COPPER MINERALIZATION IN ANIMIKIE SEDIMENTS OF THE MARQUETTE RANGE MARQUETTE COUNTY, MICHIGAN

Thesis for the Degree of M. S.

MICHIGAN STATE UNIVERSITY

Robert C. Reed

1965

ABSTRACT

COPPER MINERALIZATION IN ANIMIKIE SEDIMENTS OF THE MARQUETTE RANGE MARQUETTE COUNTY, MICHIGAN

by Robert C. Reed

Copper mineralization in four areas within Animikie sediments of the eastern Marquette syncline has been studied and described in detail. The copper mineralization consists of chalcocite, chalcopyrite, bornite, covellite, and native copper. Specular hematite, red hematite, pyrite, and limonite are abundant. Associated silicification is widespread in the Kona dolomite. Other minerals include sericite and chlorite.

The mineralized areas are practically "clean" of most important trace elements. Only copper, titanium, and manganese were found. Trace copper is widespread throughout the Kona dolomite.

The metallic and gangue minerals present in the eastern Marquette syncline are very simular to those within and surrounding Mount Bohemia, a syenodiorite intrusive in the Keweenaw Peninsula of Michigan, and of Keweenawan age.

COPPER MINERALIZATION IN ANIMIKIE SEDIMENTS OF THE MARQUETTE RANGE MARQUETTE COUNTY, MICHIGAN

By

Robert C. Reed

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Geology

1965

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to the many persons who aided and supported the present study:

Dr. Harold Stonehouse for assistance and guidance in the use of the spectrograph and interpretation of spectrographic data.

Dr. Justin Zinn and Dr. James Trow for helpful guidance.

The North Range Mining Company for use of drilling data and drill core.

Mr. David Bennett for assisting in the sampling of test pits and drill core.

Mr. James Tusa for assisting in taking photomicrographs and use of equipment.

Mr. John Byerlay for photographing polished specimens.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

Figure		Page

CHAPTER I

INTRODUCTION

The understanding of the environment and habit of ore deposition depends largely on the accumulation of field and labratory data from known ore. Such descriptive characteristics as ore and gangue mineralogy, types of host and source rock, metamorphic grade, and wall rock alteration serve as aids in the exploration for new deposits.

Copper mineralization in Animikie sediments in Michigan has received little attention and has never been described in detail. It is the purpose of this investigation to add to the knowledge of copper mineralization, its environment, and hopefully, information which may lead to successful exploration.

Location

The four areas described are illustrated on Figure 1. Area A is in the NE¼NW¼ section 1, T.47 N., R.25 W. Area B is in the NW¼SE¼ section 2, T.47 N., R.25 W. Area C is located in the SW¼NE¼, section 32, T. 48 N., R.25 W. Area D is in section 10, T.47 N., R.27 W. at the 10th. level of the Cliffs Shaft iron mine. Areas A, B, and C are within the Kona dolomite series of rocks and Area D mineralization cuts the Negaunee iron formation.

Field and Laboratory Procedures

Field procedure consisted of collecting specimens from test pits and mine, and from drill core in Area A. Specimens were polished and thin sections were made for metallographic and petrographic description of minerals. Samples from test pits and drill core were analyzed spectrographically to determine trace elements, and copper content.

History

The general geology of the area was described by Van Hise and Bayley (1895, 1897) and Van Hise and Leith (1911), but copper mineralization was not indicated. The area has recently been mapped in detail by Gair et al. (1963).

The location of exploration shafts of Areas A and B are illustrated in the Michigan Geological Survey field notebook 78, in 1888, by A. E. Seaman. He noted that a shaft in Area B was being sunk at that time. In old rock descriptions of the Michigan Geological Survey, M. E. Wadsworth described "slate impregnated with chalcocite" in Area A, and "dolomite schist impregnated with sulphurete of copper" in Area B. The date of these descriptions was sometime between 1888 and 1892, when Wadsworth was State Geologist.

The history of copper exploration was compiled by Mr. Kenneth Boyer of the Marquette County Historical Society (Boyer 1961). Mr. Boyer reviewed back issues of the Marquette Mining Journal which described the "big copper excitement of 1896 to 1898":

> The lode has varying widths in this locality of from two to 65 feet and in some cases seems to have been split by volcanic action. According to Mr. Pings, assays on the Case rock have shown a run of copper as high as 7½ per cent, while the mill test, which can be depended upon absolutely, shows 3½ per cent. The rock is also both gold and silver bearing. The former has shown as high as $16 to the ton and an expert says when the shaft gets down to 200 feet, the ore will run steadily from $8 to $12 a ton. It is gray ore, the best in the world, with no sulphur content and smelting to separate the copper, gold and silver will be much easier. Twenty tons of this ore from the Case property will be loaded on cars and sent to the furnaces of the Aurora and Chicago Smelting Company. The shaft there is now sunk to a depth of 40 feet on a vein 10 feet wide and though work is now temporarily suspended, it will be resumed in the spring when the shaft will be sunk to at least 100 feet. It is mineralized from the hanging wall to the foot wall. The tests so far made shown it to be considerably richer than the famous Calumet & Hecla. In sinking the shaft about 400 tons of rock have been taken out, none of it waste and all of it fit to go to the smelter without the intermediate service of the stamp mill. About a half mile west where the Wilkinson mine is located, two shafts are being sunk, one on the Harlow estate property and the other on lands of the Iron Cliffs Company. The first has reached about 40 feet and the latter about 25, all of the ore being of the same quality as in the Case and at a suitable depth should give the same generous return. This was much better than the prospectors had hoped for. George Spencer had taken over supervision of the work for John W. Ludwig and associates, of Chicago and 8 to 10 men have been employed at these two pits. A close study of the mountain ranges south of Marquette reveals a number of veins of copper-bearing rock, but these just mentioned are the only ones to receive any

> special attention. However, Mr. Pings says he knows of other places in areas where indications are just as good.

The Case property mentioned above is that of Area A and the Wilkinson, Area B. Evidently there was no further work on these properties until 1961, when the North Range Mining Company drilled 5 holes, from late 1961 to early 1963, in Area A.

The history of Area C is obscure. It was located by J. E. Gair while mapping the bedrock geology of the Marquette quadrangle. The exploration consist of one large test pit which possibly was excavated at the same time that copper was being explored to the southeast. No written record of this exploration has been found.

Normal development of the Cliffs Shaft iron mine in the city of Ishpeming exposed iron and copper sulphides of Area D. The brilliant peacock color of the dominant mineral, bornite, attracted the miners who have been removing samples for a number of years.

General Geology

As cited above, the general geology has been described by Van Hise and Bayley (1895, 1897), and Van Hise, and Leith (1911). Currently the area has been mapped in detail by Gair et al. (1963). The geologic mapping of the area is not part of this investigation but the geology is generally described.

The Marquette range is a tightly folded synclinal belt of middle Precambrian sediments and basic intrusives enclosed in a complex of lower Precambrian rocks. The belt trends approximately east-west for about 40 miles. It plunges gently to the west so that the lower formations are exposed at the east end.

The surface geology and geologic column of the eastern part of the Marquette range are illustrated in figures 1 and 2. The copper mineralization of Areas A, B, and C are found in the Kona dolomite, the second lowest stratigraphic unit of middle Precambrian rocks. The Kona is exposed at the eastern nose of the syncline south of the city of Marquette, and trends westward on the north and south limbs. The north limb is exposed as far as the city of Negaunee and the south limb to Goose Lake. (Figure 1.) The lithology of the Kona is described by Gair et al. (1963) as:

> Mainly tan, salmon, pinkish--or pale--gray fine and medium grained massive dolomite or thinly laminated chert and dolomite. Dolomite layers commonly contain scattered detrital quartz. Lower part of formation contains much maroon, gray, and greenish sericitic slate. Thin layers and minor members consist of reddish quartzite and an orange and brown laminated siltite. Locally dolomite and slate are silicified.

The Kona has a maximum thickness of 1000 to 1200 feet.

The eastern limit of the Negaunee iron formation is in the city of Negaunee. Copper mineralization of Area D, in the Cliffs Shaft iron mine, cuts the hard ore horizon

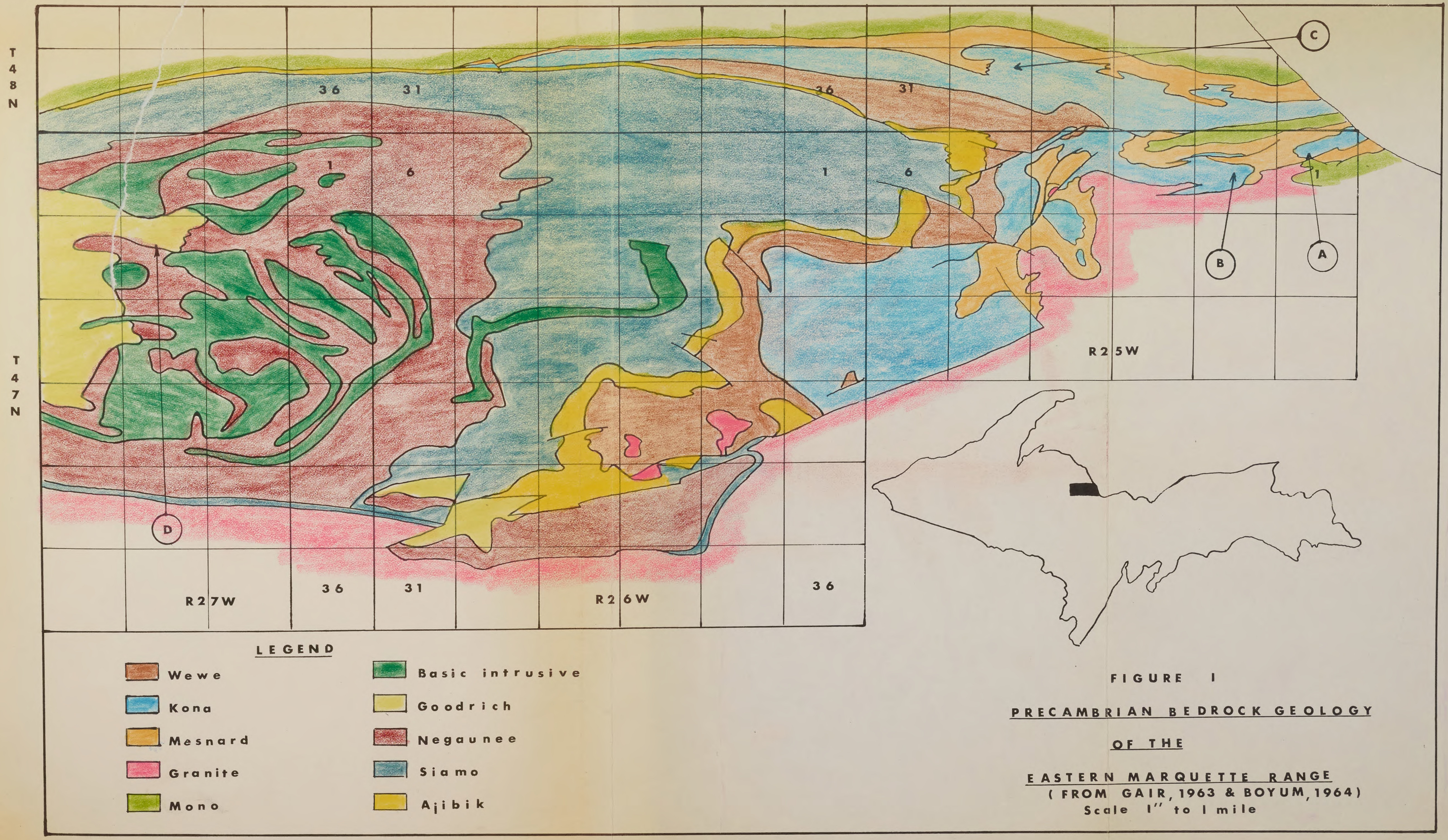


FIGURE I

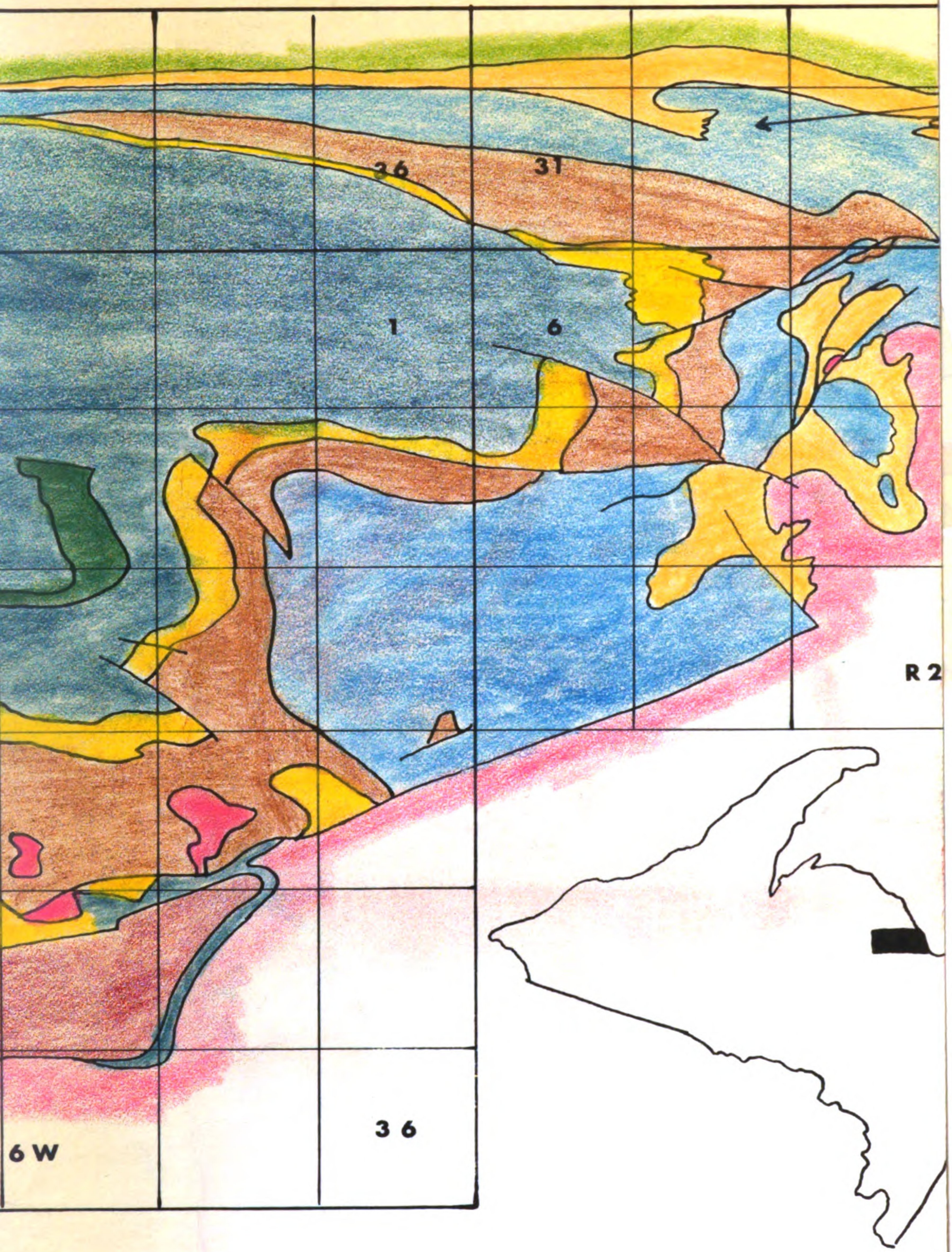
PRECAMBRIAN BEDROCK GEOLOGY

OF THE

EASTERN MARQUETTE RANGE

(FROM GAIR, 1963 & BOYUM, 1964)

Scale 1" to 1 mile



PRECAMB

EASTER
(FROM
Sc

at the top of the Negaunee iron formation, immediately below the Goodrich quartzite. Area D is approximately 13 miles west of area B.

Upper	
Precambrian	Keweenawan diabase
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx	
	Serpentinized peridotite
	Syenite
	Hornblende lamprophyre
	Felsic porphyry
	Metapyroxenite
	Metadiabase and metagabbro
	xxxxxxxxxxxxxxxxxxxxxx
Middle	Goodrich quartzite
Precambrian	Negaunee iron formation
	Siamo slate
	Ajibik quartzite
	Wewe slate
	Kona dolomite
	Mesnard quartzite
	xxxxxxxxxxxxxxxxxxxxxx
	Enchantment Lake
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx	
Lower	Granite gneiss
Precambrian	Mono schist

Figure 2.--Geologic column of the eastern Marquette range, Marquette County, Michigan. Modified from Gair *et al.* (1963).

Chapter II

MINERALOGICAL AND ROCK DESCRIPTIONS

Description of Area A

Copper mineralization in Area A is found at the west end of a small enclosed syncline of Kona dolomite. (Figure 1.) The relief is great, almost 300 feet above Lake Superior, 3500 feet to the east. Several shallow shafts and test pits attest the exploratory work done more than 65 years ago. The most successful shaft was sunk to a depth of 40 feet in a highly sheared slate overlain by red quartzite. At the surface the base of the quartzite, which is exposed, strikes N. 70 degrees W. and dips 55 degree N.E. The shaft is in an area in which malachite, the green carbonate of copper, is clearly visible and probably guided the exploration. Other shafts and pits probed the slate horizon below the quartzite, but apparently with negligible results.

The rock on the dumps of the main exploration shaft consists of a tan to reddish-tan, highly sheared and folliated siliceous slate. Despite the fact the rock is sheared, most of it is hard, dense, and compact, difficult to break with the hammer, and cut with the diamond saw. Mineralization is abundant, chalcocite and pyrite are clearly visible, chalcocite being much more prevalent than pyrite. The green coating of malachite, from alteration of chalcocite, is noticeable on massive rock and abundant on the more highly sheared friable slate.

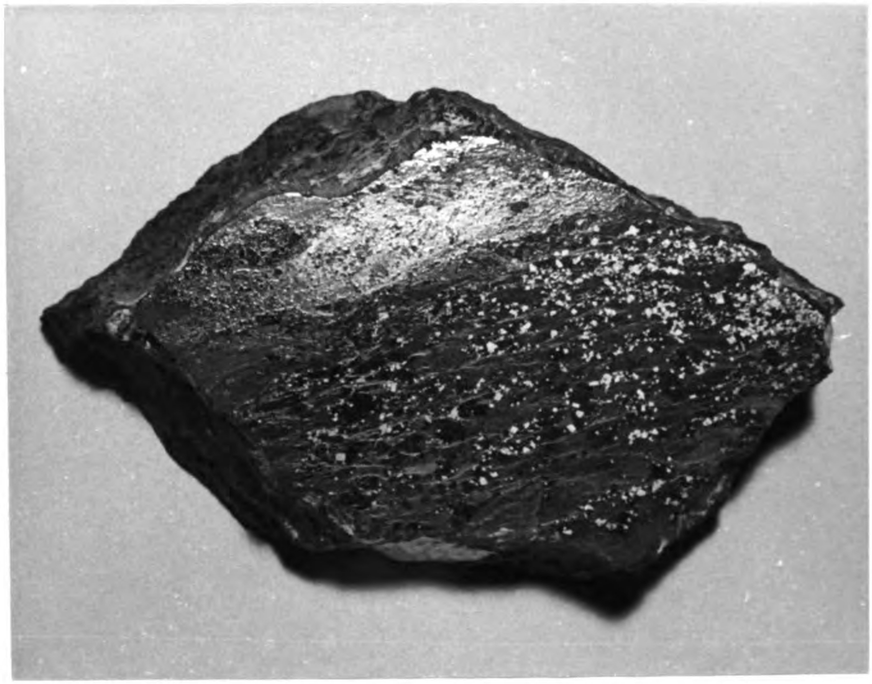
Under the binocular microscope, the rock appears highly siliceous. It is mostly very fine grained but a few bands and pods of clastics are observed. Mineralization occurs in veins, fractures, irregular masses and along foliation planes. It consists of chalcocite, pyrite and quartz with chalcocite replacing pyrite. Pyrite, scattered throughout the rock, where unreplaced, is euhedral to subhedral in crystal habit. Some specimens are highly fractured and show both granular vein and colloform chalcocite. Colloform chalcocite appears to occur at the intersection of two or more fractures.

In polished section, the mineralization is observed to occur in crosscutting veins (Figures 3 and 4) and in irregular layers parallel to bedding and foliation (Figure 5.) It is also scattered throughout the rock but to a lesser degree. Many specimens exhibit a colloform texture. (Figures 6 and 7.) The chalcocite reacts normally to the chemical etch determination described by Short (1940), and conforms to his description of hypogene origin:

> HNO effervesces vigorously; mineral stains blue; with most varieties brings out parallel etch structure; with very fine grained supergene chalcocite, however, will not show etch cleavage; with the fine-grained sooty chalcocite brings out grain boundaries only.

Figure 3.--Photograph of polished specimen cut by quartz chalcocite vein with scattered pyrite and chalcocite in host rock.

Figure 4.--Photomicrograph of quartz chalcocite vein of Figure 3. Chalcocite is white and quartz dark gray. Reflected light, 57 X, 11 micron grid.



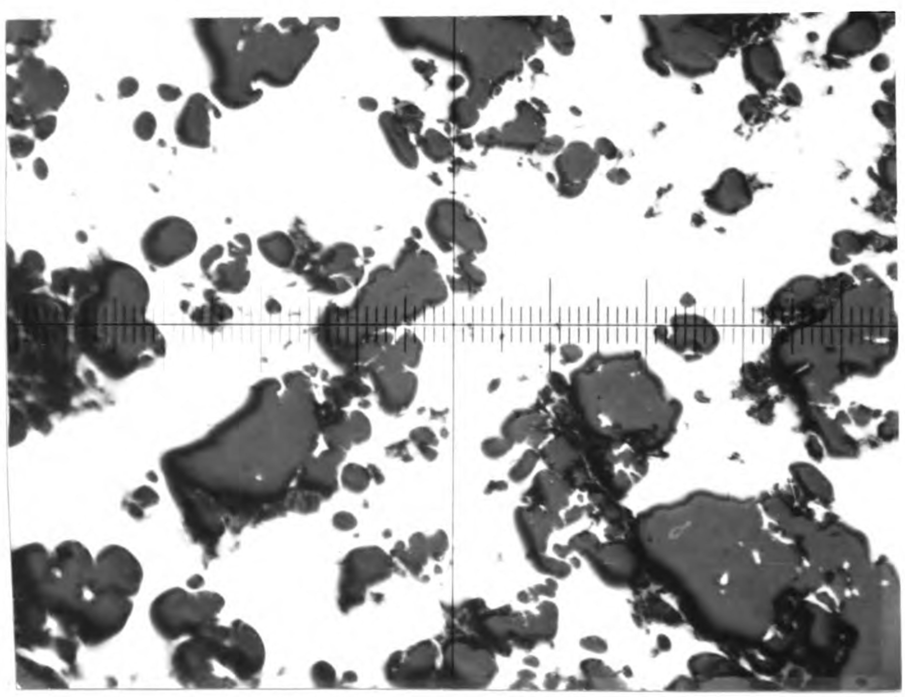
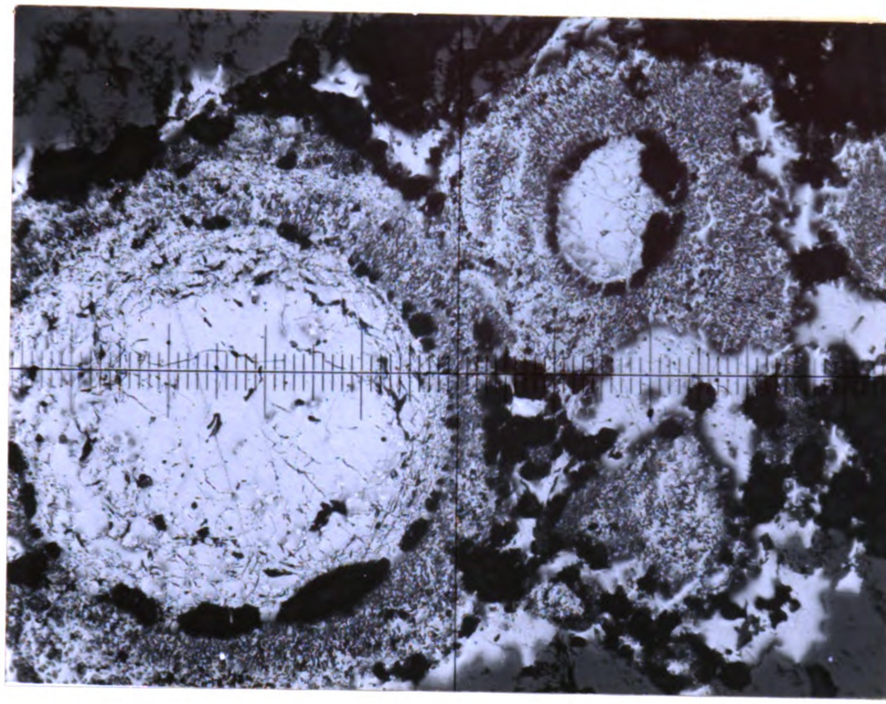
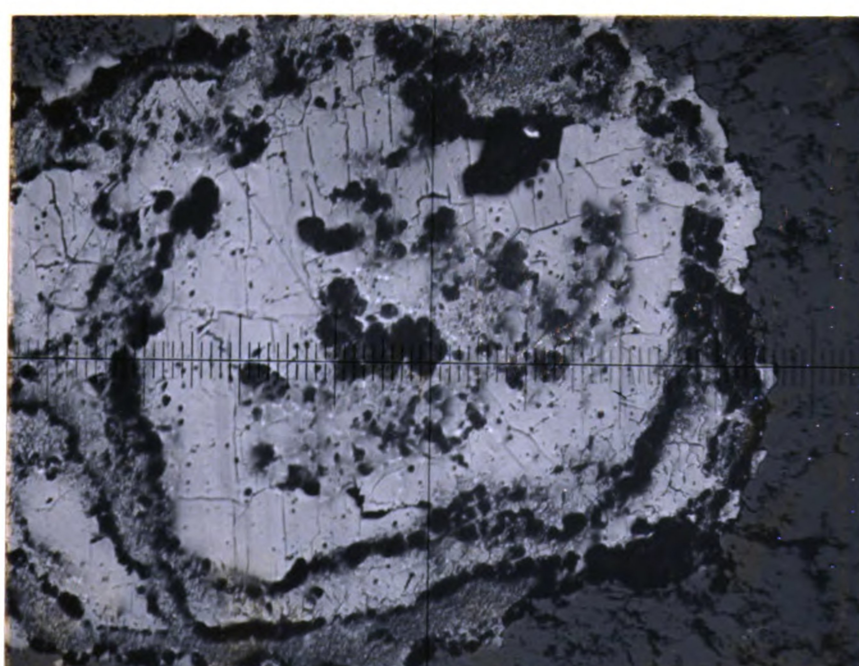


Figure 5.--Photograph of polished specimen exhibiting mineralization along foliation planes.

Figure 6.--Photomicrograph of colloform texture of chalcocite. Reflected light. 57 X, 11 micron grid.

Figure 7.--Photomicrograph of colloform texture of chalcocite. Reflected light, 57 X, 11 micron grid.





Colloform textured chalcocite etched with HNO_3 is illustrated in Figure 8. This reaction occurred with every mineral texture. It is similar to that shown by Butler and Burbank (1929, plate 68, Figure F).

Chalcocite replaces pyrite in all stages from initial replacement (Figure 9) to advanced (Figure 10), although most chalcocite does not show replacement of pyrite. Chlorite, recognized in thin section, may occassionly be observed in reflected light. (Figure 11.)

In thin section, the surface rocks of Area A consist of quartz sericite slate, foliated quartz sericite slate, quartz carbonate sericite slate and sericitic quartzite. It should be noted that though this unit of rock is part of the Kona dolomite, carbonate is rare. The optical properties of the carbonates are difficult to differentiate through the petrographic microscope (Rogers and Kerr, 1942). Specimens of carbonate from the Kona of the Marquette and Sands quadrangles, submitted for X-ray examination, show it to be dolomite (Gair, J. E., personal communication). Therefore, future references to carbonate minerals in this paper will be called dolomite.

The sericitic quartzite consist of alternating layers of medium and fine grained quartz, with layers of fine grained chlorite as foliated sheaves parallel to the banding. Fine grained sericite occurs in quartz interstices and penetrates grain boundaries. Two patches of chlorite

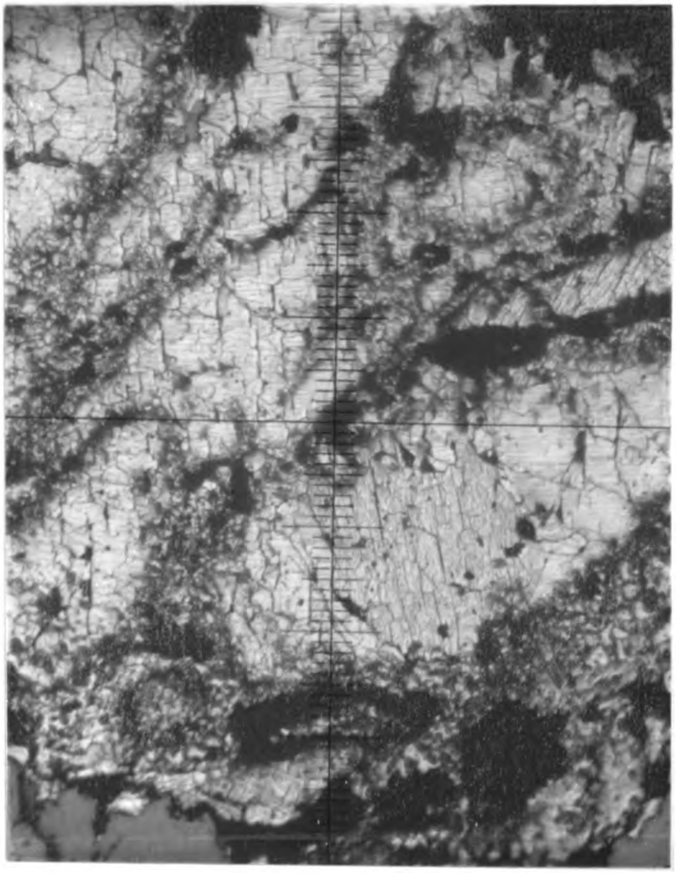
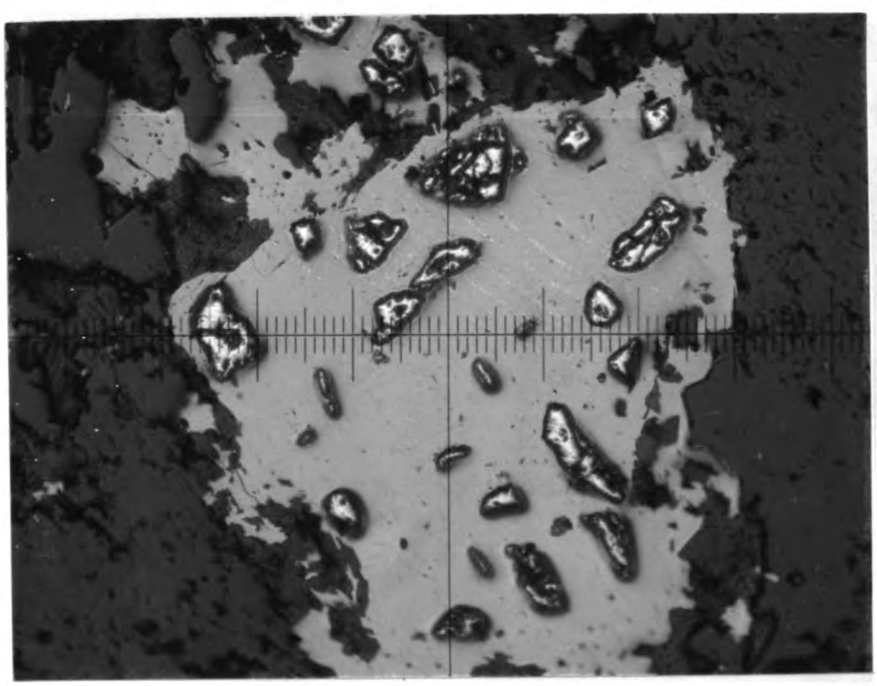


Figure 8.--Photomicrograph of colloform textured chalcocite, etched with HNO_3, showing parallel etch structure.
Reflected light, 107 X, 11.5 micron grid.

Figure 9.--Photomicrograph showing initial replacement of pyrite by chalcocite. Reflected light, 57 X, 11 micron grid.

Figure 10.--Photomicrograph showing advanced replacement of pyrite by chalcocite. Reflected light, 82 X, 11 micron grid.



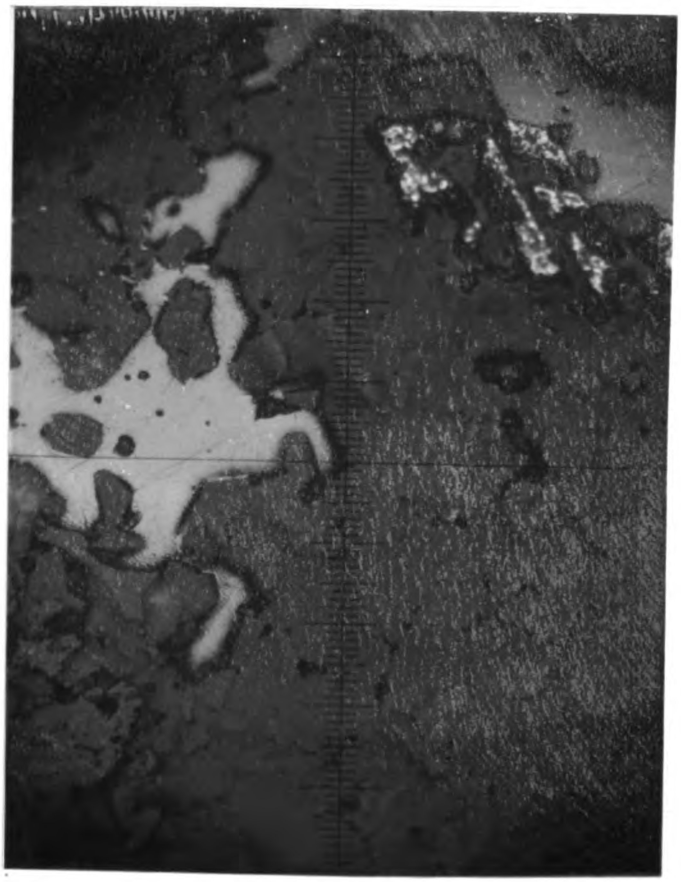


Figure 11.--Photomicrograph showing chalcocite and pyrite enclosed in lathlike chlorite and quartz. Reflected light, 153 X, 9 micron grid.

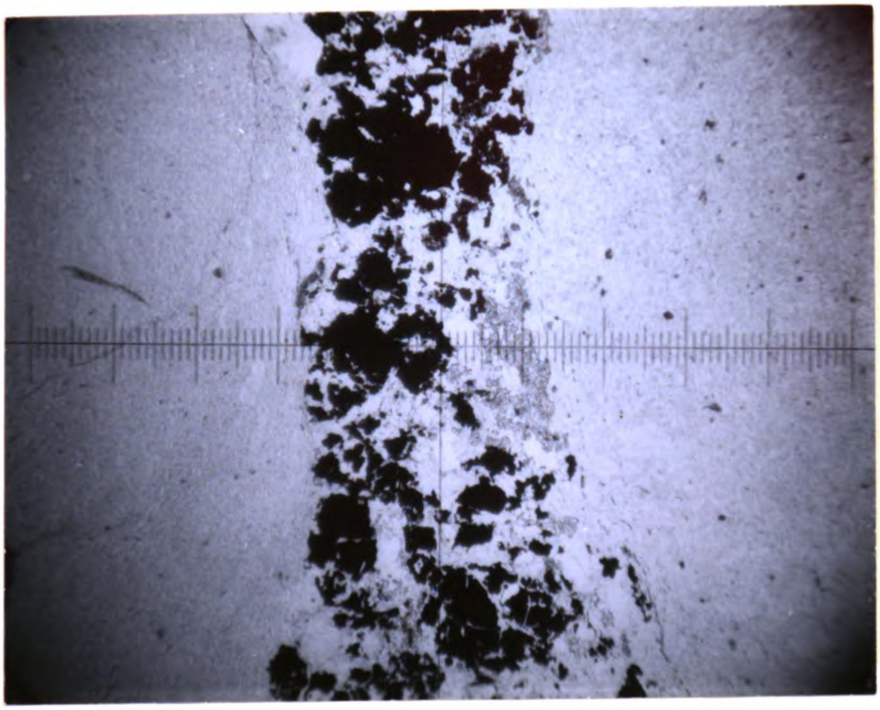
were observed, much larger than any other individual grains, which form an almost rhombic pattern. Sulphide mineralization is found primarily in irregular veins and masses. It consists of chalcocite and pyrite, with mosaic quartz, chlorite, sericite, and lesser dolomite. (Figures 12 and 13.) The chlorite is absolutely colorless. The index of refraction is greater than Canada Baslam, quartz and sericite. The birefringence is about .003. It may be delessite, as this mineral is reported to be sometimes colorless (Milner 1962) with a refractive index from 1.605 to 1.609 compared to muscovite (sericite) with 1.556 to 1.611. Delessite is the chlorite identified in the upper Precambrian of the Keweenaw Peninsula (Butler and Burbank, 1929).

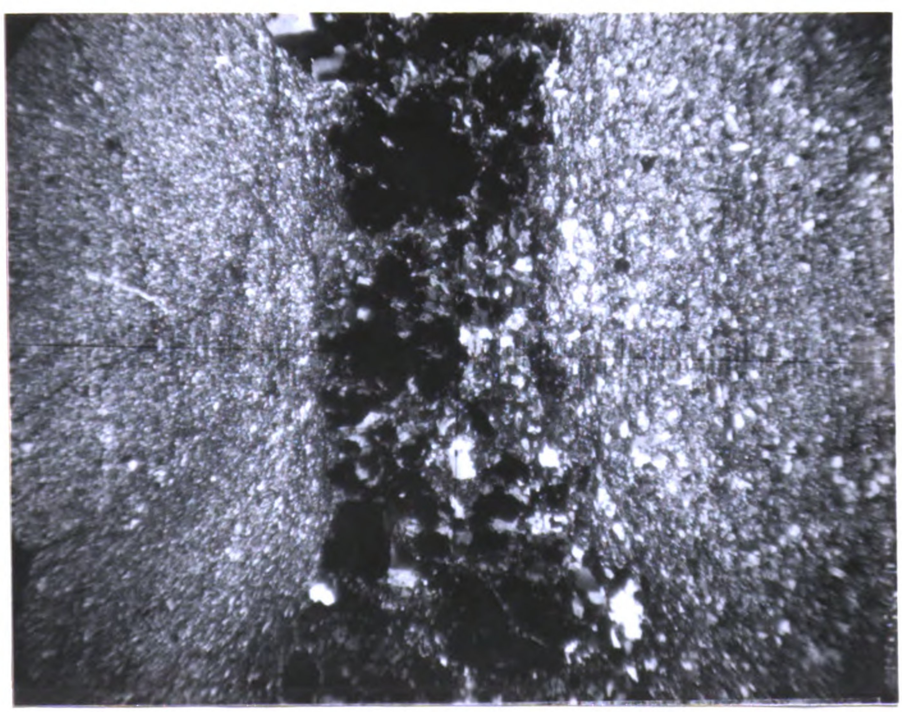
Bands of limonite transect the bedding and are found as clusters and isolated grains within the rock mass. It is also associated with the mineralization and with chlorite layers. It is normally opaque but distinctly yellow to yellowish brown in oblique reflected and convergent light. Hematite is also present, and both hematite and limonite are later minerals. Some dolomite is found in mineralized veins. It contains dusty hematite, is gray in polorized light, and anhedral in crystal outline. (Figures 12 and 13.)

The quartz sericite slate consists of large detrital quartz grains in a matrix of fine grained quartz and

Figure 12.--Photomicrograph of chalcocite, chlorite, quartz, and dolomite vein cutting quartz sericitic slate. Ordinary light, 25 X, 11.5 micron grid.

Figure 13.--Same as above, but with crossed nicols.





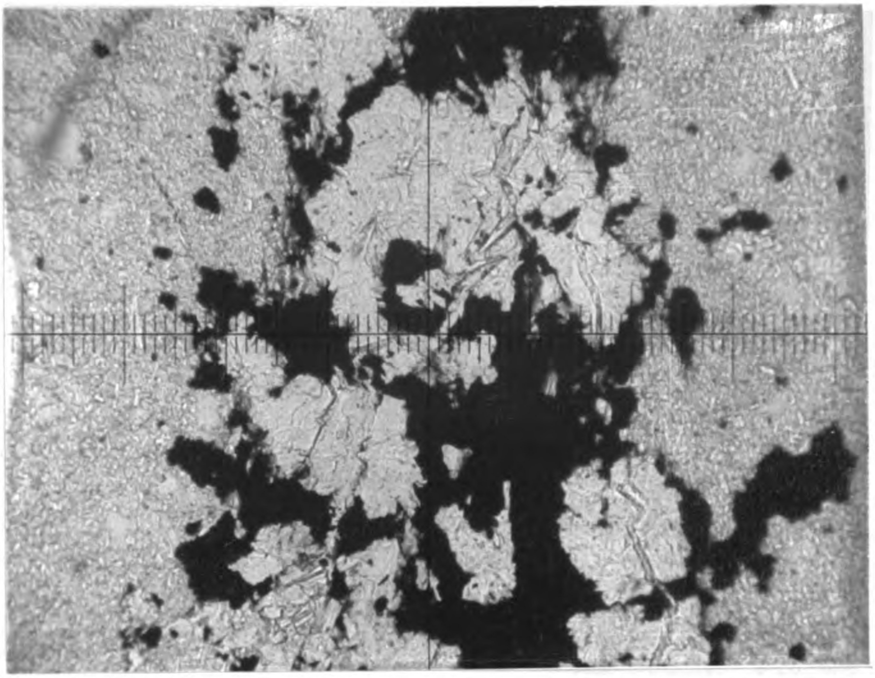
sericite. Sericite is found in interstices, penetrating quartz boundaries, and as inclusions within quartz grains. Chalcocite occurs in irregular veins (Figures 14 and 15) and as colloform textures (Figures 16 and 17). Chalcocite in veins show textures approaching skeleton crystals, surrounded by spherulitic chlorite. The ore normally occurs with chlorite, large mosiac quartz, and colorful sericite approaching muscovite in grain size. The sericite is later than quartz, chlorite, and is found within the chalcocite.

Foliated quartz sericite slate is illustrated in Figures 5 and 18. The ground mass is a well layered foliated rock consisting of fine grained quartz and sericite with subordinate coarse detrital quartz. Sericite is equally as abundant as quartz. Some carbonate occurs with inclusions of dusty hematite. Sulphide mineralization is parallel to the banding but also cuts across it. Chalcocite with coarse mosaic quartz and chlorite appear to follow bedding and foliation planes. In one vein, quartz is elongate perpendicular to the walls of the vein illustrating comb texture. Limonite is intimately associated with the ore and is a later mineral.

Specimens of drill core from 5 holes drilled by the North Range Mining Company were taken every 5 feet and all were examined under the binocular microscope. Copper mineralization occurs in buff colored siliceous slate and

Figure 14.--Photomicrograph of irregular vein of chalcocite, chlorite, and sericite in quartz sericite slate. Ordinary light, 107 X, 9 micron grid.

Figure 15.--Same as above, but with crossed nicols. Note spherulitic character of chlorite.



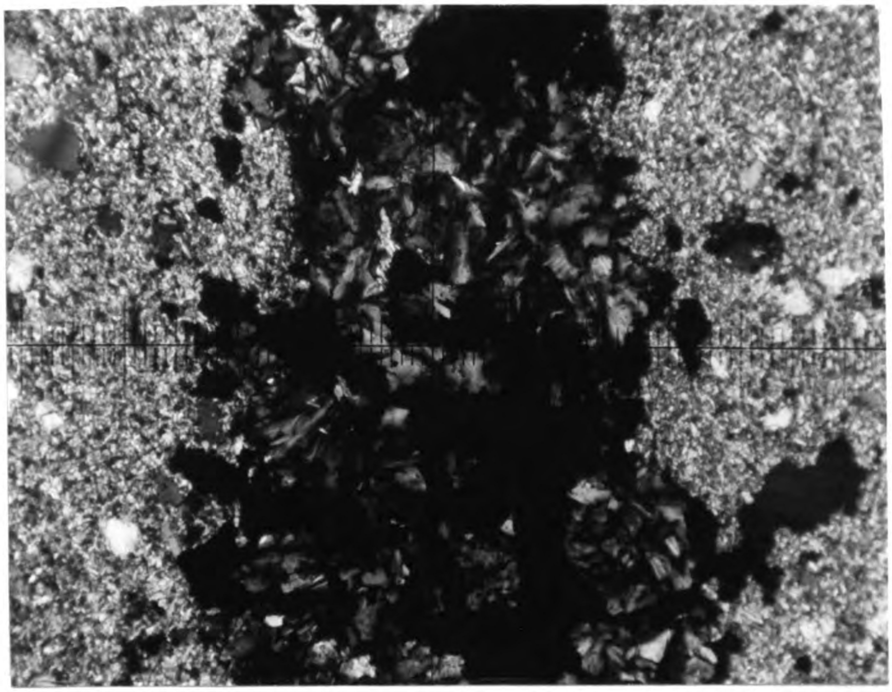
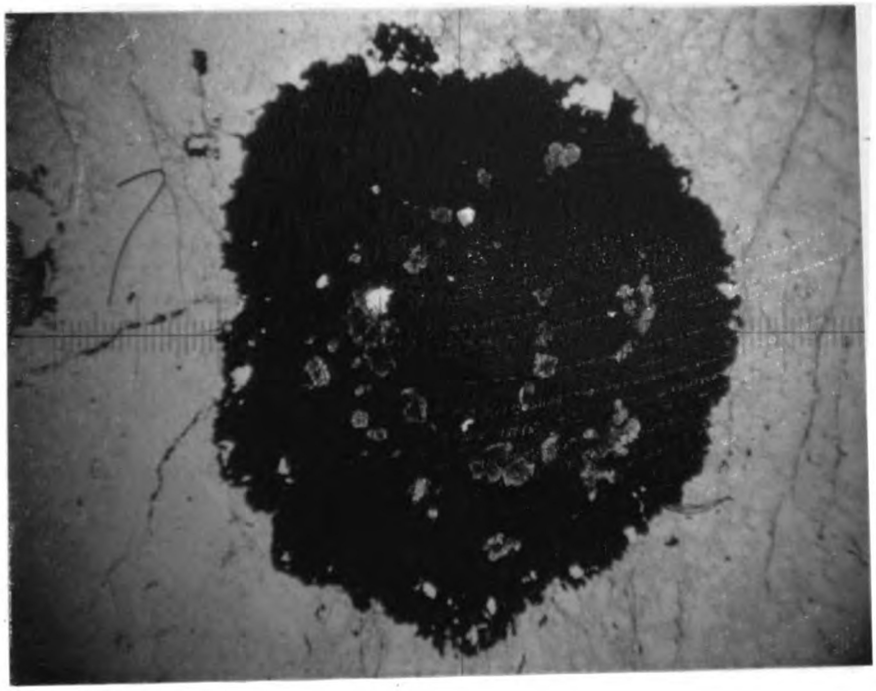
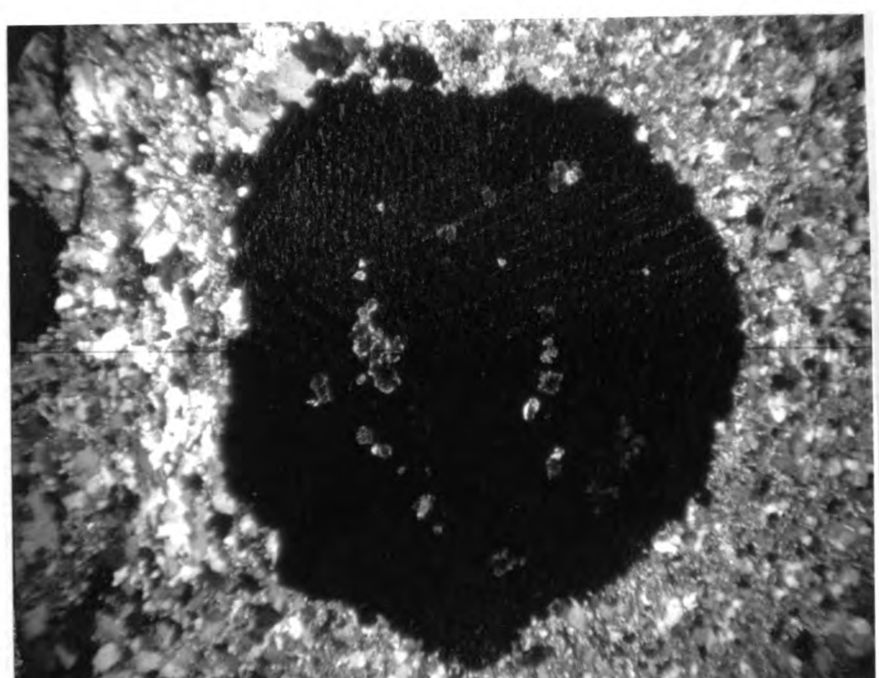


Figure 16.--Photomicrograph of colloform chalcocite in quartz sericite slate. Voids within the chalcocite contain dusty hematite and quartz and canada balsam. Ordinary light, 25 X, 11.5 micron grid.

Figure 17.--Same as above, but with crossed nicols.





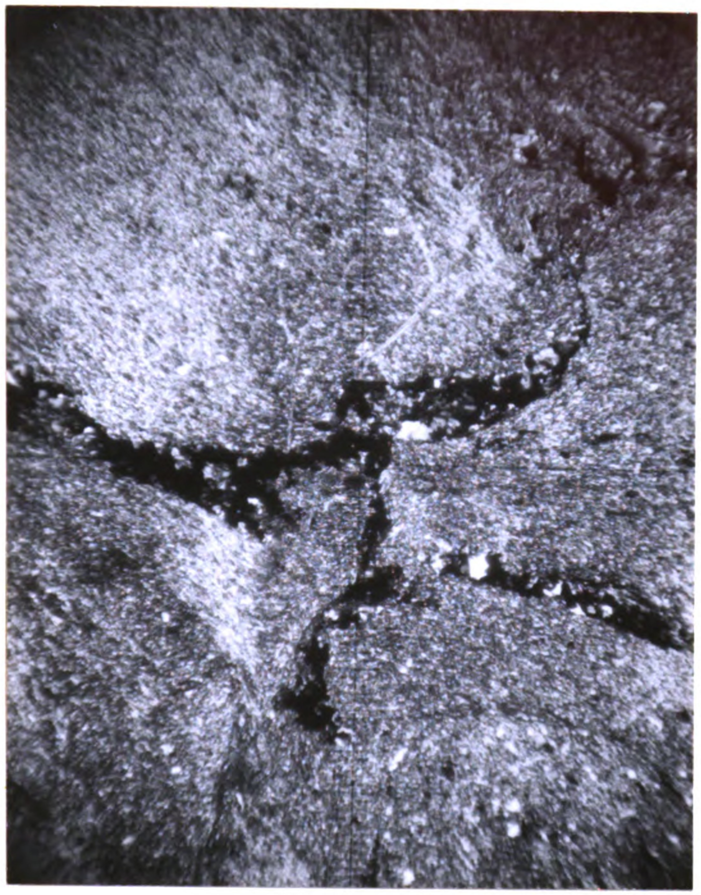


Figure 18.--Photomicrograph of chalcocite, quartz and chlorite vein in foliated quartz sericite slate. Crossed nicols, 25 X, 11.5 micron grid.

quartzite. The slate is generally fine grained but contains layers and pods of coarse grained clastics. The quartzite is fine to coarse grained and colored from almost white to deep red.

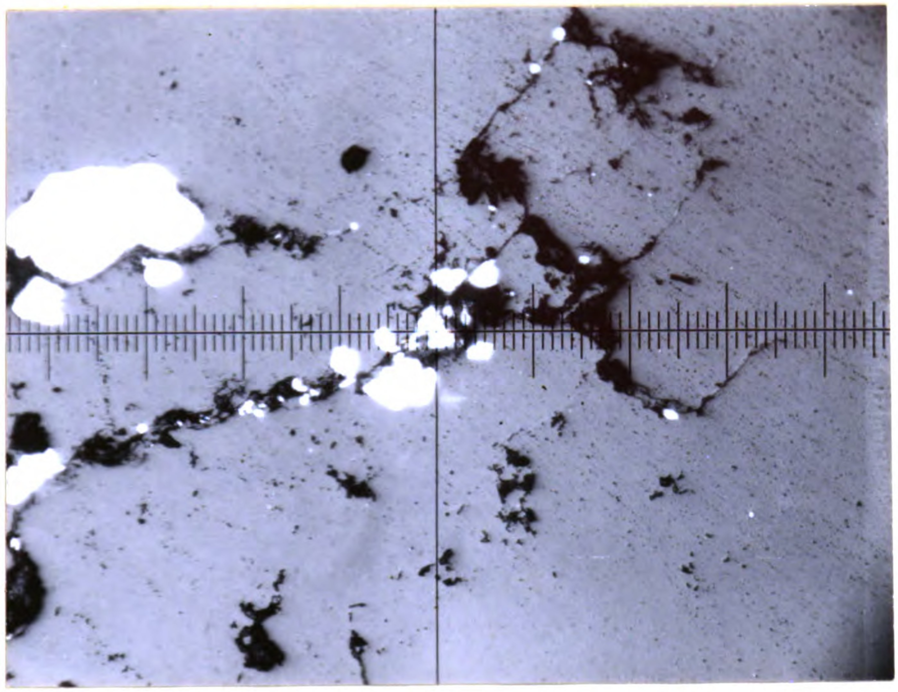
The slate is highly sheared. Chalcocite occurs in the coarse clastic layers and in shears and fractures in the fine grained portion. A small amount is scattered throughout the fine grained slate. No pyrite was observed in the mineralized intersections of drill core, but hematite is common.

Both chalcocite and native copper occur in quartzite. Primarily they occupy the interstices between the quartz often penetrating into the grains. (Figures 19 to 22.) Native copper and hematite are also found cutting the quartzite in elongated fractures. Sericite also occupies the interstices between and penetrates their boundaries and is found as inclusions in quartz grains and chalcocite. There appears to be no mineral zoning. For example, in drill hole No. 2, chalcocite occurs in quartz slate at 40 feet, and in red quartzite at 73 and 75 feet. At 80 feet, native copper is found in red quartzite with limonite in fractures. Again at 100 feet, chalcocite is in red quartzite with some limonite. Native copper is again found in red quartzite at 105, 110, and 120 feet.

Specular hematite was not found associated with the mineralization of Area A. But it was found in drill core

Figure 19.--Photomicrograph of native copper (white) in red quartzite. Reflected light, 82 X, 11 micron grid.

Figure 20.--Photomicrograph of native copper (white) in red quartzite. Reflected light, 82 X, 11 micron grid.



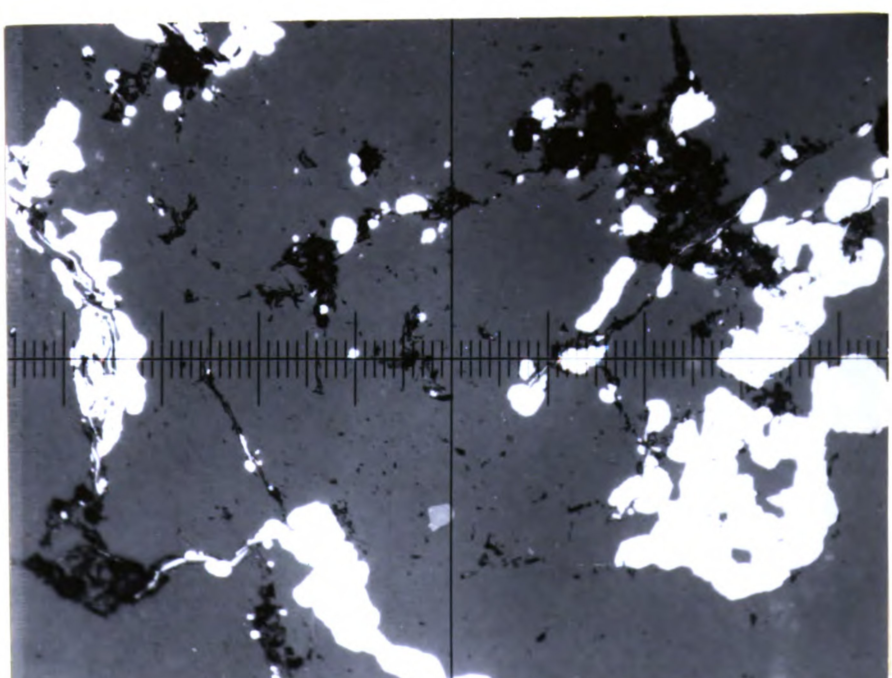
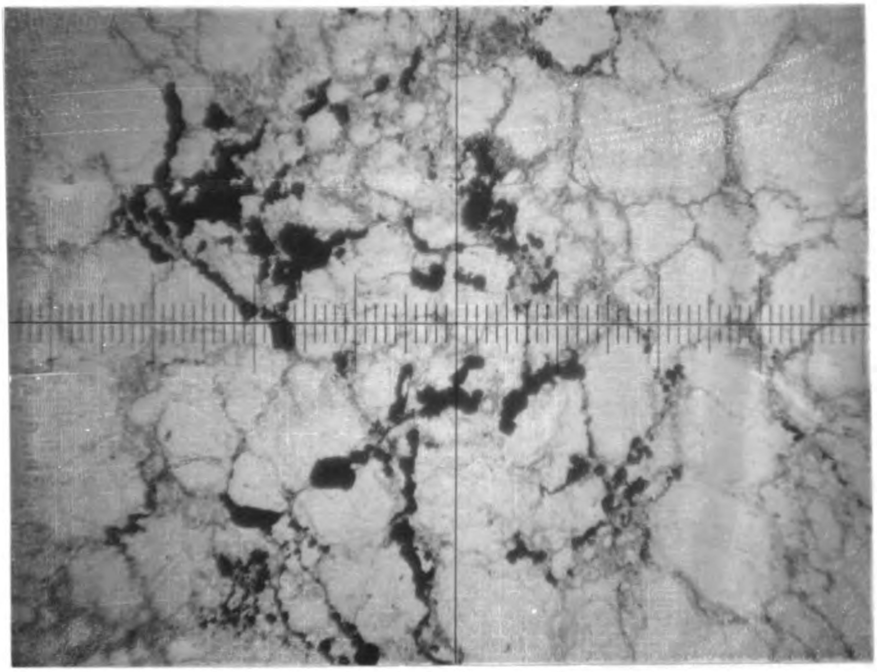
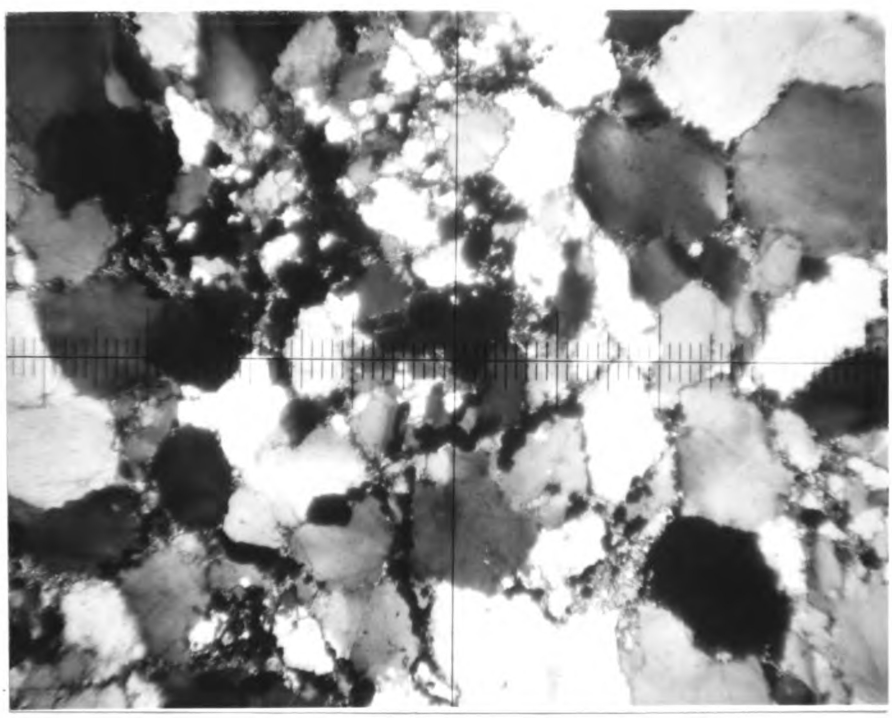


Figure 21.--Photomicrograph of native copper (black) in red sericitic quartzite. Ordinary light, 37 X, 11.5 micron grid.

Figure 22.--Same as above, but with crossed nicols.





in fractures in gray slate, and in one place forming the border of red feldspar veins cutting the slate.

Description of Area B

The copper mineralization of Area B is located approximately 4500 feet west-southwest of Area A southeast of Buschell Lake. It occurs at the eastern end of a broad syncline of Kona dolomite. (Figure 1.) Between Area A and Area B, the Kona has been eroded and the underlying Mesnard quartzite has been exposed. Several shallow shafts and test pits occur in Area B only one of which contains interesting mineralization. It is located in a valley trending northwest to Buschell Lake (formerly Copper Lake), and, observing the amount of rock on the dump and the cribbing of the shaft, it must have been one of the 25 or 40 foot shafts previously described.

The rock from the shaft is of two distinct colors, a grey banded argillaceous slate and a reddish-tan well banded siliceous slate. The slate is massive, not sheared as in Area A, but is highly fractured. It exhibits parallel bedding and crosscutting fractures and veins. Most fractures and veins are normal to the bedding but a few cross it at an angle of about 45 degrees. A small amount of malachite is found on fractured surfaces.

Under the binocular microscope, the gray slate is mostly fine grained with alternating coarse grained layers.

The coarse grained clastics also occur as irregular contorted pods at a high angle to normal banding. Mineralization occurs in hairline fractures and in small veins up to ¼ inch. It is also found in the coarse clastic bands and a small amount in the fine grained sediment. Clastic bands also contain some limonite and hematite.

The reddish tan slate appears very much the same as the gray slate except for color. It is fine grained with alternating coarse grained clastic layers. Mineralized veins and pods cut across the banding at a high angle. Most mineralization occurs in fractures, veins, and coarse clastic bands with a small amount in the fine grained portion. Some hematite is present.

In reflected light, the metallic mineralization is more than 99 per cent chalcopyrite. Only a few small grains show chalcopyrite and bornite, with bornite apparently replacing chalcopyrite. (Figure 23.) Chalcopyrite in veins and in the coarse clastic portions in the gray slate is commonly intimately associated with chlorite. (Figures 24 and 25.) In the reddish-tan slate, chalcopyrite is primarily restricted to coarse clastic bands within the sediment (Figures 26 and 27) but does occur in the fine grained portion. (Figure 28.) In the larger quartz-dolomite veins, chalcopyrite surrounds and penetrates grain boundaries. (Figure 29.)

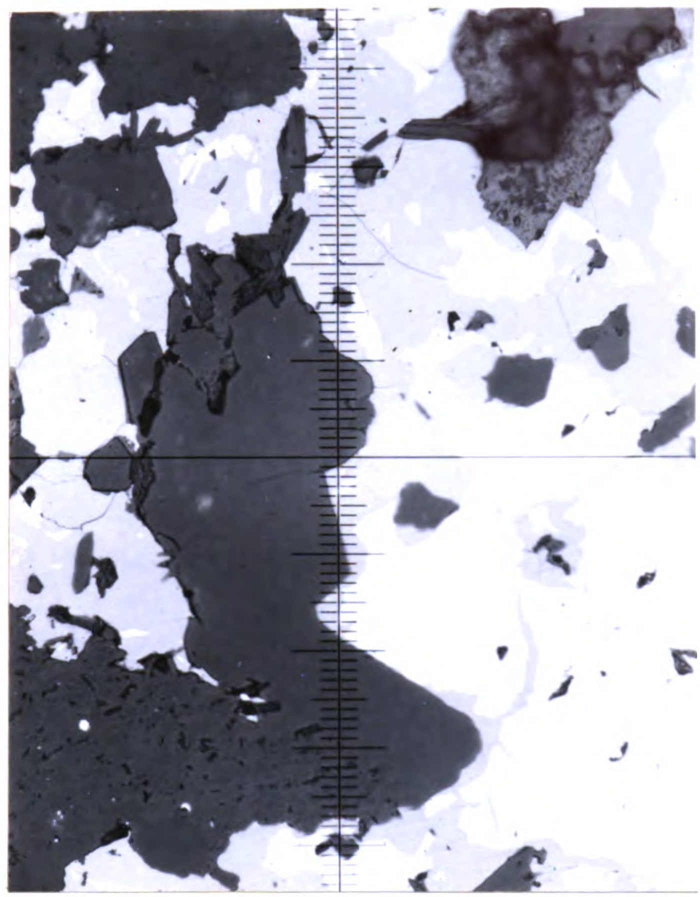


Figure 23.--Photomicrograph of bornite (light gray) apparently replacing chalcopyrite (white) enclosed in reddish-tan slate. Reflected light, 130 X, 11 micron grid.

Figure 24.--Photomicrograph of chalcopyrite (white) in vein in gray slate with chlorite (gray lathlike inclusions). Reflected light, 82 X, 11 micron grid.

Figure 25.--Same as above, a different vein.

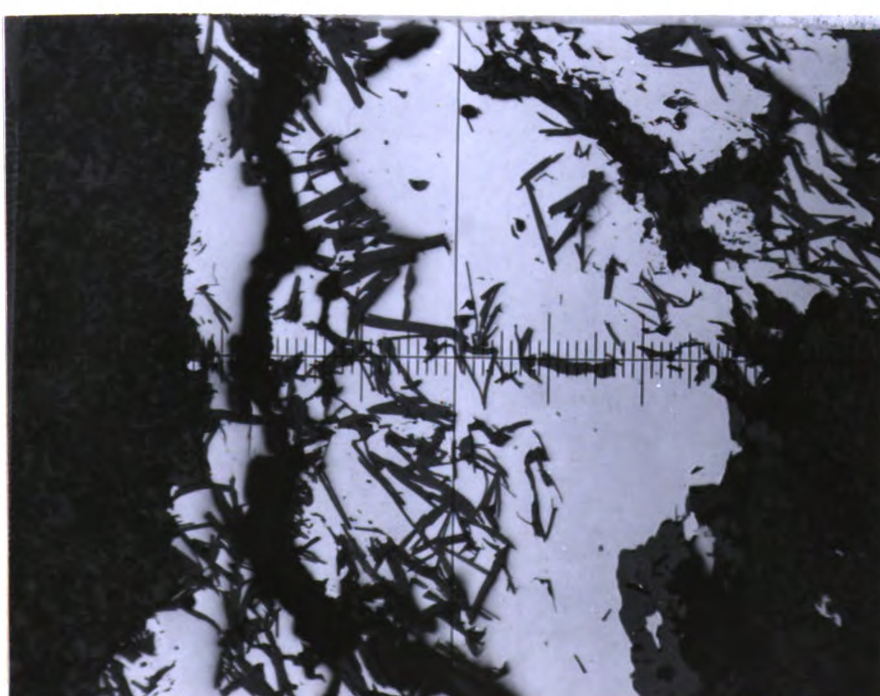
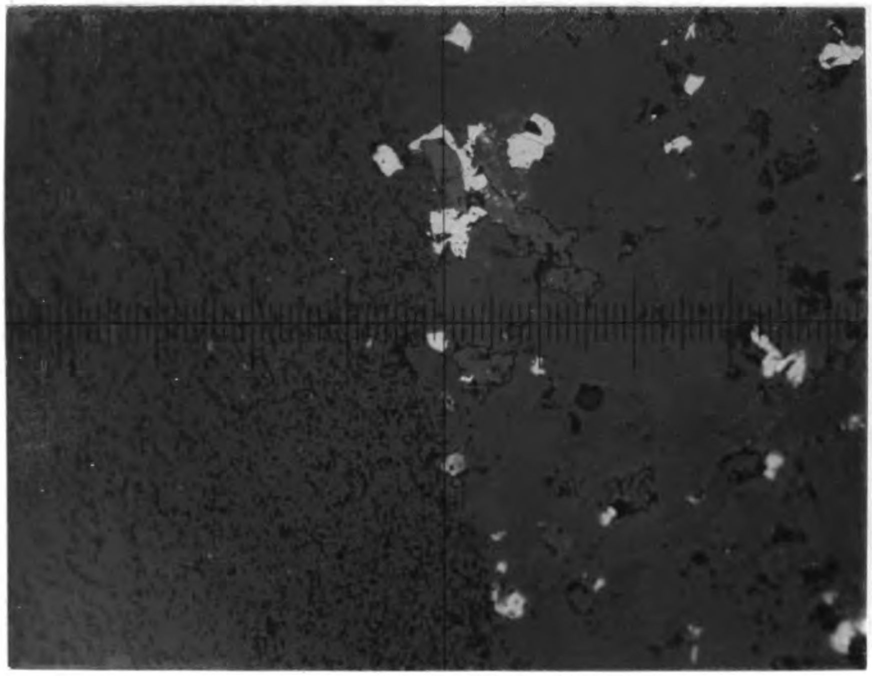


Figure 26.--Photomicrograph of contact between coarse and fine grained sediment displaying concentration in coarse layer. Reflected light, 82 X, 11 micron grid.

Figure 27.--Photomicrograph of chalcopyrite in coarse grained reddish-tan slate. Reflected light, 82 X, 11 micron grid.



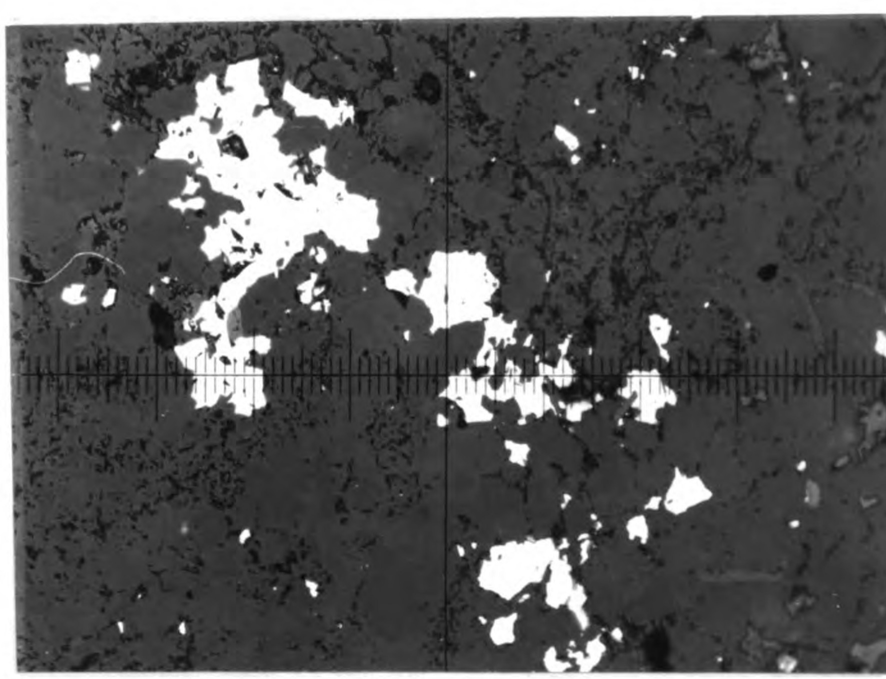
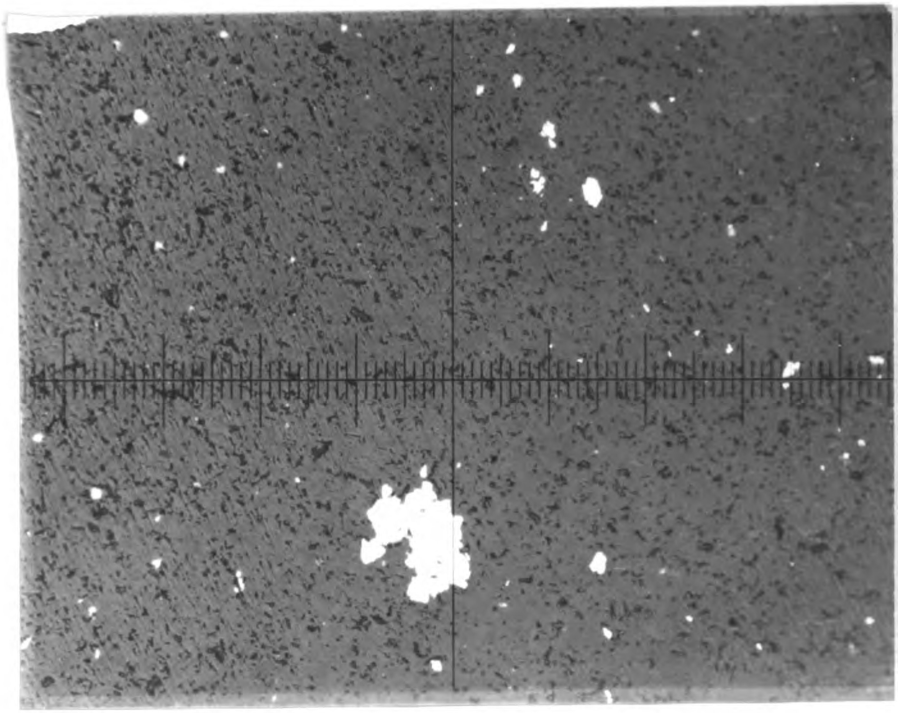
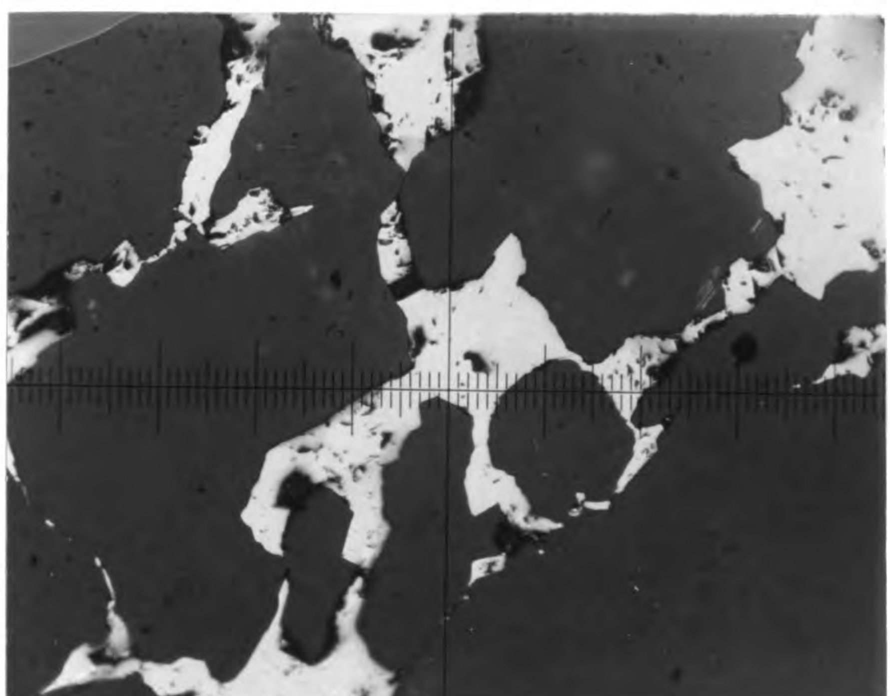


Figure 28.--Photomicrograph of chalcopyrite in fine grained matrix of reddish tan slate. Reflected light, 82 X, 11 micron grid.

Figure 29.--Photomicrograph of chalcopyrite in one of the larger quartz-dolomite veins. Reflected light, 82 X, 11 micron grid.





In thin section, the fine grained rock shows scattered large clastic quartz with some dolomite and chalcopyrite in a matrix of sericite, or, fine dolomite and quartz with interstitial sericite. The coarser layers are predominantly quartz and dolomite, with chalcopyrite, coarse sericite and a few grains of feldspar.

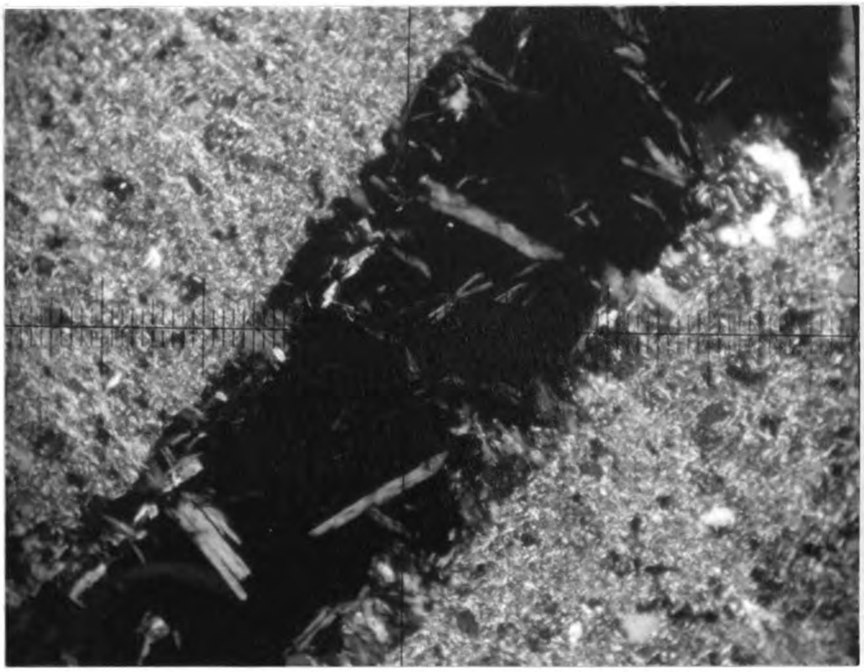
The mineralization occurs as described above. It is found in veins with quartz, dolomite and chlorite inclusions. (Figures 30 and 31.) It is common in clastic bands with lesser amount in the fine grained rock. (Figure 32.) Chlorite inclusions are common in the chalcopyrite and host rock of the gray slate. In the reddish-tan slate, chalcopyrite contains inclusions of sericite. A small amount of epidote replacing dolomite is in the reddish-tan slate. (Figure 33.)

Description of Area C

Copper mineralization of Area C is in the Kona dolomite on the north limb of the Marquette syncline about 1400 feet southeast of Enchantment Lake. The exploration is limited to one large test pit just above a narrow valley, on the south limb of a 160 foot hill of Kona, and is about 600 feet above Lake Superior. Green malachite and red iron oxide are plentiful and obviously the reason for the test pit. There is no known record of this exploration, which was encountered by J. E. Gair

Figure 30.--Photomicrograph of chalcopyrite in quartz dolomite vein cutting quartz sericitic slate. Lathlike inclusions of chlorite are colorless in ordinary light and dark gray under crossed nicols. Ordinary light, 107 X, 11.5 micron grid.

Figure 31.--Photomicrograph of chalcopyrite in quartz dolomite vein cutting coarse and fine grained quartz dolomite sericitic slate. Crossed nicols, 25 X, 11.5 micron grid.



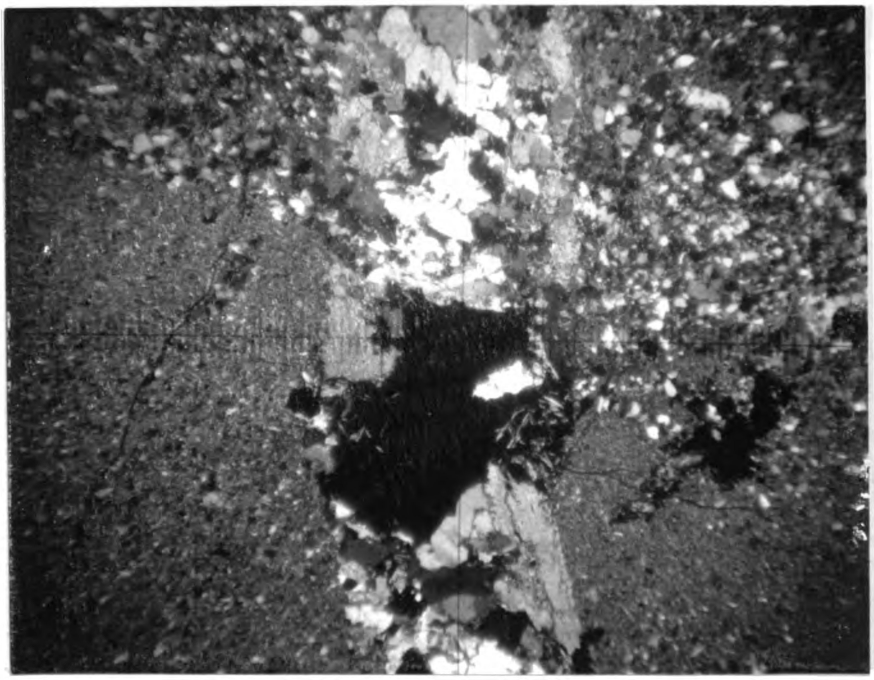
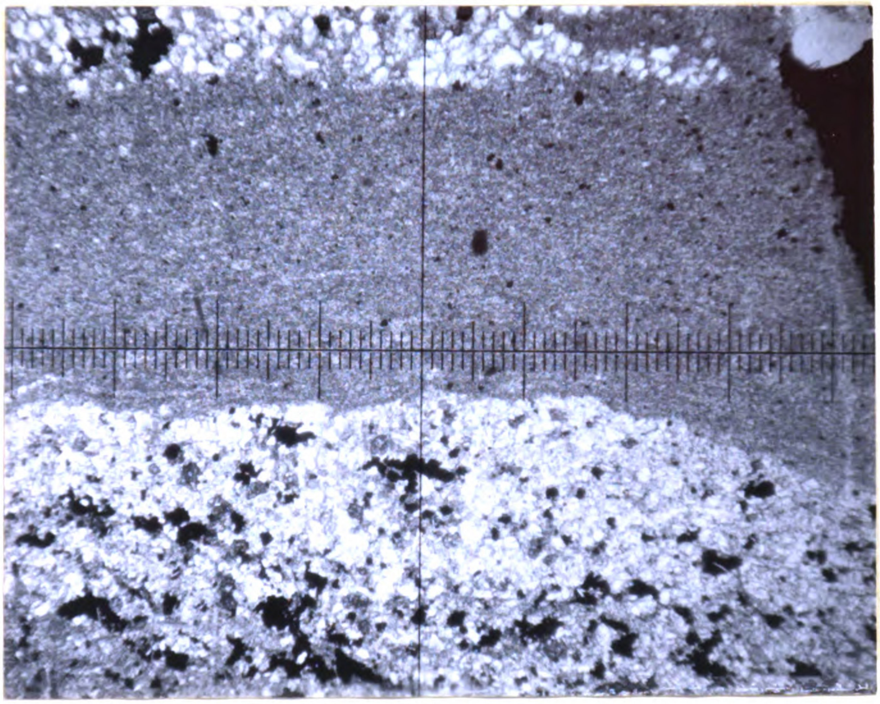
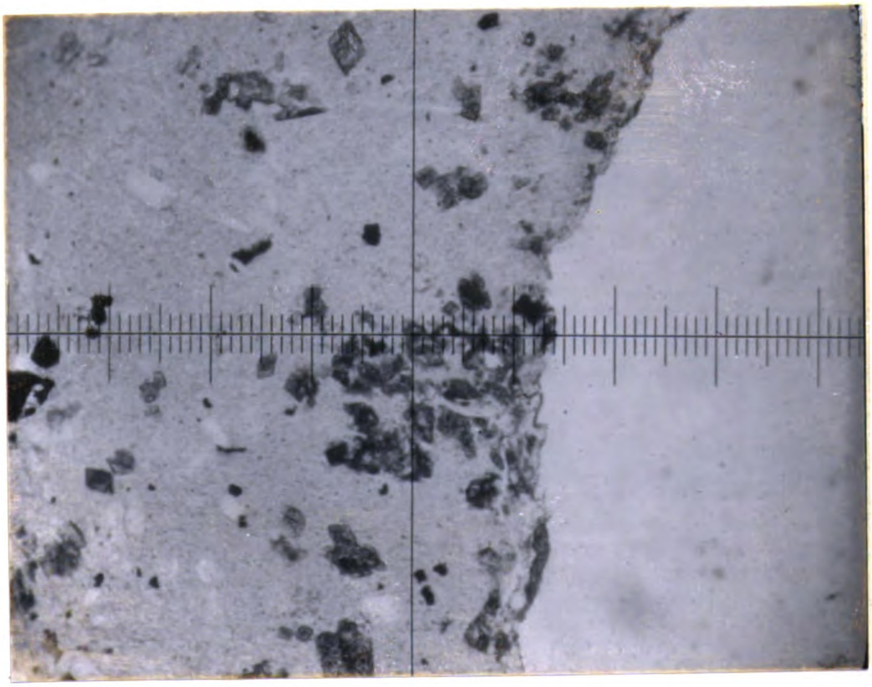


Figure 32.--Photomicrograph of scattered chalcopyrite in banded quartz sericitic slate, showing preference to the coarse grained member. Note cross cutting large segment of chalcopyrite with quartz in upper right of photo. Ordinary light, 37 X, 11.5 micron grid.

Figure 33.--Photomicrograph of epidote replacing dolomite adjoining quartz dolomite vein. Ordinary light, 107 X, 11.5 micron grid.





while mapping the Marquette quadrangle, and subsequently brought to the attention of the writer.

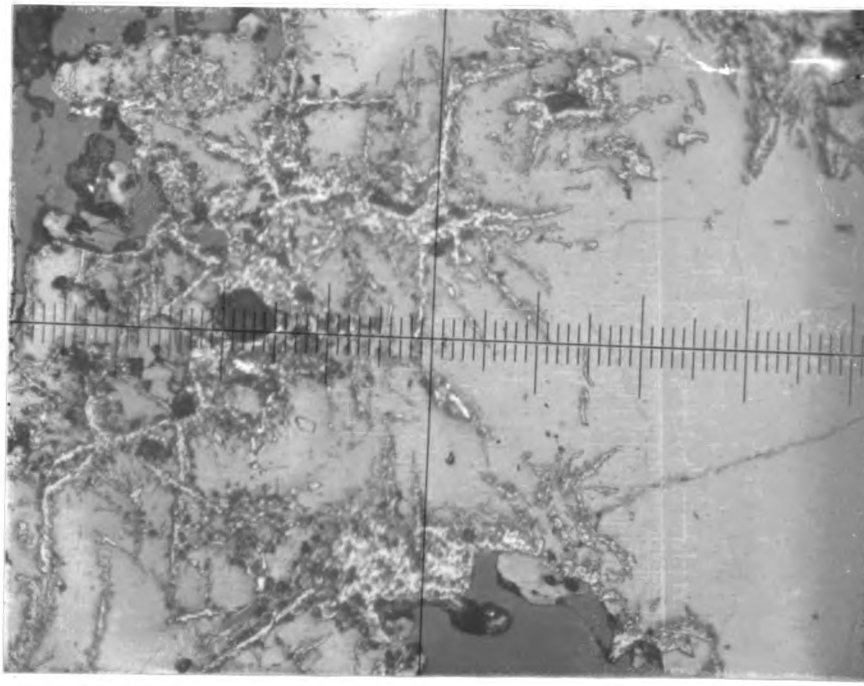
The rock from the pit is of two types, a buff-colored siliceous dolomite, and white vein quartz. Most specimens exhibit sulphide mineralization which is clearly visible. The structure appears to be a north-south shear zone although the mineralization may be associated with widespread regional silicification of the Kona dolomite described by Gair (1961).

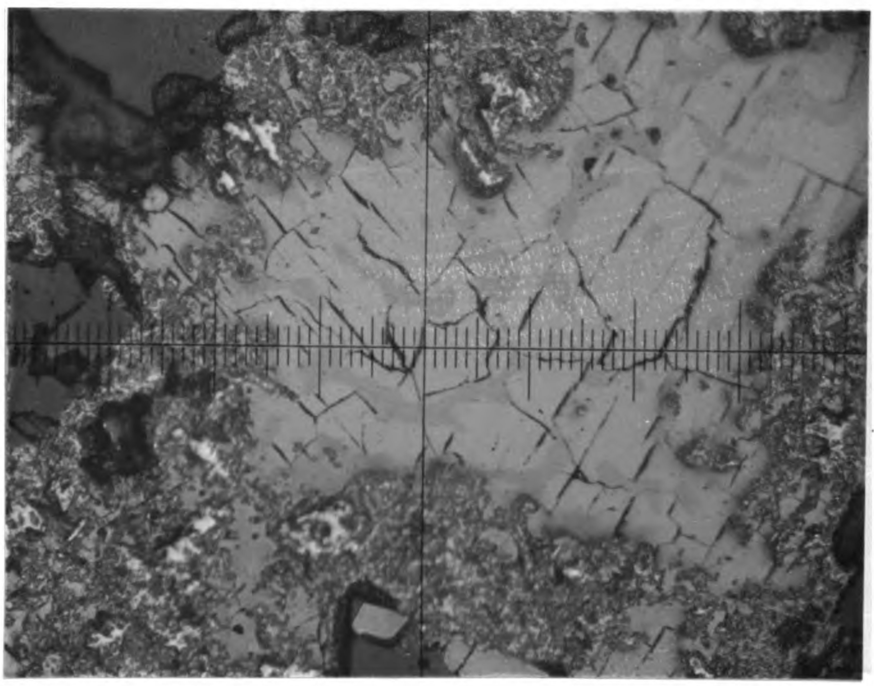
The mineralization is more varied than in Areas A and B. Chalcopyrite, bornite, covellite, chalcocite, and specular hematite are found associated with considerable red hematite and malachite. Chalcopyrite is sometimes found alone but may be replaced by bornite, covellite, and specular hematite in that order. Bornite is replaced by covellite and specular hematite. (Figure 34.) Bornite and chalcocite are replaced by covellite (Figure 35) and by specular hematite. No relationship of chalcopyrite and chalcocite were observed. A few scattered grains of anhedral pyrite occur as islands surrounded by other minerals, but were not internally replaced by them. The specular hematite is made up of very fine blades which form dendritic patterns penetrating all minerals except pyrite. Covellite also replaces chalcocite. (Figure 36.)

In thin section, the dolomitic rock consists of small to large grain mosiac quartz with 40 to 50 per cent

Figure 34.--Photomicrograph of bornite replaced by covellite and specular hematite. Reflected light, 153 X, 9 micron grid.

Figure 35.--Photomicrograph of bornite and chalcocite replaced by specular hematite. Reflected light, 153 X, 9 micron grid.





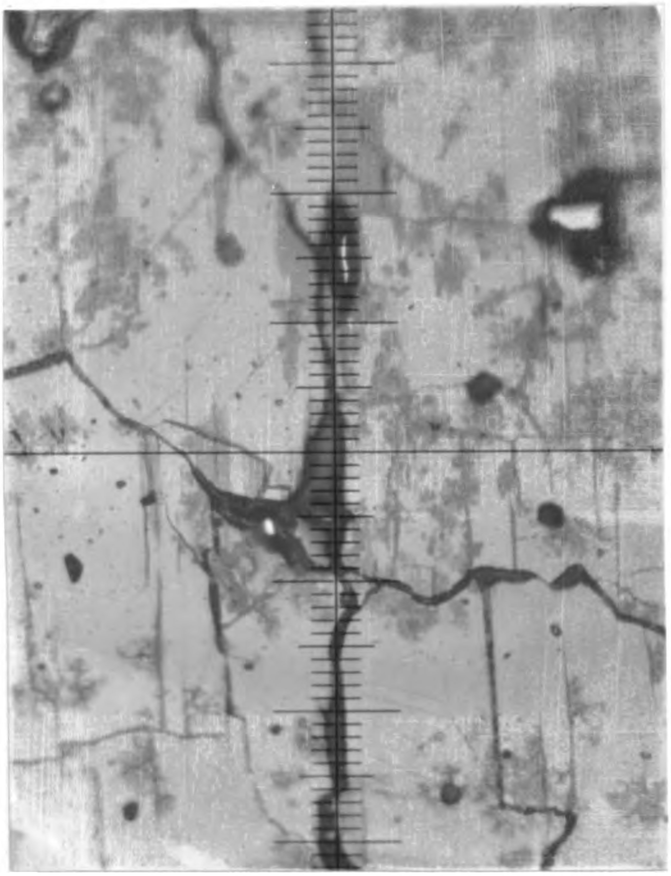


Figure 36.--Photomicrograph of covellite replacing chalcocite. Reflected light, 190 X, 9 micron grid.

dolomite scattered equally throughout the rock. Both quartz and dolomite exhibit frequent euhedral and subhedral grain boundaries. Most dolomite is clouded with hematite which is normal in many areas of the Kona. Mineralization is scattered and occurs primarily in association with the larger grains of quartz and dolomite. (Figure 37.) A small amount of mineralization appears to follow fractures but most are found surrounding grains of quartz and dolomite.

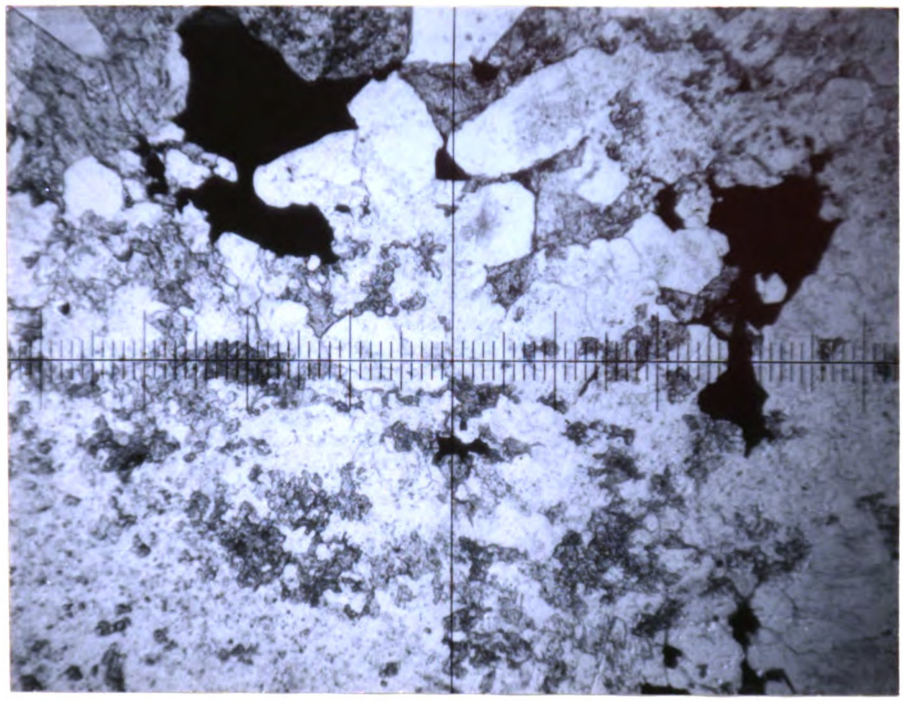
The vein quartz is wholly fine to coarse grained mosiac quartz with metallic mineralization primarily associated with the coarse grained quartz. Malachite is found in fractures and surrounding boundaries of ore minerals. The mineralization is scattered and appears to be fracture controlled. It may have been introduced following silicification. (Figure 38.)

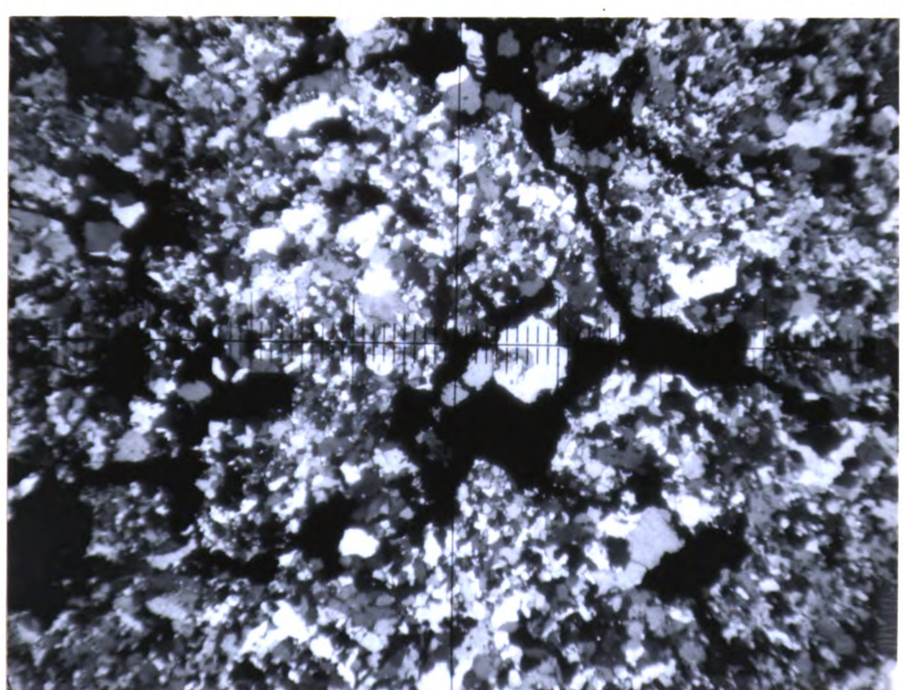
Description of Area D

The copper mineralization of Area D is found in the Cliffs Shaft iron mine located within the City of Ishpeming. The mineralization described is on the tenth level at an elevation of +735 feet or approximately 725 feet below the surface. The mineralization is in a two foot vein cutting the iron formation and is exposed for about 40 to 50 feet. The vein trends approximately east-west. Copper mineralization has been intersected in other parts of this mine but the veins are smaller and more erratic in trend.

Figure 37.--Photomicrograph of chalcopyrite in quartz-carbonate vein. Crossed nicols, 37 X, 11.5 micron grid.

Figure 38.--Bornite in mosiac quartz vein. Crossed nicols, 37 X, 11.5 micron grid.



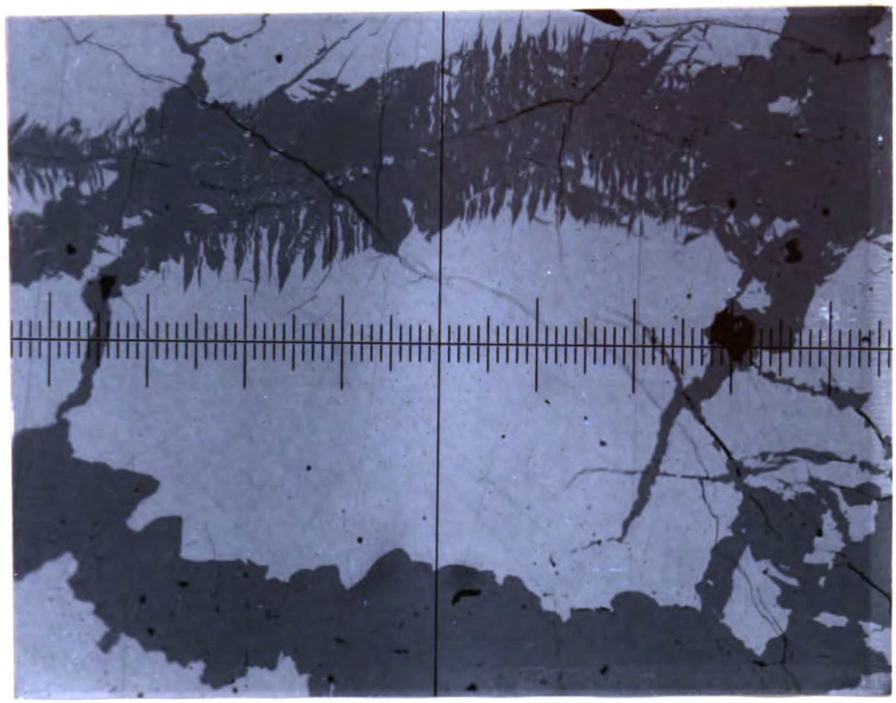


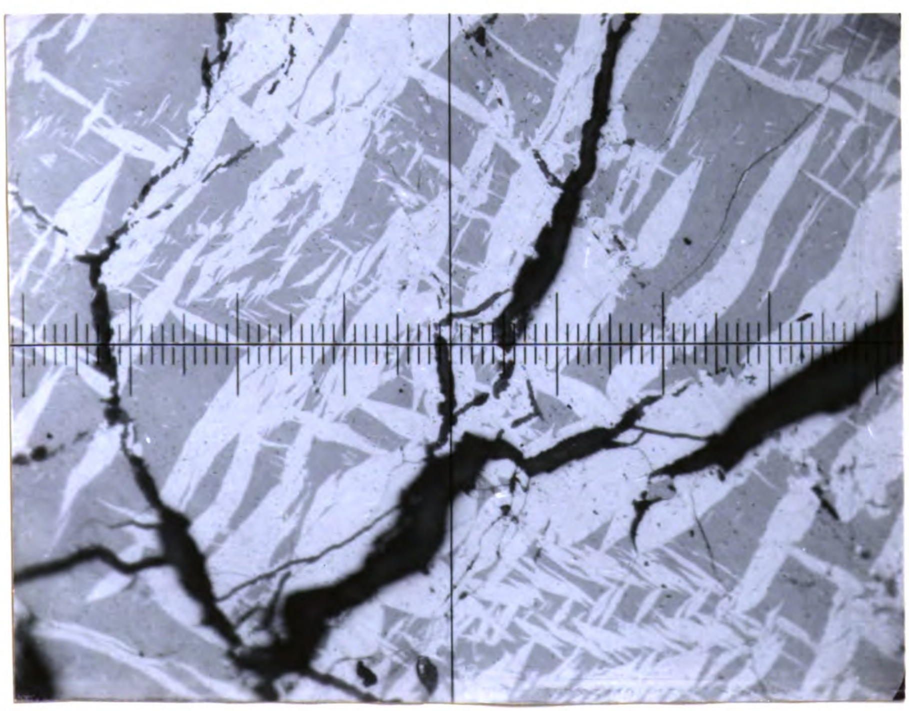
The dominant mineral is bornite, followed by chalcopyrite, pyrite, hematite and quartz. The chalcopyrite-bornite relationship appears to be that bornite replaces chalcopyrite (Figure 39), but some textures suggest exsolution. (Figure 40.) The predominance of surfaces suggesting the replacement of chalcopyrite by bornite entices the writer to believe this is the true relationship. Specular hematite is clearly later than bornite and chalcopyrite. It penetrates the bornite in long thin stringer in an elongated and dendritic pattern and also irregular larger masses with erratic borders. It is almost always found within the bornite, rarely intersecting chalcopyrite. The hematite is of three types; a gray relatively large bladed type which takes a high polish (Figure 41), pods with fine grained borders and extending in elongated groups of small crystals, and red hematite adjoining borders of the gray variety as isolated red clusters.

The elongated stringers of hematite are fine grained specular and often form a dendritic pattern. The stringers are primarily in the center of the bornite along fractures suggesting that bornite replaced chalcopyrite (Figure 39) and hematite replaced bornite from the same fractures. Hematite is predominatly within the bornite, but in a few places, chalcopyrite forms a border between hematite and bornite. Hematite also occurs as rims

Figure 39.--Bornite (dark) replacing chalcopyrite (white). Reflected light, 130 X, 11 micron grid.

Figure 40.--Bornite (dark) and chalcopyrite (white) exhibiting exsolution textures. Reflected light, 153 X, 9 micron grid.





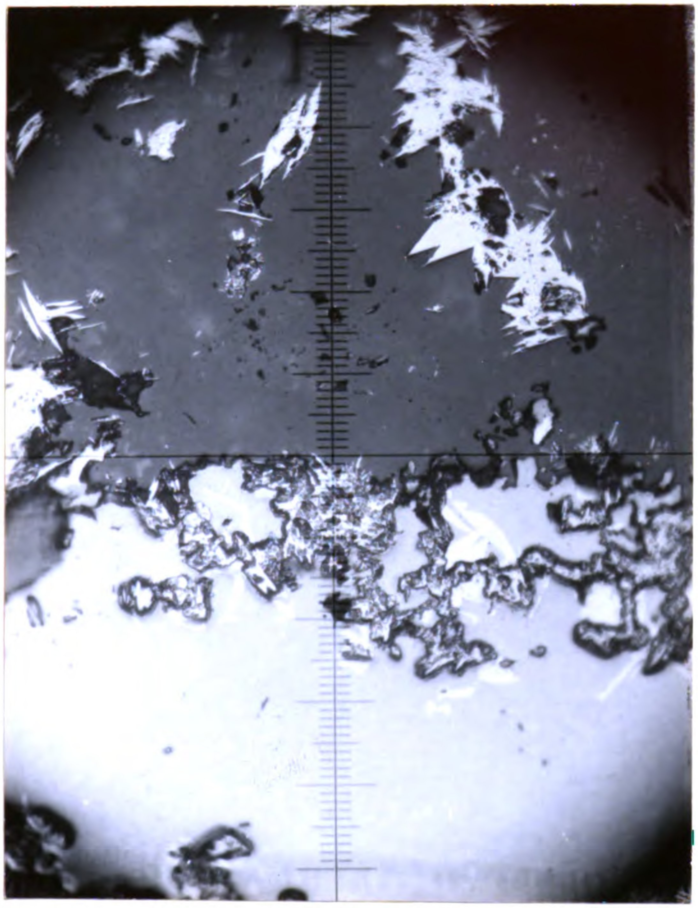


Figure 41.--Specular hematite in quartz adjacent to bornite (light gray) replacing chalcopyrite (white) and replacement by specular hematite (high relief mineral). 116 X, 9 micron grid.

between the chalcopyrite-bornite and pyrite-quartz, penetrating the chalcopyrite-bornite but not the pyrite.

Pyrite is found within the chalcopyrite-bornite primarily as enhedral to subhedral crystals but occasionally has corroded borders suggesting replacement. Pods of quartz, sometimes with pyrite, are within the chalcopyrite-bornite. They are often rimmed with specular hematite.

Most pyrite occurs as massive groups of crystals, in rounded form some almost perfect spheres. They are sometimes vugular, but more often the interstices between the crystals are filled with quartz. The pyrite masses are commonly highly fractured and in one instance the fractures are quartz filled. Isolated chalcopyrite-bornite is also found within the pyrite masses.

The quartz is coarse grained crystalline suggesting slow cooling. The faces are clearly visible under the binocular microscope. The quartz contains pyrite, both fine and coarse crystalline; hematite and bornite; along crystal faces and within quartz grains. Bladed specular hematite is also found within the quartz. (Figure 41.)

Chapter III

GEOCHEMISTRY

Nintey specimens were prepared for spectrographic examination to determine trace elements and the dissemination of copper adjacent to the ore zone. The samples were arced in a Baush & Lomb grating spectrograph with dispersion of 4 A per millimeter in the first order. The source unit was an A. R. L. multisource. Arc conditions were as follows: a resistance of 40 ohms, an inductance of 360 microhenries, a capatance of 12 microfarads for 12 seconds, and a tabulate wave length of 3100 - 4100 were used. Prior to arcing, samples were heated to 900 degrees C., quenched in distilled water to facilate grinding, ground in mortar and pestle and mixed with carbon and an internal standard of strontium carbonate.

The ore samples of Areas A, B, and C were examined for Ag, Au, As, Ba, Be, Cd, Cr, Co, Cu, Hg, Li, Mn, Mo, Ni, Pb, Sb, Th, Ti, U, V, and Zn. Only Cu, Ti, and Mn of the examined elements were represented in the samples, and Ti and Mn only in minor amounts. As clastic pods and layers are present, titanium probably exists as ilmenite granules. Manganese may be a minor constituent of the fine grained portion of the sediment. There are no good elemental guides to ore. Copper may be a guide, but it is widespread in trace amounts.

In the spectrographic determination of copper, a sample from Area A with colloform texture chalcocite shows an estimated copper content of 6 to 7 per cent. In Area B, the green slate contained 1.8 per cent while the buff slate showed 1.2 per cent copper. In Area C. bornite mineralization was 2.6 per cent copper. Two samples of chalcocite showed .85 and 1.1 per cent and chalcopyrite .15 per cent. The above determinations should not be representative of the mineralization, although those of Areas B and C are more representative than that of Area A.

A Keweenawan diabase dike, located about 1300 feet south-east of Area B has a copper content of approximately .04 per cent.

The copper content of drill hole 3 of Area A is illustrated in Figure 42. Small samples of core are represented for each 5 feet of the drill hole. Figure 42 shows 2 ore zones with trace copper surrounding each zone. All samples contain copper although some was less than .01 per cent. As the samples examined are small, they are not meant to represent the average analysis of copper in the ore zone.

The slates and quartzites along the road cut south of the City of Marquette, generally known as the "purple

FIGURE 42

COPPER CONTENT OF D.H. 3.

AREA A

slates," have been mapped as part of the Kona dolomite (Gair, et al., 1963). These rocks were sampled every 25 feet, normal to the bedding, for a length of 500 feet. The results of the copper content are illustrated in Figure 43. Admittedly, the copper content is low, but it does illustrate copper penetration 3500 feet east of Area A.

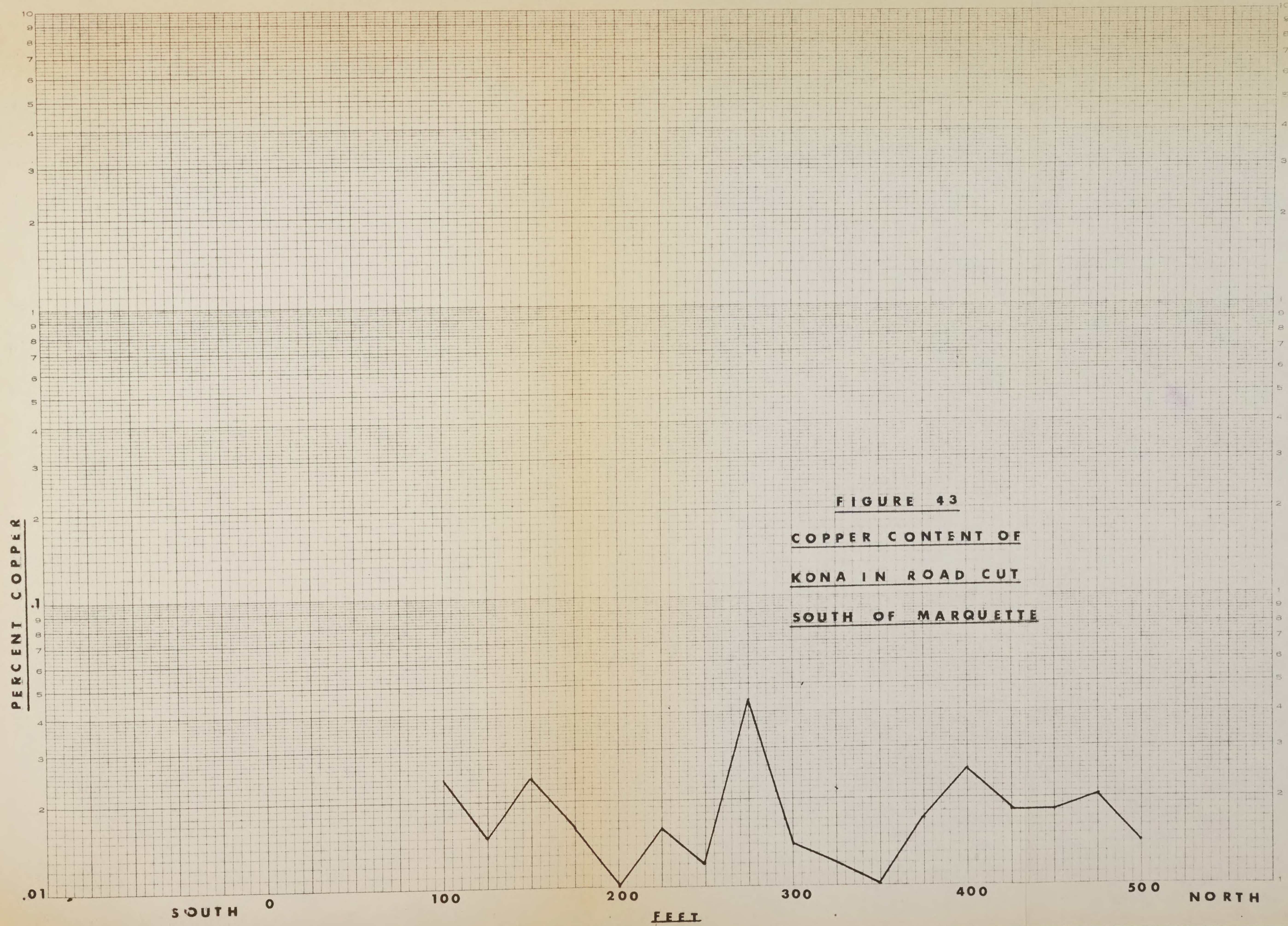


FIGURE 43
COPPER CONTENT OF
KONA IN ROAD CUT
SOUTH OF MARQUETTE
PERCENT COPPER
.01
.1
1
10
SOUTH
0
100
200
300
400
500
NORTH
FEET

Chapter IV

CONCLUSIONS

In summarizing the four described areas, we have:

1. In Area A, chalcocite obviously replaces pyrite and is associated with quartz, chlorite and sericite. Also, native copper in clastic quartz with sericite occurs at depth. Specular hematite is found in fractures in drill core as well as in the Mesnard quartzite stratigraphically below the Kona.
2. In Area B, the metallization is primarily chalcopyrite with a small amount of bornite. It is asociated with quartz, chlorite and sericite and also occurs in quartz-dolomite veins. Specular hematite is found in abundance in a test pit in the Kona about 3400 feet to the west of Area B (Holway 1952).
3. In Area C, metallic mineralization consists of chalcopyrite, bornite, covellite chalcocite and specular hematite, with red hematite and malachite. Chalcopyrite is replaced by bornite, covellite, and specular hematite. Chalcocite may be replaced by bornite, and is replaced by covellite and specular hematite.
4. In Area D, chalcopyrite is replaced by bornite and specular hematite. The relationship of quartz and

pyrite to the other minerals is not clear, but quartz contains inclusions of pyrite, bornite, and hematite along quartz crystal boundaries and within crystal grains. Pods of quartz are found within the chalcopyrite bornite and also chalcopyrite bornite, quartz, and red hematite are found within the pyrite.

Trace copper in the Kona shows a wide distribution. Examination of other important trace elements shows that most are not present and mineralized areas of the eastern Marquette range are practically "clean" of trace elements.

Wall rock alteration of the mineralized zones is primarily silicification followed by sericitization and chloritization. The area is within the chlorite or equivalent metamorphic zone (James 1955).

The nearest local approximation to the mineralization existing in the eastern Marquette range is that adjacent to, and within, the syenodiorite intrusive of Mount Bohemia in the Keweenaw Peninsula. Exploration in the vicinity of Mount Bohemia has disclosed copper sulphides in amygdaloidal flows, intrusive basic dikes and the syenodiorite intrusive. Sulphides in the amygdaloid and basic dikes consist of predominant chalcocite with bornite, chalcopyrite, pyrite, and covellite. Subordinate native copper also occurs, and specularite. In the syenodiorite, the predominant sulphide is bornite followed by chalcopyrite, chalcocite, and a little pyrite. Associated minerals include calcite, chlorite, and epidote with minor silification (Weege, R. J., personal communication).

Calcite, chlorite and epidote are the most important gangue minerals surrounding Mount Bohemia. Quartz, chlorite, sericite, and dolomite are predominant in the eastern Marquette syncline. While the simularity in mineralogy is striking, it is not direct proof of a genetic relationship. But it may be inferred as indicative of a similar source of rock type and age. Figure 44 illustrates the geographical relationship of the copper area described with the Keweenawan basin and Keweenawan dikes.

One dissenting objection to a Keweenawan age of this mineralization is that the Mount Bohemia intrusive shows a positive aeromagnetic anomaly of 1140 gammas (Balsley et al., 1963). In the eastern Marquette range, over the copper mineralization, there is no aeromagnetic expression. An intrusive source of mineralization may be at some depth.

An interesting note, Wright (1909), discussing the area of Mount Bohemia stated:

> Near Marquette, diabase dikes outcrop whose jointing cracks are often filled with diklets of red feldspathic material not unlike certain felsites in aspect, thus indicating that there also the sialic portion of the diabase magma finally solidified to produce such a rock.

FIGURE 44

GENERALIZED GEOLOGIC MAP SHOWING KEWEENAWAN BASIN AND ASSOCIATED DIKES

0 50

MILES

REFERENCES

Balsley, J. R., Meuschke, J. L., and Blanchelt, Jean. Aeromagnetic map of the Delaware quadrangle, Michigan: U. S. Geological Survey Map GP 315, 1963.

Boyer, Kenneth. Copper prospects south of Marquette near Chocolay: Radio program delivered February 12, 1961 over WDMJ, Marquette, Michigan, 1961.

Boyum, Burton H. The Marquette mineral district, Michigan: Conference on Lake Superior Geology, 1964, 37 pp.

Butler, B. S., and Burbank, W. S. The Copper Deposits of Michigan: U. S. Geological Survey Professional Paper 144, 1929, 237 pp.

Gair, J. E., Thaden, R. E., and Jones, B. F. Silification of the Kona dolomite in the eastern part of the Marquette iron range, Michigan: U. S. Geological Survey Professional Paper 424-C, 1961, p C78-C80.

Gair, J. E., Thaden, R. E., and Jones, B. F. Geologic maps of the Marquette and Sands quadrangles, Michigan: U. S. Geological Survey open file maps, 1963.

Holway, W. The origin and occurrence of specular hematite (specularite) in the Lower Huronian of the Marquette district, Michigan. Unpublished M. S. Thesis, Michigan State College, 1952, 46 pp.

James, H. L. Zones of regional metamorphism of the Precambrian of northern Michigan: Geological Society of America, vol. 66 (1955), pp. 1455-1488.

Milner, Henry B. Sedimentary Petrography (The Macmillan Company, New York, New York, 1962), 715 pp.

Rogers, A. F., and Kerr, P. F. Optical Mineralogy (McGraw-Hill Book Co., Inc., New York, 1942), 390 pp.

Short, M. N. Microscopic determination of the ore minerals: U. S. Geological Survey Bulletin 914, 1940, 314 pp.

Van Hise, C. R., and Bayley, W. S. Preliminary Report of the Marquette Iron-Bearing District of Michigan: Fifteenth Annual Report of the U. S. Geological Survey, 1895, pp. 477-650.

Van Hise, C. R., and Bayley, W. S. The Marquette Iron-Bearing District of Michigan: U. S. Geological Survey Monograph 28, 1897, 608 pp.

Van Hise, C. R., and Leith, C. K., The Geology of the Lake Superior Region: U. S. Geological Survey Monograph 52, 1911, 641 pp.

Wright, F. E. The Intrusive Rocks of Mount Bohemia, Michigan: Geological Survey of Michigan Annual Report, 1909.