Geology of the Meat Cove Zinc Deposit Cape Breton Island Nova Scotia

by A K Chatterjee

Nova Scotia Department of Mines

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1979

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ABSTRACT

Parageneses, mineralogical and geochemical peculiarities of alteration and zinc mineralization in the skarn of the deposit are described.

The mineralization consists mainly of disseminated and massive replacement of pyrite, pyrrhotite, sphalerite, chalcopyrite, galena and magnetite in the magnesian skarn.

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

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

The hydrothermal stage was followed closely by the main sulphide mineralization stage during which most of the sulphides were deposited. This main sulphide mineralization consisted of pyrite, germanite, pyrrhotite, chalcopyrite, sphalerite, galena, bornite and renierite, in this sequence, and probably was separated from the hydrothermal stage by no significant time interval.

Geochemical data on the distribution of Zn, Fe, Mn, Cu, Pb, As, Ni, Cd, Zr, Ge, Sn and Hg, in and around the mineralized veins, indicate that the ore forming elements were introduced into the host rock at Meat Cove.

INTRODUCTION

The rocks of the George River Group contain more mineral showings than any other single rock unit in Cape Breton Island. Within the George River Group, metamorphosed siliceous dolomitic limestone hosts nearly 30% of the mineral occurrences and 70% of the known zinc-lead mineralization.

The Meat Cove zinc deposit is situated about three miles east of the village of Meat Cove, Inverness County, Cape Breton Island, at latitude 47°00'N and longitude 60°35'W. 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.

This paper is a result of a study based on personal observations of the property, surface geological mapping and sampling supplemented by microscopic observations and XRF and microprobe analyses of more than three hundred samples. It draws heavily on information and assessment work done by Minex Co. since 1953.

EXPLORATION HISTORY

The first indication of possible zinc mineralization at Meat Cove was glacial boulders containing disseminated sphalerite, found by the personnel of the Minex Co. in 1953. As a result of geological investigation, an electromagnetic survey and exploratory drilling the main ore body (adit zone) was identified in 1955. Prospecting, trenching and diamond drilling has continued over several periods since the first discovery. By 1965, diamond drilling had outlined a restricted area of low grade mineralization. Dunbar (1965) estimated a possible tonnage of 4.4 million tons of 4.0% zinc and 0.15 to 0.47 pound of cadium per ton in two adjacent deposits. In 1968, several trenches were bulldozed and it was reported that a sample across 254 feet assayed 5.65% zinc with a 102 feet section averaging 10.5% zinc. In 1970, Cava Exploration Consultants Ltd. outlined an anomalous zinc area southeast of the main mineralized zone on the basis of geochemical and V.L.F. electromagnetic investigations. 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 3,494,700 tons of 2.08% 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 a sequence of interbedded siliceous dolomitic limestone and garnetiferous quartz-feldspar-biotite schist. Regional mapping (Neale, 1964) indicates that it is a roof pendant in a large area of syenite. Later, diabase and aplite dykes cut both the syenite and the metasediments. Figure 1 shows the general geology of the Meat Cove region and the location of the adit zone, NW mineralized zone and East anomaly zone. This compilation is based on information supplied by various companies to the Nova Scotia Department of Mines.

Skarn bodies of the Meat Cove deposit are confined to the contact of syenite with the siliceous dolomitic limestone, argillaceous limestone and siliceous limestone. The contact zone, where the skarns are formed, is characterized by complex mineral associations resulting from repeated alteration of carbonate rocks. The skarn bodies have a lenticular shape with rather irregular contacts and attain a maximum width of approximately 80 feet.

In addition to contact metamorphism and skarn formation, intense magnesian alteration is displayed with the mineralization. The three major products of alteration are brucite, antigorite and talc. The colour of the antigorite varies from pale greenish yellow to dark greenish black. Brucite occurs as white spots on the weathered surface, and a pitted clayey surface showing onion-skin structure is characteristic. This process of alteration is developed along contacts near

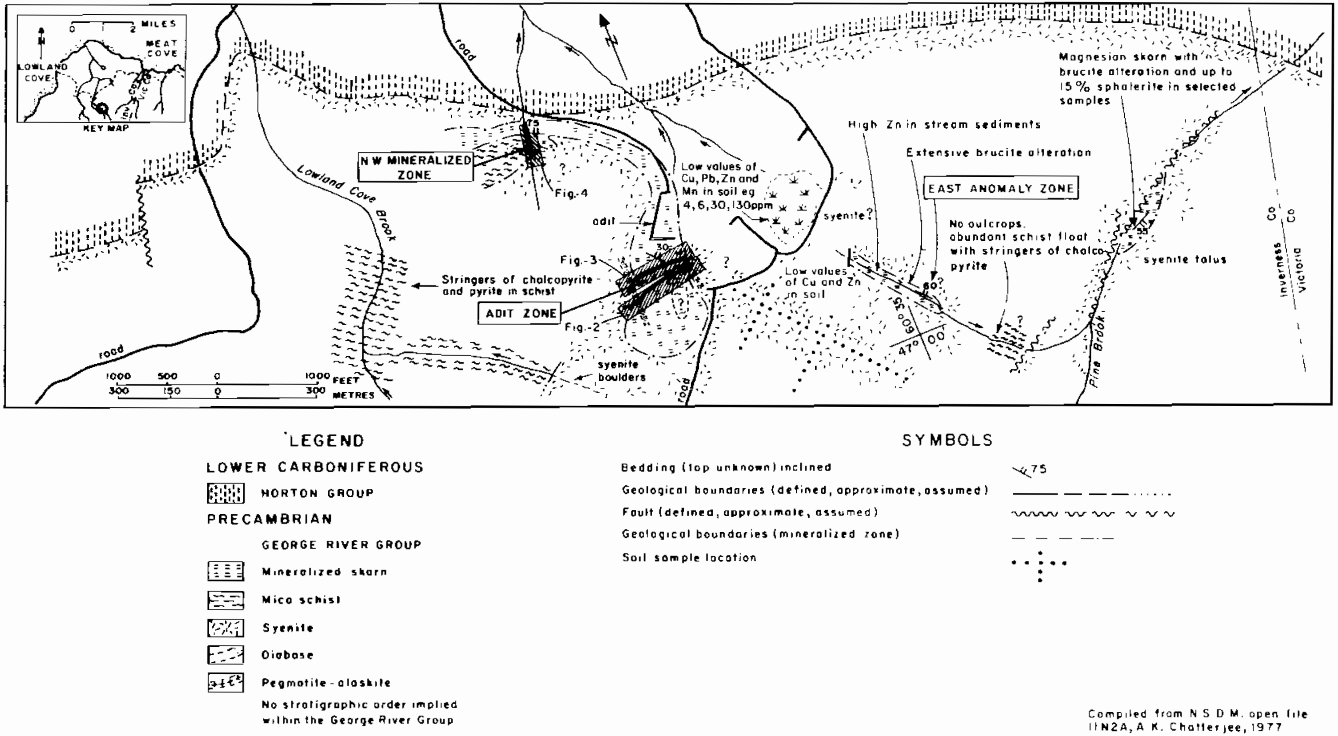


Figure 1. Surface plan, Meat Cove zinc prospect.

apical parts of the intrusion, its apophyses and skarn bodies. At several places the presence of sulphides below the surface is indicated by the presence of gossan. In a few places, the gossan is rather hard and massive, probably indicating massive sulphides. In places the gossan is banded; the colours of the individual bands are various combinations of pale yellow to dark reddish brown with distinct pink patches randomly distributed. The colour and the nature of the gossan are indicative of varying amounts of different sulphides.

MODE OF OCCURRENCE

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

1. Dissemination and stringers of pyrite and some chalcopyrite occur in the fine grained quartz-feldspar-biotite schist. The rocks show some tourmalization and strong chlorite and sericite alteration.

2. Banded pyrrhotite and sphalerite mineralization is found on a small scale in the bed of the brook (NW mineralized zone). The finely banded gossan exposed in the trench may have been derived from this type of mineralization.

3. Rare veins (seen only in drill core samples) of pyrite-bornite-chalcopyrite-quartz-carbonate occur in the syenite. Generally, these veins are rimmed by sericitic alteration. These veins may be considered "ore leading channels".

4. Impregnations and stringers of sphalerite occur in argillaceous and calcareous skarns.

5. Selective replacement of forsterite and forsterite-bearing units of the magnesian skarn is prevalent. This replacement is the most productive in terms of mineralization, and is chiefly developed as a zone along the magnesian skarn and syenite contact. The magnesian skarn with sphalerite mineralization has a distinct and intense brucite, antigorite, and talc alteration.

6. Mineralized veins are not uncommon. They are composed of sphalerite, galena, and pyrite. These veins are generally oxidized, and are also present in brecciated magnesian skarn. This brecciation is due to fault movements which predate the mineralization.

TYPES OF SKARNS

The term "skarn", borrowed from Swedish miners, was introduced into the literature by Lindgren (1902). Hess (1918) originally applied the term tactite to contact metasomatic rock ".....of complex mineralogy formed by 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). Gary, et al. (1972) define skarn as ".... lime bearing silicates of any geological 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 applied here to recrystallized carbonate rock 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 1). The minerals mentioned in the table are of special interest because they have been useful in differentiating lithological units (Figures 2, 3 and 4) and establishing certain relationships of the units to the mineralization. The details on various types of skarns are given below:

TABLE 1

Diagnostic minerals in various types of skarns

Compositional Units	Skarn Type	Diagnostic Minerals
siliceous dolomitic limestone	magnesian skarn	periclase, chondrodrite, monticellite, forsterite, diopside, & tremolite
argillaceous dolomitic limestone	argillaceous skarn	idocrase, scapolite, epidote, & phlogopite
siliceous limestone	calcareous skarn	wollastonite, akermanite

Magnesian Skarn (Siliceous Dolomitic Limestone)

The magnesian skarn is characterized by an alteration of almost pure dolomites and strongly silicated units. Emphasis here is placed on the lithologic unit containing mineralization (ore grade values) where mapping and diamond drilling have provided much, although far from conclusive, information. Table 2 lists the units identified within the magnesian skarn.

Many of the silicated units, in turn, can be subdivided into subunits that include alternating dolomitic or calcitic marbles, serpentinous and silicated marbles, quartzose and micaceous rocks. The repeated alteration of competent and incompetent beds on all scales, from tens of feet down to inches, is undoubtedly a prime factor in the formation of the usually complex mineralization at Meat Cove.

The spatial relation of the skarn and the syenite intrusion suggests that the calcareous rocks were subjected to high temperature "contact metamorphic" changes. This implies that a mixture of calcite-

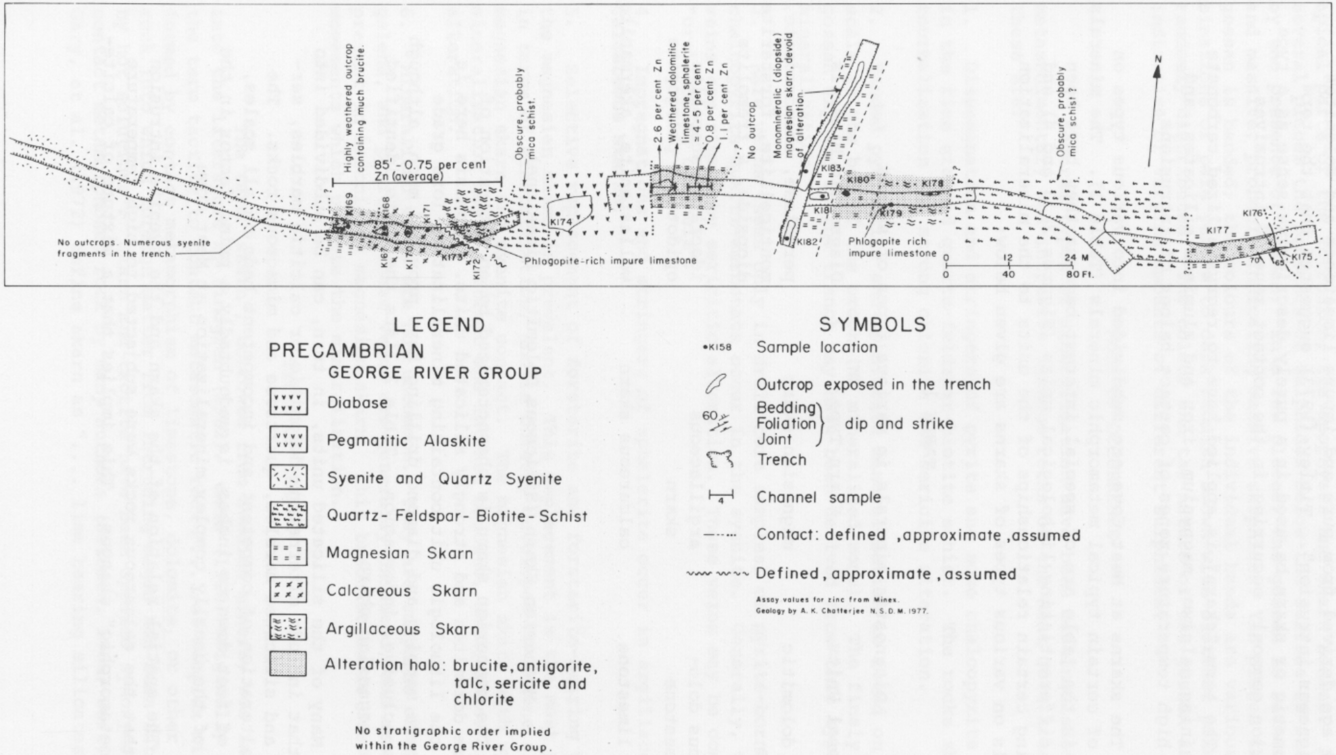


Figure 2. Surface trenching, geology and assay plan for adit zone, trench #1.

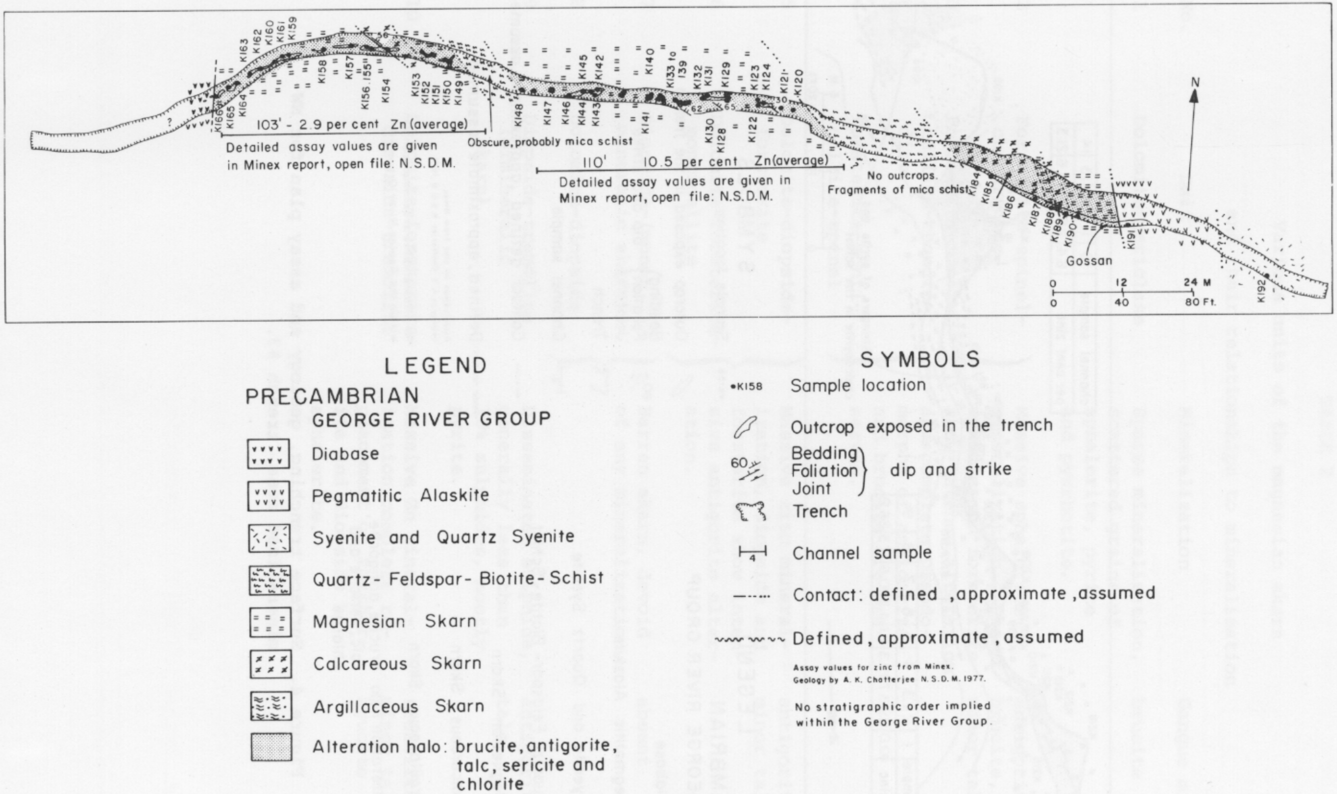
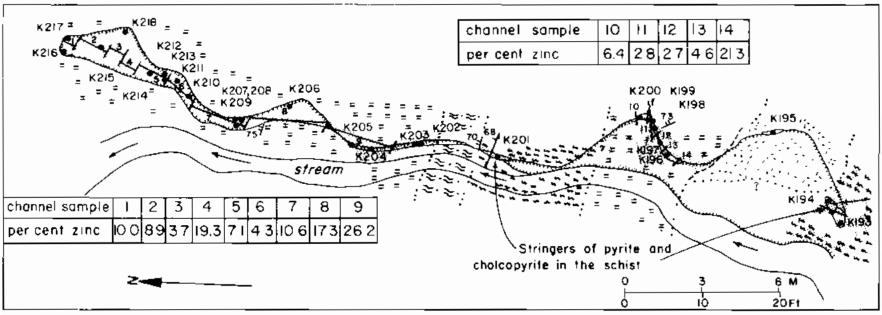


Figure 3. Surface trenching, geology and assay plan for adit zone, trench #2.



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 Skorn
- 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 Mines Geology by A. K. Chatterjee N.S.D.M. 1977

No stratigraphic order implied within the George River Group

Figure 4. Surface trenching, geology and assay plan for NW mineralized zone, trench #3.

TABLE 2

Various units of the magnesian skarn

and their relationships 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 of antigorite and brucite are preserved.	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 skarn)	Barren skarn, devoid of any mineralization.	absent
8	Dolomite-diopside		
9	Diopside-tremolite (bimineralic skarn)	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

dolomite-quartz must become unstable with rising temperature. To explain the contrasting mineralogy in various units of the magnesian skarn, there are only three likely alternatives: (1) a gradient in temperature, (2) a gradient in pore fluid, or (3) a gradient in fluid composition. Detailed physicochemical considerations regarding these three possibilities are considered elsewhere. However, the following pertinent points must be mentioned:

1. A significant temperature gradient is highly unlikely because of the relatively small size of the skarn bodies.

2. A gradient of P_f is ruled out because CO_2 and H_2O would be produced actively in all the layers suggesting that $P_f = P_s$.

3. As a result of slight changes in initial bulk compositions of various layers of the siliceous dolomitic limestone a gradient in fluid composition produced the contrasting mineralogy in these layers.

4. From Table 2, it is clear that olivine bearing skarns are the most important host for ore grade mineralization. It is also noteworthy that these <u>always</u> have at least one of talc, antigorite or brucite in close association. The significance of this association is discussed further in the text.

Argillaceous Skarn (Argillaceous Dolomitic Limestone)

Argillaceous skarns are characterized by recrystallized rocks made up of high temperature lime-magnesia-potassium-iron silicates and aluminosilicates. Typical minerals are idocrase, scapolite, K-feldspar, plagioclase, muscovite, zoisite and phlogopite. In the field argillaceous skarn is easily identified on the basis of the "schistose" character of the carbonate rock and a high amount of phlogopite.

The argillaceous carbonate rocks are devoid of any mineralization, hence detailed paragenesis of minerals is not considered here.

Calcareous Skarn (Siliceous Limestone)

Calcareous skarns are characterized by recrystallized rocks made up of high temperature Ca-Mg-Fe silicates and aluminosilicates. Typical metamorphic minerals are diopside, wollastonite, akermanite and idocrase. The following mineral assemblages are common at Meat Cove:

Diopside-wollastonite
Diopside-wollastonite-akermanite
Diopside-scapolite-wollastonite-idocrase.

WALL ROCK ALTERATION

Brucite, Antigorite and Talc Alteration:

Rocks derived through chemical alteration of the siliceous dolomitic limestone (magnesian skarn) occupy a considerable part of the mineralization at Meat Cove (see Figures 2, 3 and 4). In hand specimen brucite, antigorite and talc are closely associated with the sulphides. Textural relations, summarized below, indicate that these were derived largely from pre-existing high grade metamorphic minerals:

Brucite:

(1) has resulted from the action of water on forsterite; antigorite is an additional product (Plate 1, Figure A).

(2) has resulted from the alteration of antigorite (Plate 1, Figure B).

Antigorite:

(1) has been derived from tremolite; pseudomorphs preserve the amphibole cleavage (Plate 1, Figure C).

(2) has been derived from periclase; rounded antigorite grains contain relics of a periclase core (Plate 1, Figure D).

(3) has been derived from forsterite; the antigorite grains show relics of forsterite and the fracture pattern is also preserved (Plate 1, Figure E).

Brucite and antigorite were both derived directly from dolomite as well; the formation of antigorite and brucite releases calcite (Plate 1, Figure F). The direct alteration of periclase to form brucite has apparently not occurred; instead the periclase formed antigorite.

Talc:

Talc is invariably intergrown with brucite and antigorite, and no talc has been found at Meat Cove that is not associated with these two minerals.

As has been indicated in Table 2, all the three alteration minerals are present in the vicinity of sulphide mineralization. For samples from the trenches, where the exact position is known, it can be shown that brucite, antigorite, and talc occur up to 30 feet from sulphide mineralization. Lack of exposures makes it impossible to see how much farther alteration extends.

Chlorite and Sericite Alteration:

In the Meat Cove area the quartz-feldspar-biotite schist is accompanied by chlorite and sericite alteration. This alteration is generally feeble and can only be seen in samples adjacent to pyrite-chalcopyrite stringers. This alteration is generally associated with epidote.

Here again, the alteration minerals were formed later than those formed during regional metamorphism. This is shown by such textural evidence as: garnet altered to chlorite, biotite altered to chlorite, plagioclase altered to epidote, and K-feldspar altered to sericite.

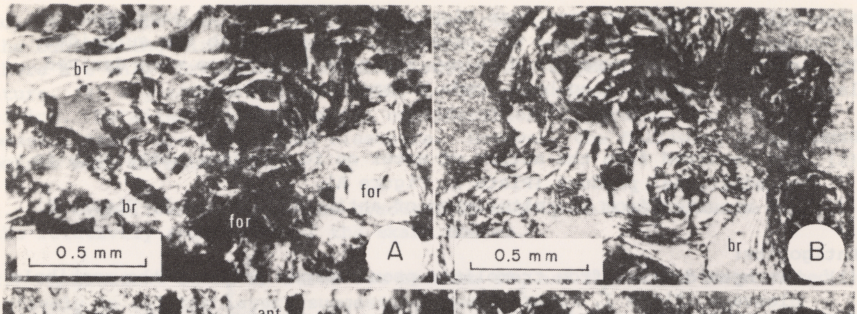


Plate 1. Photomicrographs showing the textural relationships of antigorite and brucite. A, Alteration of forsterite to brucite. B, Alteration of antigorite to brucite. C, Alteration of tremolite to antigorite. D, Alteration of periclase to antigorite. E, Alteration of forsterite to antigorite. F, Alteration of dolomite to brucite and antigorite. for, forsterite; dol, dolomite; ant, antigorite; br, brucite; pe, periclase.

CHEMICAL VARIATIONS IN THE ALTERATION HALO

Mineral assemblages of wall rock alteration in the magnesian skarn are grouped into: (1) a periclase zone, (2) a brucite zone, (3) a brucite-antigorite zone, and (4) an antigorite zone. The zones are named according to the mineral or minerals by which they are recognized in the field. These zones are described progressively inward from the marginal, unaltered segment to the intensively altered segment which is in immediate contact with the sulphide vein.

Periclase zone:

This unaltered zone is coarsely crystalline and appears nearly as white marble in hand specimen. It is characterized by the presence of periclase and monticellite. Minute grains of magnetite are also sparsely scattered.

Brucite zone:

The matrix of this zone is greenish owing to antigorite. It is characterized by development of brucite, and there are lesser amounts of antigorite, talc and secondary calcite. Rocks of this zone are widespread in the area.

Brucite-antigorite zone:

The mineralogy of this zone is similar to the previous zone, but antigorite is the major constituent. Remnants of periclase in antigorite are common.

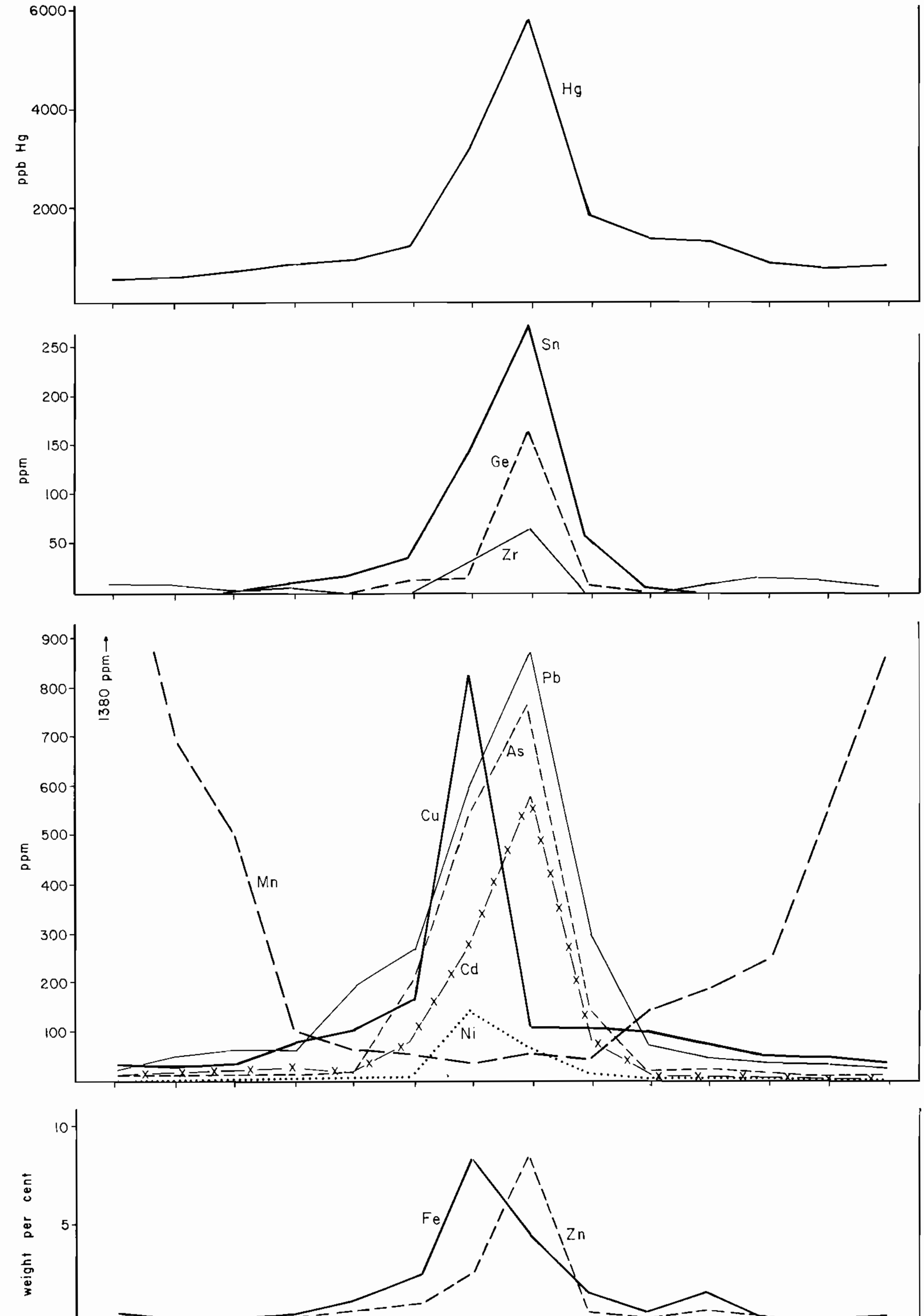
Antigorite zone:

It is characterized by abundant development of antigorite and talc. The zone is green and periclase and dolomite are totally replaced by antigorite. The inner part of the zone contains disseminated pyrite and pyrrhotite.

The mineralogy of the vein, the alteration envelope and the distribution of Zn, Fe, Mn, Cu, Pb, As, Ni, Cd, Zr, Ge, Sn and Hg in the zones of alteration are presented in Figure 5. The following inferences can be made from the data:

1. The lateral zonation adjacent to the veins appears to have developed contemporaneously, or nearly so, with the deposition of the vein minerals. The evidence in favour of a contemporaneous origin is: (1) that certain constituents, such as antigorite, brucite, talc, pyrite and pyrrhotite, present in the altered zones, are the same as those in the veins, and (2) that the same type of alteration zones are present in both the ore-bearing and gangue-bearing veins without ore.

2. The wallrock enclosing the vein is enriched in Zn, Cu, Pb, Fe and Hg compared with the background values, and the endogenic halo has a bilateral symmetry.



Sample Number	K 166	K 165 K 164	K 163	K 162 K 160	K 161 K 159	K 158	K 157 K 155	K 153	K 152 K 149
Alteration Zones	Zone 4 Periclase Zone	Zone 3 Brucite Zone	Zone 2 Brucite-Antigorite Zone	Zone 1 Antigorite Zone	Mineralized Zone	Zone 1 Antigorite Zone	Zone 2 Brucite-Antigorite Zone	Zone 3 Brucite Zone	Zone 4 Periclase Zone
Mineralogy	Calcite Dolomite Periclase Forsterite Chondrodite Diopside Tremolite (trace)	Calcite Dolomite Brucite Antigorite Tremolite Diopside (trace)	Calcite Dolomite Antigorite Brucite Tremolite (trace)	Calcite Dolomite Pyrite Pyrrhotite Talc Antigorite Brucite	Sphalerite Magnetite Pyrrhotite Pyrite Chalcopyrite Stannite (trace) Brucite Talc Antigorite Calcite	Calcite Dolomite Talc Antigorite Brucite Pyrite	Calcite Dolomite Brucite Antigorite Diopside (trace) Tremolite (trace)	Calcite Dolomite Brucite Antigorite Diopside Tremolite	Calcite Dolomite Periclase Forsterite Monticellite

Figure 5. Mineralogy and the distribution of trace elements in and around the sulphide vein.

3. The distribution pattern of various trace elements in the vein, altered and unaltered wall rocks suggests that the mobilization of the ingredients does not seem either a necessary or likely process during metamorphism or mineralization. From this it may be concluded that there is no evidence to suggest that elements moved from one alteration zone to another during metamorphism. This implies that lateral migration of elements is not possible and the sulphides were introduced into the host rocks.

MINERALOGY OF THE DEPOSIT

Sphalerite is the major sulphide mineral at Meat Cove. Pyrite, pyrrhotite, chalcopyrite, galena, and bornite are common accessories, and germanite, renierite, and stannite occur locally.

Pyrite:

Pyrite is abundant but generally is subordinate to sphalerite. It commonly occurs as independent crystals and granular aggregates. The pyrite has a variety of shapes and forms and has such relations as to suggest that it was formed at different times. Some of the pyrite is finely crystalline, but the larger part is in coarse cubic form. 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 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 susceptible to replacement by other sulphide minerals than pyrite of generation I.

Pyrite of Generation III (?): Another generation of pyrite is suspected to occur 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 generations of pyrrhotite may be distinguished. Pyrrhotite I forms very minute grains in sphalerite, as inclusions showing a 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, Figure A). Pyrrhotite II appears as bands alternating with sphalaerite in brecciated ore (Plate 2, Figure B). These composite bands are entirely devoid of any inclusions. The brecciation and bending of the composite bands is probably due to later structural deformation.

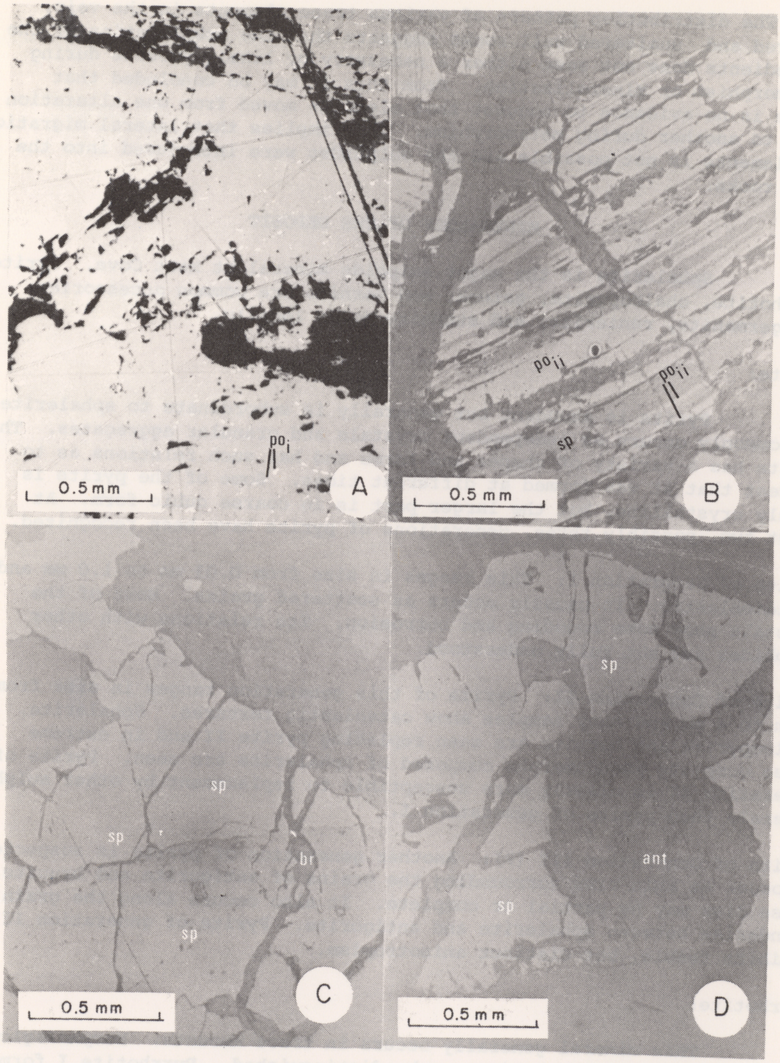


Plate 2. Figure A, photomicrograph showing minute grains of pyrrhotite (I) as an exsolution product in sphalerite. The inclusions show definite crystallographic orientation. Figure B, alternating bands of pyrrhotite (II) and sphalerite. The sphalerite is devoid of any inclusions. Figures C and D, photomicrographs showing partial to complete replacement of brucite and antigorite by sphalerite. ant, antigorite; br, brucite, po_i, pyrrhotite (I); sp, sphalerite; po_{ii}, pyrrhotite (II).

Vokes (1969) classified this kind of banding as "metamorphic banding"; however, in the present situation it appears that the banding is due to the contemporaneous deposition of pyrrhotite and sphalerite.

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% 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 these gangue minerals is retained (Plate 2, Figures 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, as streaks or as irregular thin stringers.

None of the chalcopyrite examined contained cubanite or other exsolution minerals. Whether chalcopyrite was exsolved from any of the sphalerite at Meat Cove has not been satisfactorily determined, although it is suggested by chalcopyrite occurring as blebs within sphalerite and by small irregular veinlets that follow sphalerite grain boundaries. Formation temperatures for much of the sphalerite were high enough for chalcopyrite to be exsolved as 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 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 is a rather difficult mineral to identify under the microscope. The stannite forms somewhat elongated grains, but shapes are irregular because of uneven penetration by younger minerals. Its properties were correlated with those listed in Short (1964), Uytenboogardt (1951), Schouten (1963), Springer (1968), and Kissin and Owens (1979). Its position in the paragenetic sequence is highly speculative.

Galena:

Galena is somewhat less abundant than pyrrhotite, but it is, nevertheless, an important sulphide mineral. In some places, it has been deposited around, and as fillings 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. The bornite appears to be younger than chalcopyrite, but no clear-cut evidence was seen.

Germanite and Renierite (?):

The presence 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 3, Figure A). Rarely it also occurs as perfect euhedral cubic crystals with euhedral pyrite crystals (Plate 3, Figure B). In places, veinlets of the sphalerite cut across and replace the germanite ovoids (Plate 3, Figure 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 3, Figure D) that is distinctly harder than germanite. Essentially all the inclusions are less then 10μ long and 5μ wide. The rod-shaped inclusions and the anhedral disoriented inclusions are considered to be of replacement origin. The unidentified mineral is very similar in appearance to sphalerite. It is difficult to distinguish from sphalerite unless both minerals are present in the same field. Here 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 3, Figures 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 forming a regular intergrowth with that mineral;

5. irregular grains disseminated through the host rock;

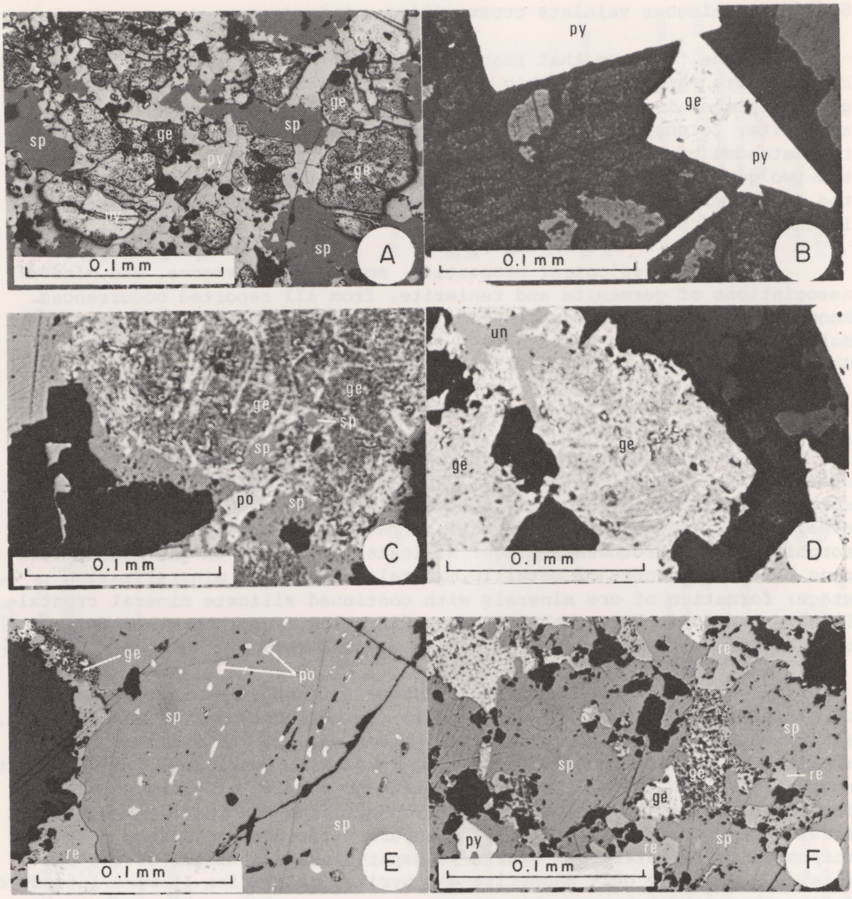


Plate 3. Photomicrographs showing the textural relationships of germanite and renierite. A, Ovoid islands of germanite disseminated through aggregates of coarse grained sphalerite and pyrite. B, Euhedral cubic crystal of germanite with euhedral pyrite. C, Sphalerite crosscutting and replacing germanite. 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.

6. discontinuous veinlets crosscutting sphalerite.

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. Regarding the paragenesis of the two germanium sulphides, it is noteworthy that germanite is one of the oldest minerals and that renierite is one of the youngest minerals in the sequence.

The mineralogical properties, modes of occurrence, and mineral associations of germanite and renierite, from all reported occurrences known to the author, are summarized in Table 3. Detailed mineralographic data on germanite are available in standard works by Harcourt (1942), Short (1948), Uytenboogardt (1951) and Murdock (1953).

PARAGENETIC SEQUENCE

A generalized paragenetic diagram for the observed mineral assemblages is given in Table 4. Mineral associations have been divided somewhat arbitrarily into four stages: (1) metamorphic stage: an outer zone, chiefly representing minerals formed during contact thermal metamorphism, (2) hydrothermal stage: silicates developed in the mineralized zone before the onset of metallic mineralization, (3) mineralization stage: formation of ore minerals with continued silicate mineral crystallization, and (4) late gangue stage: final low temperature mineralization and weathering products. Some details follow:

In siliceous dolomitic limestone (magnesian skarn), remnants of periclase, monticellite, chondrodite, spinel, forsterite, and diopside, as well as the shapes of antigorite aggregates, and the evidence of brucite, antigorite and talc replacing forsterite, periclase, and tremolite, suggest that the first mineral assemblage to develop after syenite intrusion was calcite-dolomite-spinel-chondrodite-monticellite-periclase-forsterite-diopside-tremolite. The impure siliceous rocks were metamorphosed to garnetiferous quartz-feldspar-biotite schist. Of the ore minerals, probably only magnetite and pyrite (generation I) were introduced during the contact metamorphic stage.

The hydrothermal stage probably followed contact metamorphism without a perceptible break and many of the processes carried over from one to the other. The hydrothermal or retrograde alteration converted the earlier-formed assemblages to brucite, antigorite, talc, chlorite and sericite. The first three minerals formed in the siliceous dolomitic limestone and the latter two, in quartz-feldspar-biotite schist. This alteration was probably the beginning of the process of sulphide mineralization.

The main sulphide mineralization consists of pyrite, germanite, pyrrhotite, chalcopyrite, sphalerite, galena, bornite, and renierite, in this sequence, and probably was separated from the hydrothermal stage by no significant time interval.

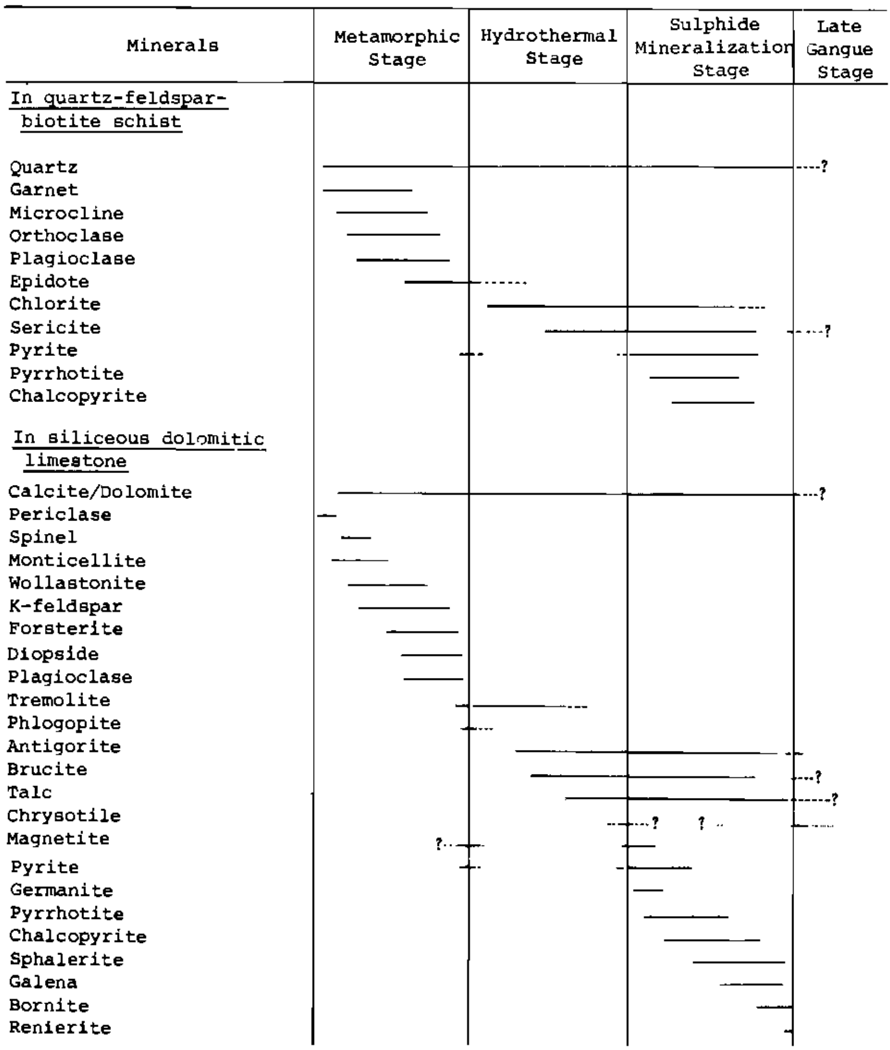
TABLE 3

Mineralographic data, mode of occurrence, and mineral associations of germanite and 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 grey
Quality of polish	Very good	Very good	Very good	Very good
Hardness	>galena, bornite; slightly <tennantite; >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	Nonmagnetic	Nonmagnetic	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 minerals 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. 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.

TABLE 4

Paragenetic sequence of minerals
Meat Cove zinc prospect



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

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.

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