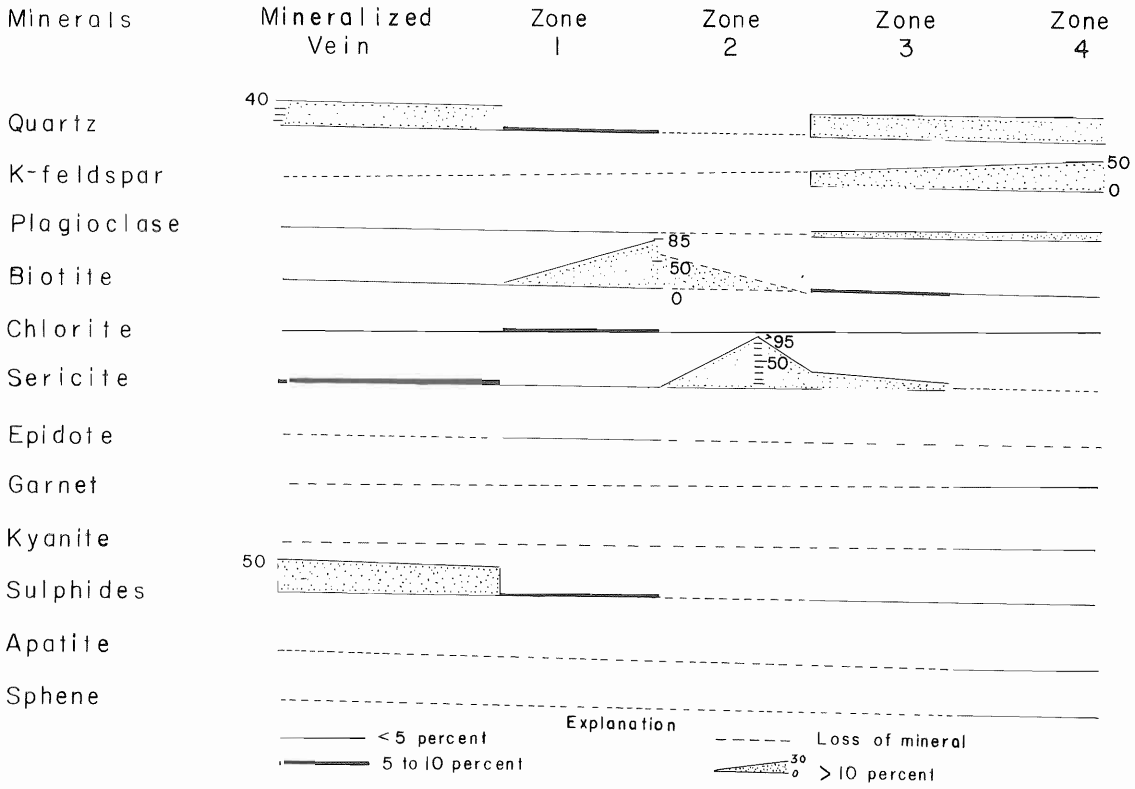


Diagram of alteration halo, Nile Brook. Zone 4 extends at least 150 feet from vein.

Figure 8-2

Table 8-1

Stability and Relative Abundance of Minerals in the Alteration Zones.



Paragenetic Sequence

The paragenetic sequence of minerals has been determined in metamorphic, hydrothermal, mineralization and gangue stages. The first occurred during the metamorphism which was associated with the intrusion of the granite. Argillaceous rocks near the granite were metamorphosed to microcline-quartz-plagioclase gneiss, biotite gneiss and sillimanite-kyanite-garnet-quartz gneiss.

The metamorphic stage was followed by the hydrothermal stage during which the earlier formed minerals were altered. Plagioclase, generally within a range of composition of An_{7-20}, makes up as much as 35 per cent of the host rocks, and is the least stable major rock constituent in the alteration environment. In fresh rock, it occurs as white, subhedral to anhedral, prominently twinned, medium-sized grains. In the early stages of alteration, it is altered along twin plane traces to patchy aggregates of sericite (clay?) and some calcite (Figure 8-3A). As observed in thin section, the sericite appears to be composed of several irregularly intermixed components that have different optical properties. Where similar material was X-rayed at Faribault Brook, it proved to be an aggregate of clays. Altered patches increase in size and abundance until they coalesce, leaving a few clear and fresh "island" remnants, or cloudy, partly altered and twinned crystals (Figure 8-3B). In zone 2 the plagioclase is completely altered.

In general, the K-feldspar occurs as white to pink, subhedral to anhedral, tabular, well-twinned porphyroblasts ranging in size from 0.02 mm to 1.5 mm. In places, small amounts of sericite incipiently and randomly replace K-feldspars along crystal margins, cleavage and fractures.

FIGURE 8-3

THE ALTERATION OF EARLIER-FORMED METAMORPHIC MINERALS DURING HYDROTHERMAL STAGE AT NILE BROOK

A. Zone 4: quartz (Q) and biotite (BO) are unaltered, plagio clase (P) is altered to sericite (Se), calcite (Ca) and clay minerals (Cl?) along cleavage planes in irregular patches.

B. Zone 3: plagioclase (P) and biotite (B) are altered to sericite (Se), clay minerals (Cl?) and chlorite (C); altered biotite grain at X.

C. Zone 3: biotite flake (B) is altered along cleavage to chlorite (C), iron oxide (Fe), and clay minerals (Cl?); adjoining plagioclase grain (P) is altered to sericite (Se).

D. Zone 2: biotite (B) is altered along cleavage initially to bleached biotite and chlorite (BCl) and clay minerals (Cl?) and gradually as the crystal is altered, a vermicular clay mineral (kordinite) growth is observed.

E. & F. Zones 4 and 3: sketch of fresh and altered garnet in gneiss. Quartz (Q), garnet (G) and biotite (B) are altered. In zone 3, garnet and biotite are altered along cleavages and fractures - garnet alters to biotite and chlorite, and biotite alters to chlorite. Some garnet "islands" are replaced by calcite and clay minerals (?), and the biotite-chlorite seams along garnet fractures are enlarged.

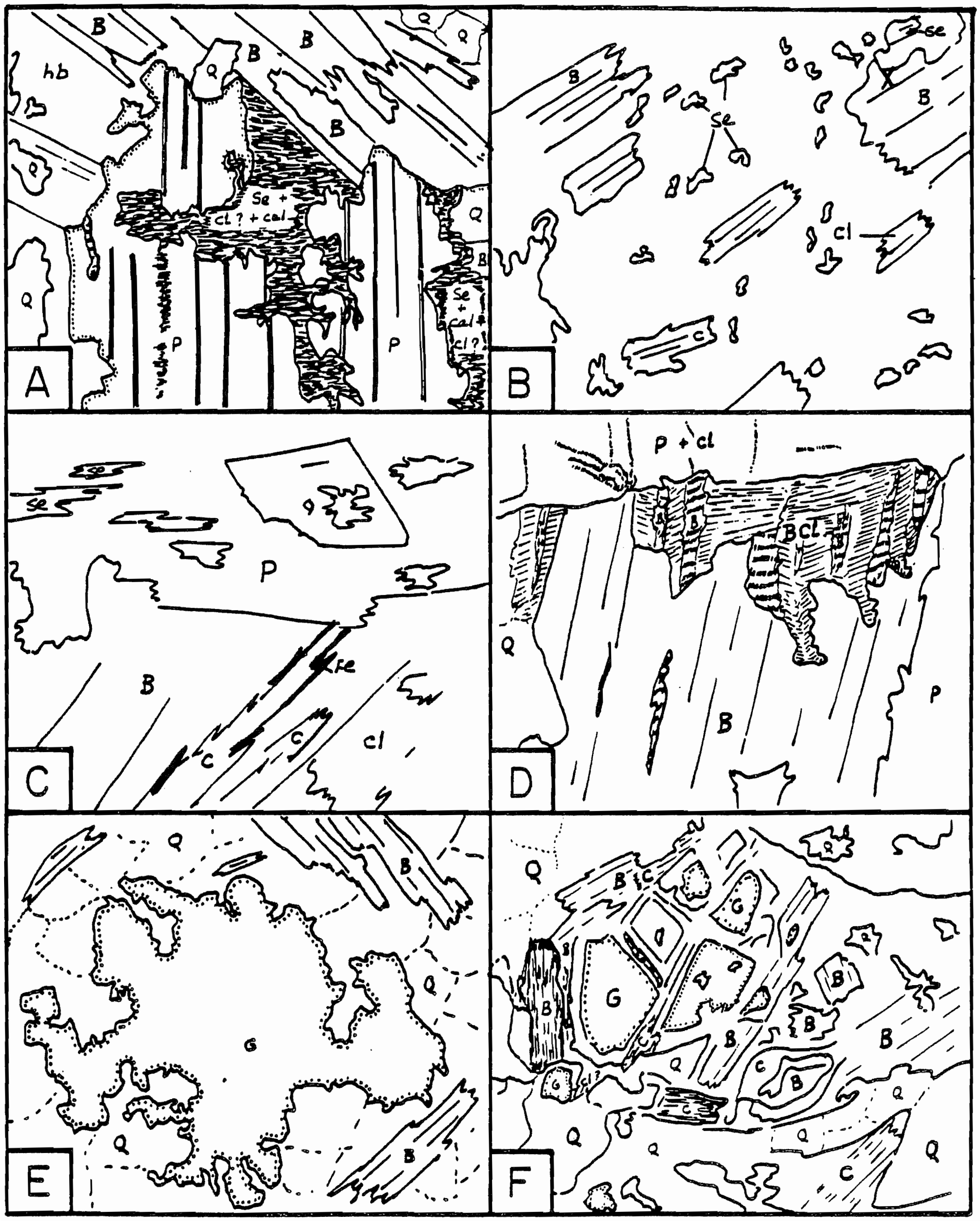

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Figure 8-3

Garnet commonly is a sparsely disseminated mineral in metasedimentary gneiss layers. Fractures and crystal margins of garnets are the loci of early alteration (Figure 8-3 E and F); as the rim of alteration expands residual islands are formed, and finally even the islands are overwhelmed, leaving recognizable textural pseudomorphs composed of biotite, chlorite, sericite (?) and calcite.

Biotite occurs as elongated cleavage plates that are generally brown to black or, less commonly, a greenish brown. Biotite within successive alteration zones is bleached from dark brown to light greenish brown, and subsequently to yellow to silvery white. This loss of dark colour is accompanied by a loss of pleochroism and birefringence. Locally, biotite flakes are replaced irregularly along certain cleavage planes by chlorite, which occurs either as discontinuous or patchy, randomly oriented aggregates of small crystals or as continuous, thin plates (Figure 8-3 C and D). Under the microscope both the aggregates and plates of chlorite are characterized by low relief, low birefringence and an index of refraction greater than balsam; this is in contrast to degraded biotite which has weak pleochroism, high relief and strong birefringence. The iron liberated by this alteration may be fixed as magnetite or other iron oxides in irregular streaks that are also parallel to the cleavage planes.

Chlorite occurs about edges and along cleavages of biotite. In zones 1 and 2 biotite is replaced by chlorite.

The hydrothermal stage during which silicate minerals of the metamorphic stage were altered, was followed closely by the sulphide mineralization stage. This sulphide mineralization stage consisted of pyrite, pyrrhotite, chalcopyrite and sphalerite, in this sequence, and probably was not separated from the hydrothermal stage by any significant time interval.

Following the sulphide mineralization stage, after a long time-gap, the upper parts of the mineralized zone were oxidized. The most important secondary copper mineral in the oxidized zone is malachite, which commonly forms pods, patches and veins.

CHAPTER 9

SUMMARY OF CHARACTERISTICS OF GEORGE RIVER GROUP DEPOSITS

A. Geological Setting

Cape Breton Island measures about 90 km east-west and 180 km north-south, and is located roughly in the middle of the Appalachian Orogen, which has been subdivided into five zones, the Humber, Dunnage, Gander, Avalon and Meguma zones (Williams, 1979). Cape Breton Island forms part of the Avalon Zone. Keppie (1980), on the basis of contrasting metamorphism, deformation and plutonism, divided the Avalon Zone into three tectonic domains, the Louisbourg, Ingonish and Antigonish domains (Figure 9-1). The rocks of the George River Group and those of the older basement complex are included in the Ingonish Domain.

The Ingonish Domain measures about 30 km east-west and 150 km north-south, and forms the basement of several shallow-marine basins of lower and upper Palaeozoic age. The Domain is geologically very complex because of its history of multiple deformation, metamorphism and widespread plutonism. For simplicity of presentation, the rocks of the George River Group are grouped into three divisions.

The first division consists essentially of quartzites, feldspathic quartzites, slates and minor amphibolites. These rocks are the most extensive, and probably the most abundant, in the George River Group. In the Margaree area, these rocks are succeeded by feldspathic and garnetiferous gneisses of the amphibolite and granulite facies (Milligan, 1970; Keppie and Muecke, 1980).

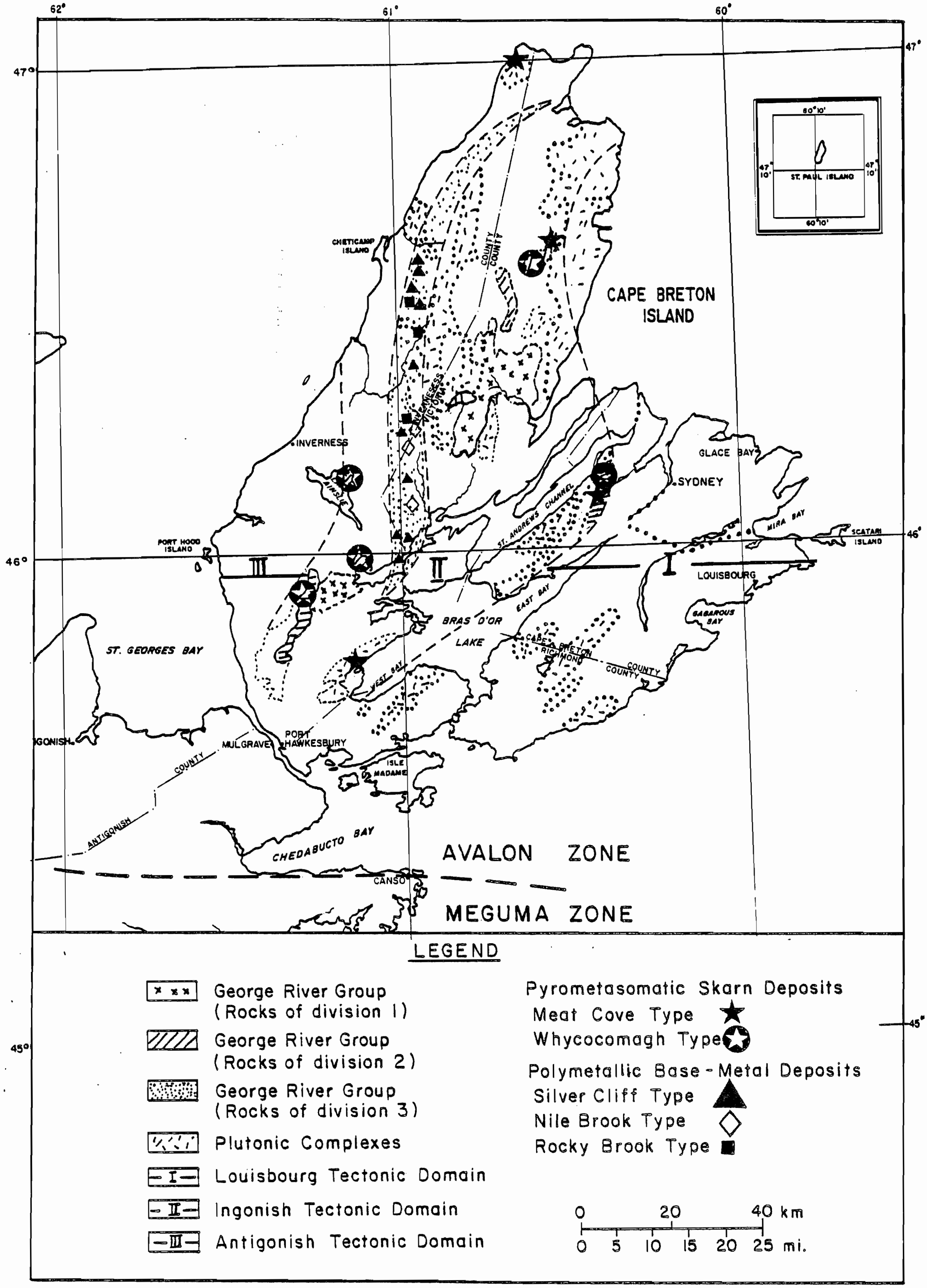


Figure 9-1. Distribution of the George River Group, tectonic domains, and classes of Mineral Deposits in Cape Breton Island.

The *second division* consists of marbles and dolomites, calc-silicate rocks, amphibolites and intermediate - to - basic flows or sills. These rocks are exposed best in parts of Boisdale Hills, Craignish Hills and North Mountain.

The *third division* consists of greywacke, slates and volcanic rocks of mafic - to - intermediate composition. These rocks are widely distributed in parts of Crowdis Mountain, Middle River, Cheticamp and West Indian Brook areas.

Large, elongate, syntectonic plutonic complexes (520-613 Ma) and smaller, equant, post-tectonic plutons (360 Ma) intrude the rocks of the three divisions. Granitic rocks are common in the southwestern part, and a gabbro-diorite-granodiorite-granite complex, with associated mafic and ultramafic hypabyssal intrusions, characterize the northern and northeastern part of the Ingonish Domain.

The Ingonish Domain is cut by numerous major faults which trend north-northeast in the northern part, and northeast in the south and southeastern parts. These two distinct fault systems apparently merge with one another in the Craignish Hills area. Also, prominent in this domain is a major zone of positive gravity anomalies, which trends north-northeast for over 75 km (Haworth and MacIntyre, 1975). Many major faults coincide with or diverge from this zone, and the Wreck Cove, Kingross and Upper Margaree (informal designations) Igneous complexes are located near it.

B. Types of Occurrences in the George River Group

A total of 59 mineral occurrences are known in the Ingonish Domain (Gregory *et al.*, 1980). Of these, 48 are hosted by the rocks of the divisions 2 and 3 of George River Group and the remainder are confined to the plutonic complexes. These mineral occurrences have been broadly categorized into two classes: (1) pyrometasomatic skarn deposits and (2) polycyclic hydrothermal deposits (Chatterjee, 1980a).

In the skarn deposits, the forsterite-rich, the diopside-wollastonite-rich, and diopside-andradite-rich, rocks were the site of most metallization. Most of the mineralization occurs as massive replacement of earlier silicates and also as fracture fillings.

The polycyclic hydrothermal deposits are typically characterized by their polymetallic nature and unusually complex association of minerals (details are provided in Chapters 6, 7 and 8) and by metals in metamorphosed pelitic hosts.

C. Modes of Occurrence

The mineral deposits in the rocks of the George River Group appear to have been in the form of relatively flat to steep, rather irregular, lenses. The width of these rarely exceeds 5 metres, though mineralization at Meat Cove and Lime Hill is as much as 18 metres thick in parts. The mineralized zones have well-defined "walls", and the concentration of sulphide drops off sharply into barren rocks on either side. The sulphides in the mineralized zone commonly follow veins which cross-cut bedding or layering. In all cases, the mineralized zones are associated with zones of alteration. In the calcareous rocks, the deposition of the sulphides was guided partly by impure dolomitic limestone. In the pelitic host rocks, the mineralization rarely shows poorly defined macroscopic banding more or less parallel to the schistosity and the original banding of the enclosing rocks.

D. Mineralogy

In the zinc deposit at Meat Cove and Lime Hill, the principal sulphides are sphalerite, pyrite, pyrrhotite, galena and chalcopyrite. Sphalerite occurs as coarse-grained, massive, crystalline aggregates, as disseminations, as bands and also as veins. It may form up to 95 per cent of the massive crystalline aggregates. Pyrite generally occurs as independent crystals and granular aggregates. Pyrrhotite, galena and chalcopyrite generally occur as blebs, as streaks or as irregular thin stringers.

In the copper-tungsten deposits at Whycocomagh and Boisdale Hills, the principal ore minerals are chalcopyrite, scheelite, pyrite, pyrrhotite, bornite and molybdenite. Chalcopyrite occurs as irregular shaped stringers growing around and between the other sulphide minerals. It also occurs as blebs in pyrrhotite and as fracture-filling pyrite. Scheelite occurs as coarse, idiomorphic crystals which measure up to 8 mm in diameter and show a poikiloblastic texture. Generally scheelite is associated with magnetite. Pyrite is euhedral to subhedral and, in general, finer grained than scheelite. Pyrrhotite is typically associated with, and replaces, carbonate and silicate minerals. Bornite occurs chiefly as fracture fillings associated with chalcopyrite, but also is present in anhedral grains, some with blebs of chalcopyrite. Molybdenite generally occurs as fine disseminations and is always associated with scheelite.

In the base metal deposits at Silver Cliff, Core Shack and Galena Mine, the principal sulphides are pyrite, pyrrhotite, chalcopyrite, sphalerite, galena and arsenopyrite. A characteristic feature of these deposits is that any one of these minerals may form up to 30 per cent of the crystalline aggregates. Pyrite and pyrrhotite generally occur as euhedral to subhedral grains that range in size from 2.0 to 3.0 mm. Poikilitic and skeletal crystals are common. Chalcopyrite occurs as scattered grains intergrown with sphalerite, galena and pyrite. Sphalerite is generally associated with arsenopyrite, pyrite and pyrrhotite. Textural and cross-cutting relations suggest that sphalerite is younger than pyrrhotite and older than chalcopyrite and galena. Arsenopyrite generally occurs as euhedral crystals. The crystals are as much as 5.0 mm long and characteristically show wedge-shaped forms having short prism faces and domes.

In the base metal deposits at Nile Brook and Second Gold Brook the principal sulphides are chalcopyrite, sphalerite, pyrite and pyrrhotite. Chalcopyrite ranges in grain size from extremely fine grained to coarse crystalline and it is interstitial to the pyrite grain and in places is partly replaced by sphalerite. Sphalerite forms rims around chalcopyrite and fills cavities in it. Pyrite occurs as tiny cubes, as corroded relics in chalcopyrite and as irregular masses along fractures.

At Meat Cove, the common non-opaque minerals, associated with the mineralization, are periclase, forsterite, diopside, tremolite, brucite, antigorite and talc. At Lime Hill, the common skarn minerals are forsterite, diopside, wollastonite, tremolite, antigorite and talc. At Whycocomagh typical skarn minerals are diopside, garnet, tremolite, epidote, antigorite and talc. At Boisdale Hills, the calc-silicate minerals are diopside, wollastonite, forsterite, antigorite, tremolite and talc. At Boisdale Hills, the calc-silicate minerals are diopside, wollastonite, forsterite, antigorite, tremolite and talc. The skarn minerals from the above localities are always associated with calcite and dolomite.

At Faribault Brook and Nile Brook the metamorphic silicate minerals are sillimanite, andalusite, garnet, K-feldspar, plagioclase feldspar, biotite, muscovite, chlorite, epidote and clay minerals. At Second Gold Brook, the silicate minerals are feldspars, biotite, muscovite, chlorite and clay minerals.

The relationships between the opaque and non-opaque minerals seem to suggest that the metamorphic silicates of the host rocks are replaced by sulphides. The common feature of such replacement is that a group of similarly oriented residuals of silicates and/or carbonates has been found in sulphides. Idiomorphic pyrite and other sulphides include corroded silicate (same optical orientation), indicating, in part at least, development in their present form after the formation of metamorphic silicates. In some cases sulphides have developed in cleavage planes in silicates, and there is strong evidence that in many cases sulphides have formed pseudomorphs.

E. Wall Rock Alteration

An alteration halo surrounds all known deposits in the George River Group and involves recrystallization of earlier metamorphic silicates. Wherever the entire system is visible, the halo is zoned and the zones are always in the same sequence. In areas too large to see in their entirety, the same zones are present and the same sequences are found.

In the calcareous rocks of the George River Group, the fresh rock (zone 4) grades veinwards through tremolite-antigorite rock (zone 3) to moderately altered tremolite-antigorite rock (zone 2) to strongly altered talc-antigorite rock (zone 1). The rock of zone 1 is in immediate contact with the mineralized zone.

In the pelitic rocks of the George River Group, the fresh rock (zone 4) grades veinwards through zones 3 and 2, in which clay minerals are dominant to zone 1, in which the clay minerals are reconstituted to sericite. The sericite in zone 1 is in part a replacement of plagioclase, K-feldspar and biotite following their alteration first to clay minerals. The sericite zone is always found adjacent to the mineralized zone.

There is a close relationship between the sulphide mineralization and secondary minerals. At Meat Cove, the mineralized samples always contain brucite, antigorite and talc. For samples from the trenches, where the exact position is known, it has been shown that brucite, antigorite and talc occur up to 15 metres from the sulphide veins (see Figure 2-2, p. 10). At Lime Hill dolomitic beds are the most important host for sulphides, which occur as massive layers and heavy disseminations. In hand specimens, thin sections and polished sections, antigorite and talc are closely associated with the sulphides. The situation at Lime Hill is similar to that at Meat Cove and, on the basis of this comparison, it seems probable that the alteration minerals are also a product of the mineralizing episode. This assumption is based principally upon the close association of alteration minerals with sulphides. At Whycocomagh the metamorphic silicates were altered to tremolite, antigorite and talc. This alteration was probably the beginning of the process of mineralization. The assemblage that was formed and partially replaced by ore minerals was antigorite-talc-calcite-dolomite. In the Boisdale area, antigorite and talc have been found only in association with the sulphide mineralization.

At Faribault Brook the wall rock alteration has a close spatial relation to the sulphides. No sulphides have been found without accompanying alteration. Proximity to sulphide mineralization is shown by the presence of clay minerals and sericite. At Nile Brook sulphide mineralization is confined to a shear zone, and within the shear, chalcopyrite, pyrite and sphalerite are associated with chlorite and sericite. At Second Gold Brook chalcopyrite, pyrite and pyrrhotite are associated with clay minerals and sericite.

F. Geochemical Characteristics in Two Type Deposits

The distribution of heavy metals was studied in and around two deposits characteristic of the two types of occurrences in the George River Group. Twenty-two samples from Whycocomagh (pyrometasomatic skarn) and thirty-four samples from Faribault Brook (polycyclic hydrothermal) were analyzed for various elements which are characteristic of the mineralized zone.

Because the physical, mineralogical and, probably, chemical changes in most rock types within the calcareous and argillaceous rocks are similar, an example of the geochemical characteristics is presented for the Whycocomagh and the Galena Mine deposits.

Heavy metal analyses of the calcareous and pelitic rocks reveal systematic changes in heavy metal concentration in the altered wall rocks adjoining the mineralized zone. These changes are interpreted as reflecting gain from the mineralized zone. There are, however, two factors that complicate comparison of data: (1) a wide range in original composition of pelitic and calcareous rocks is possible and (2) it can only be assumed that initial heavy metal concentration in the altered wall rock was similar to that found in the unaltered zone outside the mineralization. Thus, the analytical data have not been re-calculated in terms of gains and losses per unit volume of rock but are simply presented as element variation diagrams.

Whycocomagh W-Mo-Cu Deposit: The content of Cu, Pb, Zn, Sn, W, Mo, Co, Ni, Ag, Bi, V, Se and Sb in twenty-two samples from DDH W7 is presented in Table 9-1. A geochemical profile showing the distribution and variation with depth of selected heavy metals is shown in Figure 9-2.

The average copper content in the alteration halo is 1410 ppm and the average copper content in the unaltered wall rock is 213 ppm - about a 7-fold increase in the alteration halo. The average copper content in the talc-antigorite zone is 1415 ppm (omitting one anomalous value of 0.9 per cent copper - the sample was in immediate contact with the mineralized zone). Also, from Figure 9-2 it is clear that a broad zone of high copper concentration coincides with the alteration halo. The distribution patterns of Mo, Co, W, Zn and Pb are very similar to that of copper. The concentration of Ni, Ag, Bi, V, Se and Sb is generally restricted to the mineralized zone and the immediate wall rocks. Tin is generally concentrated in Zone 1 but was not detected in the outer halo.

Galena Mine Cu-Pb-Zn-Ag Deposit, Faribault Brook Area: In a drill hole (HM-2) from Galena Mine, for which the systematic mineralogical changes were demonstrated earlier, the concentration of 14 elements was determined in each rock sample (Table 9-2) and of these, the distribution patterns of Cu, Pb, Zn, Hg, Sn, Ni, W and Ag are shown in Figure 9-3.

The distributions of Cu, Pb, Zn and Hg are remarkably similar and reflect the alteration halo to a large extent. Marked increases in Cu, Pb, Zn and Hg contents are characteristic on crossing the boundary between Zone 3 and the unaltered wall rock of Zone 4; in the sericite

TABLE 9-1

Analyses for Heavy Metals$^{\theta}$ in Drill Core Samples (W-7) from Whycocomagh

Sample Number	Cu (1)	Pb (2)	Zn (2)	Sn (1)	W (3)	Mo (2)	Co (1)	Ni (2)	Ag (5)	Bi (1)	V (2)	Se (5)	Sb (1)
29	300	56	15	ND	21	ND	9	ND	ND	ND	ND	ND	ND
48	610	90	18	3	35	ND	4	ND	ND	ND	ND	ND	ND
60	1257	500	280	9	80	21	48	15	ND	ND	ND	ND	ND
61	0.90$^{\oplus}$	600	400	12	190	300	62	16	7	ND	ND	30	30
80	5.28$^{\oplus}$	778	510	55	1.69$^{\oplus}$	0.70$^{\oplus}$	142	18	43	10	270	93	ND
90	1630	415	200	21	100	735	51	17	6	ND	ND	ND	17
100	1400	400	268	14	80	300	72	16	ND	ND	ND	ND	11
119	1286	400	440	8	28	315	79	ND	ND	ND	ND	ND	ND
130	1190	496	300	ND	32	380	68	ND	ND	ND	ND	ND	ND
138	1195	570	217	ND	52	600	83	ND	ND	ND	11	ND	ND
152	1400	600	896	4	61	415	100	ND	ND	ND	82	ND	19
159	1685	1043	1030	22	109	900	136	105	ND	ND	300	61	35
165	1.05$^{\oplus}$	1300	1026	90	3.96$^{\oplus}$	1.30$^{\oplus}$	600	165	ND	30	900	110	350
167	1700	858	548	72	400	1100	358	43	ND	30	175	ND	63
176	1600	633	490	16	31	30	99	29	ND	10	180	ND	ND
183	1600	605	400	2	28	ND	82	ND	ND	10	35	ND	ND
198	800	90	110	ND	17	ND	41	ND	ND	10	ND	ND	ND
211	713	62	100	ND	9	ND	22	ND	ND	ND	ND	ND	ND
228	300	31	21	ND	4	ND	8	ND	ND	ND	45	ND	ND
236	300	22	ND	ND	4	ND	ND	ND	ND	ND	65	ND	ND
242	162	26	ND	ND	4	ND	ND	ND	ND	ND	ND	ND	ND
249	90	27	ND	ND	4	ND	ND	ND	ND	ND	ND	ND	ND

θ in parts per million
⊕ in weight per cent
(1) detection limits of the elements
ND not detected
Analysis: Bondar Clegg and Co. Ltd.

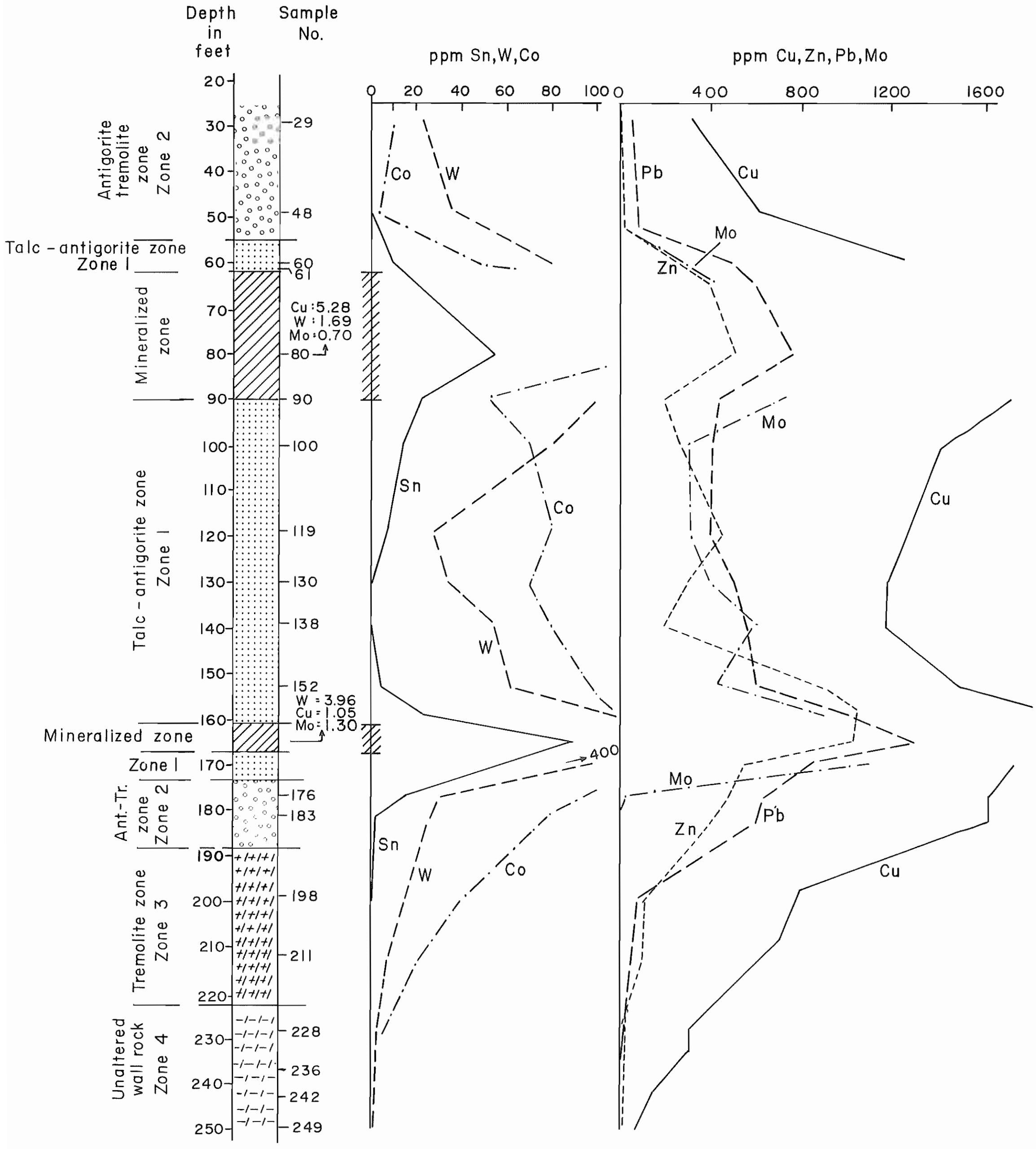


Figure 9-2 Distribution of selected heavy metals in and around the mineralized zones in D.D.H. No.7 at Whycocomagh. For location of drill hole see Figure 4-1

zone the concentrations of these elements are still higher. For example, the average copper content on the foot wall side is 2836 ppm, whereas on the hanging wall side it is 1500 ppm. This is probably due to reactive host rock and in part due to slight differences in the original composition of the rock. Mercury was found in all the samples analyzed; the mean value in the alteration halo is 2260 ppb and the range is from 775 to 4900 ppb. The average Hg content of the mineralized zone is 7060 ppb. The sericite zones show more than a 3-fold increase in mercury content when they are compared to the unaltered wall rock of zone 4.

Tin values greater than 5 ppm were found in only 13 samples analyzed, with a 6-275 ppm range. The distribution of tin is rather irregular on the hanging wall side of the mineralized zone and suggests slight changes in the composition of rock types. Marked concentrations of tin do occur in the mineralized samples, but values greater than 30 ppm are restricted to samples which are only 2 feet away from the mineralized zone. This is considered as leakage outward from the mineralized zone. Cobalt was found in about 45 per cent of the samples analyzed; the average abundance is about 15 ppm. All the cobalt values are confined to the mineralized zone and the sericite alteration halo that is in immediate contact with it. Approximately 10 per cent of the samples analyzed have a tungsten concentration greater than 3 ppm, the lower detection limit; the highest concentration of 47 ppm was obtained for the mineralized sample. Silver is confined to the mineralized zone and the immediate sericite zone. Its concentration in alteration zones 2, 3 and 4 is below 5 ppm, the lower detection limit. Antimony is high in the mineralized zone; the average is 2400 ppm with a 1200-4400 ppm range. In the sericite zone, on the footwall side, the average is 395

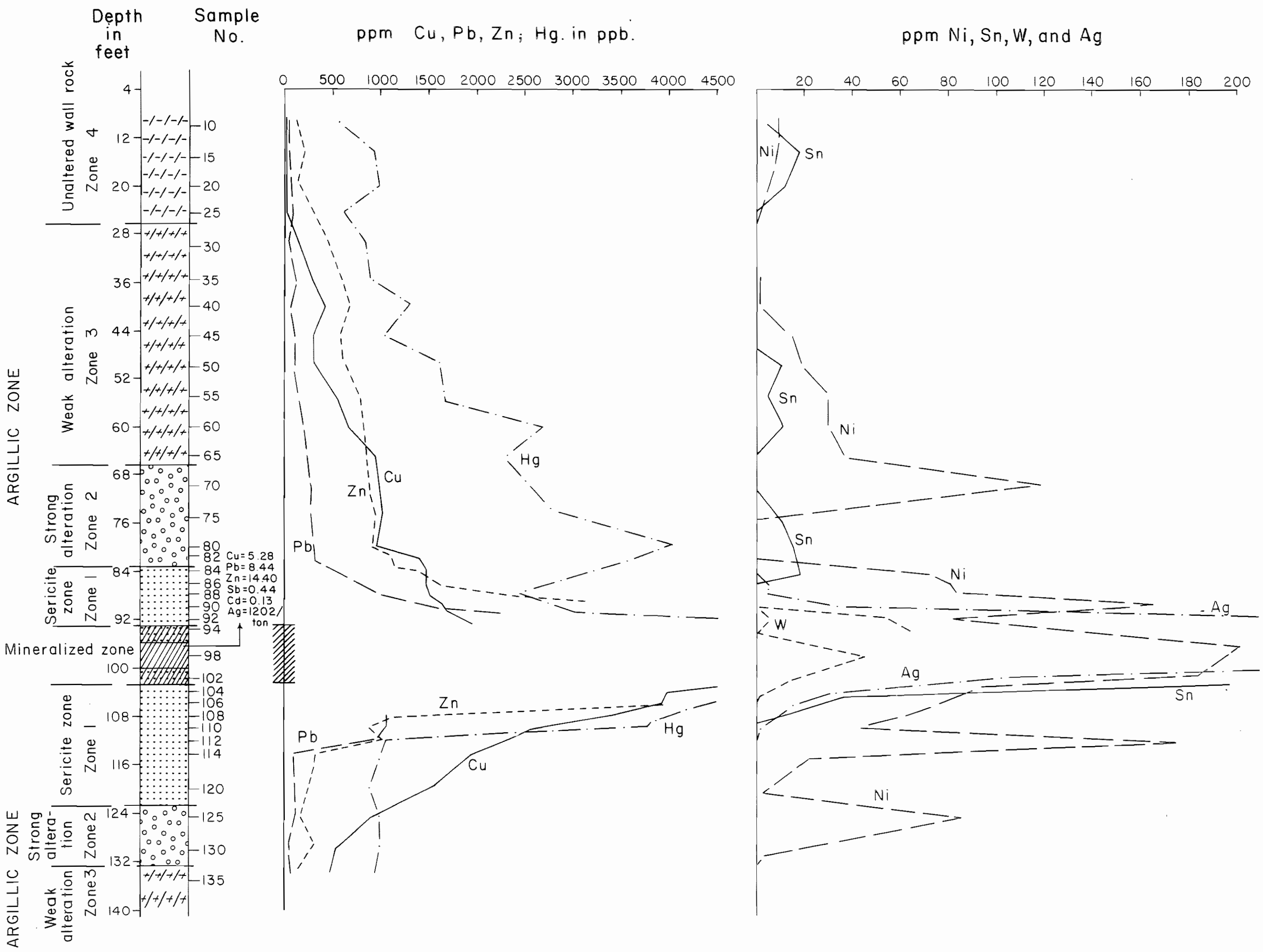
TABLE 9-2

Analyses of Heavy Metals$^{\otimes}$ in Drill Core Samples (HM-2) from the Galena Mine: Faribault Brook

	Cu (1)	Pb (2)	Zn (2)	Ag (5)	Cd (0.5)	Co (1)	Ni (2)	Bi (1)	Hg$^{\oplus}$ (5)$^{\oplus}$	Cr (2)	V (2)	Sb (1)	Sn (1)	W (3)
10	18	24	160	ND	ND	ND	8	15	638	21	16	ND	6	ND
15	26	34	230	ND	ND	ND	6	18	900	24	12	ND	18	ND
20	35	63	185	ND	ND	ND	4	19	950	39	46	ND	13	ND
25	42	58	265	ND	1	ND	2	ND	680	48	52	ND	ND	ND
30	110	73	487	ND	2	ND	ND	ND	875	ND	19	ND	ND	ND
35	260	175	615	ND	4	ND	2	ND	890	17	21	ND	ND	ND
40	442	132	704	ND	ND	ND	2	ND	1235	13	ND	ND	ND	ND
45	360	119	692	ND	ND	ND	14	ND	1107	15	ND	ND	ND	ND
50	340	106	648	ND	4	ND	18	27	1585	9	ND	ND	ND	ND
55	564	167	766	ND	5	ND	28	ND	1630	6	ND	ND	10	ND
60	605	195	785	ND	7	ND	30	34	2900	22	ND	ND	6	ND
65	905	206	823	ND	4	ND	36	ND	2300	41	ND	4	11	ND
70	927	311	857	ND	8	ND	118	ND	2630	34	48	17	ND	ND
75	992	278	896	ND	7	ND	ND	ND	2810	9	65	16	ND	ND
80	927	290	890	ND	9	ND	ND	ND	3795	11	ND	34	11	ND
82	1400	260	1120	ND	11	7	ND	ND	3635	35	ND	32	17	ND
84	1428	635	1148	ND	63	9	74	ND	2400	26	ND	21	16	ND
86	1407	759	0.13$^{\ominus}$	ND	55	16	84	24	1700	33	ND	16	18	ND
88	1448	1135	o.16$^{\ominus}$	6	49	19	86	117	2240	38	ND	18	ND	ND
90	1638	1640	0.24$^{\ominus}$	4	63	21	165	ND	3190	55	14	14	ND	5
92	1600	0.26$^{\ominus}$	0.33$^{\ominus}$	43	78	13	82	ND	4300	67	10	666	57	8
94	1967	0.46$^{\ominus}$	0.78$^{\ominus}$	230	180	13	110	275	6300	85	14	1200	65	4
98	5.28$^{\ominus}$	8.44$^{\ominus}$	14.4$^{\ominus}$	369	1300	19	192	367	9000	230	43	0.44$^{\ominus}$	275	47
102	0.6$^{\ominus}$	3.12$^{\ominus}$	6.4$^{\ominus}$	105	400	14	184	69	5880	14	16	1600	195	15
104	4000	1.3$^{\ominus}$	0.7$^{\ominus}$	31	192	18	95	30	4900	13	19	1195	37	5
106	3957	0.6$^{\ominus}$	0.4$^{\ominus}$	16	89	21	64	14	4120	24	ND	705	ND	ND
108	3400	1135	1110	8	82	24	68	ND	3867	33	ND	630	ND	ND
110	2600	1070	700	ND	73	23	58	ND	3716	38	ND	140	ND	ND
112	2338	900	960	ND	19	4	43	ND	900	17	ND	60	ND	ND
114	1930	160	385	ND	21	2	175	ND	975	36	ND	32	ND	ND
120	1630	146	340	ND	24	ND	ND	ND	775	24	ND	ND	ND	ND
125	865	157	295	ND	32	ND	82	ND	832	19	ND	ND	ND	ND
130	668	104	321	ND	ND	ND	ND	ND	914	15	9	4	ND	ND
135	492	88	208	ND	ND	ND	ND	9	792	14	10	ND	ND	ND

⊕ in parts per billion
⊖ in weight per cent
⊗ in parts per million
(1) detection limits of the elements
ND not detected
Analysis by Bondar Clegg & Co. Ltd.

Figure 9-3. Distribution of selected heavy metals in and around the mineralized zone in drill hole HM 2 at Galena Mine, Faribault Brook. For location of drill hole see Figure 6-2



ppm; however, while on the hanging wall side the average is 17 ppm (excluding one value of 666 ppm, which is only 2 feet away from the mineralized zone).

G. Age of Metallization

There is no available information on the age of metallic mineralization in the George River rocks. From the observations outlined in Chapters 2 to 8, all that can be said with certainty is that the metallization and the attending alteration post-date the thermal metamorphism of the George River rocks. However, in the Cheticamp and Boisdale Hills areas, the quartz-feldspar-biotite schists are intruded by granites and granodiorites which are dated at 530 Ma and 563 Ma respectively by the Rb/Sr whole-rock method (Cormier, 1972). At Meat Cove the syenite intruded the George River carbonates but approximately 4 km northwest of the village of Meat Cove, the calcareous rocks are overlain by unmetamorphosed volcanic rocks. These volcanic rocks are dated at 497 Ma by the Rb/Sr whole-rock method (Cormier, 1964). All these would imply that the metamorphism was prior to about 550 Ma ago.

Preliminary data are presented here on the lead isotopic composition of two samples, one from Meat Cove and the other from the Faribault Brook area. The samples were crushed and galena was separated from powder by heavy liquid separation. The isotopic determinations were made by the Teledyne Isotopes of New Jersey. The results obtained on isotopic composition, isotopic ratio and the model lead ages, assuming single-stage evolution, are given in Table 9-3.

TABLE 9-3

Isotopic composition, Isotopic Ratio and the Model Lead Ages of Galena from Meat Cove and Faribault Brook.

Lead Isotope	Locality - Meat Cove Sample Number K205	Locality - Galena Mines: Faribault Brook DDH HM2 - 97'8"
	Atom per cent	Atom per cent
^{204}Pb	1.384	1.367
^{206}Pb	24.843	24.846
^{207}Pb	21.498	21.468
^{208}Pb	52.275	52.319
Isotope Ratios		
$^{206}Pb/^{204}Pb$	17.950	18.176
$^{207}Pb/^{204}Pb$	15.533	15.704
$^{208}Pb/^{204}Pb$	37.771	38.273

Primary Isochron slope:

$$\frac{(^{207}Pb/^{204}Pb)_t \quad - \quad (^{207}Pb/^{204}Pb)_T^{\oplus}}{(^{206}Pb/^{204}Pb)_t \quad - \quad (^{206}Pb/^{204}Pb)_T^{\theta}}$$

slope:	0.60616	0.60999
Model Age:	415 m.y.	454 m.y.

$\oplus$ 10.294 (Tatsumoto, 1973)
θ 9.307 (Tatsumoto, 1973)

It has been pointed out by Doe and Stacey (1974) and Sangster (1976) that model lead ages, determined from single-stage leads, approach the time of formation of mineral deposits. Thus, the metallization at Meat Cove and Faribault Brook area is 415 Ma and 454 Ma old, i.e., younger than the intrusive rocks. Wanless et al. (1972) dated muscovite* from Meat Cove and his description is as follows: "Muscovite flakes occur with massive sphalerite and serpentine. The formation of muscovite appears to be synchronous with sphalerite; age of muscovite therefore records time of sphalerite mineralization". The muscovite yielded a K-Ar age of 409 Ma which is in excellent agreement with the age of galena (415 Ma) from Meat Cove.

H. Classification of Deposits

1. Pyrometasomatic Skarn Deposits: In Cape Breton Island, the pyrometasomatic skarn deposits are developed at or near contacts of limestone or dolomites (division 2) with the granitic rocks. The shape and distribution of the skarn bodies are generally controlled by (1) the attitude of the intrusive contact that forms one wall, (2) favourable composition of the invaded host rock and (3) the structural relations of the strata to the contact. These deposits contain zinc, tungsten, copper, molybdenum and, in some cases, small but significant amounts of cobalt, nickel, tin, lead, cadmium, germanium and beryllium (Table 9-4). The skarn deposits can be grouped into two types - the Meat Cove type and the Whycocomagh type.

a) The Meat Cove Type: Pyrometasomatic zinc deposits of the Meat Cove are in general larger than those of the Whycocomagh type. The Meat Cove

*At Meat Cove massive sphalerite is present only in magnesian skarn; probably the sample came from argillaceous skarn which may have been in immediate contact with the magnesian skarn. The association of muscovite-serpentine would imply that Wanless' date is actually the time of alteration rather than metallization - though in the present case they are synchronous.

TABLE 9 - 4

Partial Elemental (Assay) Make-up of Pyrometasomatic Skarn Deposits Hosted in Rocks of the George River Group
A = Meat Cove type, B = Whycocomagh type. * = in weight per cent, + = in parts per billion, ND = Not Detected

No.	Type	Locality / Sample No.	Zn	W	Cu	Mo	Co	Ni	Sn	Pb	Cd	Ge	Be	F	Hg^+	Ag	Sb
1	A	Meat Cove K206	40.2*	12	0.17*	4	18	7	200	0.82*	250	170	21	83	5000	8.8	116
2	A	Meat Cove K212	36.5*	16	0.15*	1	14	5	195	0.65*	195	300	14	107	5000	12.6	180
3	A	Meat Cove K140	21.6*	19	0.53*	1	12	ND	400	0.32*	440	430	7	68	5000	14.9	140
4	A	Lime Hill 117-118' DDHS - 12	27.7	ND	120	3	2	44	380	240	770	18	5	140	3600	9.7	73
5	A	Lime Hill 105-106' DDH 5-12	21.9*	ND	40	3	1	ND	460	340	580	21	17	111	4600	4.4	68
6	A	Lime Hill 25-27' DDHS-12	41.4*	ND	60	1	2	ND	290	180	1330	ND	ND	120	5000	10.4	145
7	A	DDHS-10 14-14'	39.9*	260	20	ND	2	1	700	680	1220	ND	1	69	5000	9.6	145
8	B	Whycocomagh DDH-W7-165	1026	3.96*	1.05*	1.30*	600	165	90	1300	1.5	ND	195	645	72	ND	350
9	B	Whycocomagh 6" same from trench	220	2.8*	5.28	745	142	18	1	780	1.0	ND	260	730	180	7.3	ND
10	B	Whycocomagh	90	1.92*	0.86*	21	74	38	18	230	0.5	ND	315	860	215	12.8	73
11	B	Glencoe	140	0.65*	2.25*	6	425	187	39	140	ND	ND	485	1100	60	3.6	ND
12	B	Glencoe DDH-12	1100	360	1.85	12	590	280	160	400	ND	ND	265	490	51	2.6	ND
13	B	Boisdale	0.13*	0.55*	1.13*	200	320	65	42	630	ND	ND	380	518	68	3.2	260
14	B	Boisdale	0.68*	0.18*	0.72*	87	175	38	32	510	11	ND	205	600	130	4.8	311
15	B	Boisdale	0.35*	0.20*	0.52*	65	265	72	16	439	16	ND	117	558	110	7.2	ND

deposit itself contains approximately 4.4. million tons of 4.0 per cent zinc and 0.15 to 0.47 pounds of cadmium. The mineralization is in the form of lenticular bodies of massive sphalerite in the forsterite-bearing units of the magnesian skarn. The mineralogy of the magnesian skarn is diverse and individual samples may contain a wide variety of minerals. The most common are olivine, pyroxene, amphibole and carbonate. The level of concentrations of mercury, cadmium, lead and tin in the mineralized samples from deposits of the Meat Cove type is markedly different than that of the Whycocomagh type (Table 9-4).

b) Whycocomagh Type: The Whycocomagh-type skarn deposits are generally polymetallic and in terms of economic metals W, Mo and Cu predominate over zinc and lead combined. These deposits are generally hosted by impure dolomitic limestone of division 2. In this type also, the skarn mineralogy is diverse and complicated because of corrosion of one mineral by another. The details are given in Chapters 4 and 5. The scheelite-molybdenite-chalcopyrite mineralization in the limestone is rarely distributed uniformly and is commonly concentrated in irregular zones. The Whycocomagh type deposits generally contain beryllium, fluorine and cobalt in anomalous concentration as compared with Meat Cove type (Table 9-4).

2. Polycyclic Hydrothermal Deposits: These are base-metal occurrences containing copper, lead and zinc, in many cases significant amounts of gold, silver, bismuth, cobalt and nickel, and in some cases small amounts of tin, cadmium and antimony. A significant feature of these deposits is that a wide range of values and high values of copper, lead and zinc occur in individual deposits (Table 9-5). These deposits can be grouped into three types - the Silver Cliff, Nile Brook and Rocky Brook types.

TABLE 9 - 5

Elemental Constitution of Polycyclic Hydrothermal Deposits Hosted in Rocks of the George River Group

- = not analysed, * = in weight per cent, + = in parts per million

Analyses 1 to 8 from NSDME open file reports, 9 to 16 by Bondar-Clegg Co. Ltd.

No.	Type	Locality	Cu*	Pb*	Zn*	Ag	Au	Bi$^+$	Co$^+$	Ni$^+$	Sn$^+$	Cd$^+$	Sb$^+$	Hg
1	A	Silver Cliff	0.22	7.92	14.1	50.3	1.408	-	-	-	-	-	-	-
2	A	Silver Cliff	0.30	8.31	13.5	28.36	0.79	-	-	-	-	-	-	-
3	A	Silver Cliff	3.40	0.15	16.5	31.64	0.54	-	-	-	-	-	-	-
4	A	Silver Cliff	6.08	0.42	0.14	6.04	0.12	-	-	-	-	-	-	-
5	A	Core Shack	13.10	0.08	4.00	4.64	0.68	-	-	-	-	-	-	-
6	A	Core Shack	0.03	43.73	3.70	43.57	0.06	-	-	-	-	-	-	-
7	A	Core Shack	0.10	6.56	14.15	8.80	0.03	-	-	-	-	-	-	-
8	A	Galena Mine	0.10	6.56	14.15	8.80	0.03	-	-	-	-	-	-	-
9	A	Galena Mine	5.28	8.44	14.40	12.3	0.002	367	19	192	275	1300.0	4400	9000
10	A	Core Shack (arsenopyrite rich)	0.09	0.18	0.12	3.8	1.01	380	48	23	20	10.5	342	80
11	A	Galena Mine	0.02	9.30	16.20	16.56	1.13	485	16	96	390	1600.0	4414	8050
12	A	Fisset Brook	0.15	4.64	13.8	15.00	0.002	14	2	1	338	1460.0	539	2100
13	B	Nile Brook	3.27	2.19	0.8	0.05	0.002	8	6	15	40	11.2	45	280
14	B	Nile Brook	0.86	4.10	5.60	0.02	0.002	11	4	21	18	14.6	62	345
15	B	Second Gold Brook	0.91	0.09	0.19	0.02	0.002	ND	425	5300	5	6.5	38	100
16	B	Second Gold Brook	1.56	0.05	0.24	0.004	0.02	2	775	10700	ND	6.5	77	190

a) Silver Cliff Type: These are located in the western part of the Ingonish Domain in dominantly pelitic metasedimentary rocks of division 3. The mineralization at Silver Cliff is the largest known (length 45 m, width 5 m), and contains copper, lead, zinc, silver, gold, bismuth and minor tin. The mineralization is in the form of folded lenses of sulphide-rich metasediments that are concordant as well as discordant with the layering (bedding) of the enclosing schists. Metamorphic facies of the country rock is high amphibolite, and retrogressive metamorphism is associated with the mineralization. The sulphides present are pyrite, pyrrhotite, arsenopyrite, sphalerite, chalcopyrite, galena, enargite, bornite, argentite, covellite and tetrahedrite.

b) Nile Brook Type: The Nile Brook type occurrences are all located in fault or shear zones generally, in metapelitic schist and gneisses of division 3. All the occurrences are located in a well defined north-south zone that is aligned roughly parallel to the Margaree-Middle River drainage system. The sulphide minerals are commonly accompanied by vein quartz or quartz stringers. At Nile Brook, chalcopyrite is a major constituent in the mineralized zone; at Grandon Brook, galena is more than chalcopyrite and sphalerite combined, and at Second Gold Brook chalcopyrite is associated with nickel-bearing pyrrhotite. Both in metal content and the nature of wall rocks the Nile Brook type resembles the Silver Cliff type, and so the mineralization for both types may have been derived from a common source.

c) Rocky Brook Type: These are located in the central part of the Ingonish Domain, hosted by volcanic rocks of intermediate composition of division 3. The Rocky Brook prospect itself is located in fractured andesite approximately 300 metres west of Margaree fault.

The Rocky Brook type of mineralization was not studied during this investigation; however, the mineralization at Mountain Top is probably similar.

I. Comparison with Similar Deposits

1. Appalachian Region: The Precambrian rocks of Cape Breton Island and south eastern New Brunswick are remarkably similar in lithological succession. In both areas, the succession consists of quartzites, marble, gneisses and schists, and volcanic rocks. On the basis of this similarity the George River Group is correlated with the Green Head Group of New Brunswick. The Precambrian Conception Group of Newfoundland lacks the carbonate beds hence, is lithologically disimilar.

On the basis of regional metallogeny McCartney and Potter (1962) concluded that the skarn deposits are not known in the Precambrian rocks of the Appalachian fold belt. However, the present study has shown that in the George River Group, the skarn deposits are widely distributed. Because there are not other known skarn deposits in the Avalon Zone, direct comparisons cannot be made.

2. Others: The skarn deposits of the George River Group exhibit many features which are similar to the skarn deposits described by Zarikov (1970). A brief summary of the principal genetic types of deposits is presented in Table 9-6, and the examples from Cape Breton Island are listed for comparison.

The polymetallic skarn deposits generally favour magnesian host rock and many similar deposits are known from elsewhere, for example, Pb-Zn deposit at Mt. Hope, Nevada (Missallatti, 1973), Zn-Pb-Cu deposit at Mission, Arizona and Keban Pb-Zn deposit in Turkey (Kines, 1969). In the above deposits the alteration and replacement of the primary skarn

TABLE 9 - 6

Principal Genetic Types of Skarn Mineral Deposits

(Early Stages of Geosynclinal Evolution) (Zharikov, 1970)

Genetic Type	Skarn Composition	Mineral Deposits/ Magmatic Rocks	Example	Nova Scotia
IRON				
Magnetite	Magnesian skarn	Precambrian dolomites/diortie	Central Sweden	Craignish Hill
Magnetite-ludwigite	Magnesian skarn	Precambrian dolomites/diorite	Iron Hat, Kay Canyon	not known
Magnetite	Limy skarn	Precambrian dolomites/granite	Ural, Paleozoic fold belt	Glencoe
COBALT				
Cobaltite-magnetite	Limy skarns	Wollastonite Limestone granodiorites	Maikhura, U.S.S.R.	not known
COPPER				
Magnetite-Chalcopyrite	Limy skarns	Sulphides superimposed/ granite	Ural, Paleozoic fold belt	Boisdale
POLYMETALLIC (Zn-Pb-Cu)	Magnesian skarns	Superimposed companion types/ syenite, granite	Sweden, Urals, Yugoslavia, New Mexico	Meat Cove, Lime Hill
Molybdenum-Tungsten-Copper (occasionally with Sn)	Limy Skarns, ocassionally magnesian skarns	Superimposed W-Sn Companion type Cu/granite granodiorite, diorites	deposits in Nevada and California	Whycocomagh Boisdale
RARE METALS				
Be, Borates	Limy and magnesian skarns	companion type/granites	Iron Mountain, U.S.A. China, Ceylon	West Indian Brook
Uranium	Argillaceous skarns	not clear	Mary Kethlyn, Australia	not known
Bismuth-Tin-Tungsten	Limy and Argillaceous skarn	not clear	Sandong, Bulgaria	Glencoe/Glendale

minerals are common, and the mineral associations are complicated by the introduction of later phases including those which carry ore minerals. The mineralization is generally localized in the forsterite and diopside -rich varieties of the magnesian skarn. A variety of the alteration mineral is characteristic. These secondary minerals are amphibole, antigorite, brucite and talc. Thus, the zinc deposits at Meat Cove and Lime Hill are similar because these have similar features.

The W-Cu-Mo skarn deposits have been studied by a number of authors (Large, 1972; Brock, 1972; Morgan, 1975; Marmontov, 1968; Buseck, 1966; Constantineceu, 1971). These authors have pointed out that the W-Cu-Mo deposits are characterized by two main phases: (1) a skarn-producing phase and (2) a hydrothermal phase. During the hydrothermal phase the primary skarn minerals are corroded, replaced and altered. During the hydrothermal phase the ore minerals are deposited. The Cu-W-Mo deposits at Whycocomagh and Boisdale Hills have similar features.

CHAPTER 10

CONCLUSIONS AND RECOMMENDATIONS

1. The George River Group of Cape Breton Island is represented by thick sections of quartzites, feldspathic quartzites, slates, marbles, calc-silicate rocks and amphibolites together with some other meta-sedimentary rocks and minor amounts of volcanic rocks. The entire succession was intruded by plutonic complexes ranging in composition from gabbro to granite.
2. The mineral deposits in the George River Group may be categorized into two classes: (1) pyrometasomatic skarn deposits and (2) polymetallic, base-metal deposits. The skarn deposits are confined to contacts of dolomitic limestone with the magmatic rocks. The polymetallic, base-metal deposits are found in pelitic schists, and are also present in shear zones near the contact with the intrusive rocks.
3. The skarn hosts for zinc mineralization are generally magnesian and for the tungsten-molybdenum-copper mineralization is more calcareous. The former is characterized by periclase, forsterite, diopside and spinel mineral associations and the latter is characterized by wollastonite, diopside, andradite and actinolite associations. The pelitic host rocks for the polymetallic base-metal mineralization are characterized by sillimanite, kyanite, andalusite and almandine-bearing associations.
4. A zone of alteration surrounds all known metallic mineralization and is characterized by changes in the earlier silicate minerals.

The evidence is: complete pseudomorphs after metamorphic mineral grains, absence of fresh metamorphic minerals in zones of alteration, a recognizable quantitative increase in hydrous silicate minerals in altered zones as compared with unaltered rocks. These relationships within the alteration envelope surrounding the sulphide-filled fractures indicate post-metamorphic age of the alteration and of the vein it envelopes.

5. In the skarn deposits, alteration is characterized by antigorite, talc and brucite. In the polymetallic base-metal deposits the alteration is characterized by illite-montmorillonite, sericite and chlorite.
6. There is a close relationship between sulphide mineralization and secondary silicate minerals found in the halo surrounding it. At Meat Cove, mineralization is always accompanied by brucite, antigorite and talc. At Lime Hill, Whycocomagh and Boisdale Hill, antigorite and talc are associated with sulphides. At Faribault Brook, Nile Brook and Second Gold Brook the sulphides are always associated with illite-montmorillonite, sericite and chlorite.
7. The metallic mineralization followed the alteration stage, although mineral overlap and the envelope of alteration around the sulphides suggest continuity between the two episodes.
8. The sulphide minerals entensively replaced earlier silicate minerals. The shapes and sizes of the later sulphide grains are controlled by the texture or kind of aggregation of the grains they replaced.
9. The geological setting and style of mineralization at Faribault Brook seem to suggest that the mineralization is of a concordant type. However, the relative abundance of Cu, Pb and Zn, is quite unlike that shown by known concordant ore bodies, such as those at Bathurst-Newcastle, New Brunswick.

10. The association of gold and arsenic with the polymetallic hydrothermal mineralization at Fairbault Brook is similar to many hydrothermal gold deposits. Also, the metal abundances from the stratiform Faribault Brook occurrence are similar to those of a hydrothermal, discordant ore body.

11. Heavy-metal analyses in and around the mineralized zones in the calcareous and argillaceous rocks of the George River Group have indicated that: (a) the wall rocks enclosing the veins are enriched in essential metals of the mineralized zones when compared with the background values, and the haloes have a bilateral symmetry; (b) the heavy metal variations within the the alteration haloes are very striking, and there is systematic contrast in some heavy metal concentrations within zones of alteration; (c) the heavy metal concentrations in zones of alteration differ markedly from concentration of the same elements in nearby unaltered rock; (d) the zonal arrangement of the alteration zones and the distribution of heavy metals in them must reflect, to some degree, heavy metal dispersion into the altered wall rocks from the mineralized zones; and (e) the anomalous concentration of heavy metals is confined to the zones of alteration and this would imply that the metallization and wall rock alteration are roughly synchronous.

12. The elements having greatest potential for exploitation in the George River Group are copper, lead, zinc, tungsten, molybdenum, silver and gold. In terms of future prospects, metasomatic Cu-W-Mo, Zn-W in the rocks of the division 2 and stratabound base-metal mineralization in the rocks of the division 3 are thought to represent the most attractive exploration targets.

The rocks of division 2, in which the economically paramarginal zinc mineralization at Meat Cove and Lime Hill and the copper-tungsten-molybdenum mineralization at Whycocomagh occur, are widely distributed in parts of Boisdale Hills, Craignish Hills and North Mountain. The presence of three small prospects of the Whycocomagh type, within 5 km of one another, between Rear Boisdale and Frenchvale, may signify the existence of other deposits there. Molybdenum and cobalt may also be present in any additional occurrences of this type. Such deposits may also occur in the carbonate rocks of the George River Group, primarily in four areas where the geology is favourable and carbonates are likely to occur. Areas that might be considered include the contact aureoles around (1) the granodiorite-limestone contact, approximately 10 km west of Blue Hills (2) the granodiorite-limestone contact at Lake Ainslie, (3) rocks within an approximately 3 km-wide, east-west trending belt between the granodiorite of the North East Margaree area and the granite complex of the Frasers Mountain area and (4) the granodiorite-limestone contact approximately 4 km west of the Gisborne Lake area.

Base-metal deposits of the Silver Cliff type may be discovered in the rocks of division 3 of the Ingonish Domain and, if so, may contain significant amounts of silver and gold and small amounts of bismuth and tin. The pelitic rocks of the Cheticamp-Rocky Brook, Crowdis Mountain and Rear Christmas Island areas are potentially favourable areas for base-metal mineralization.

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