1982

Geology and mineral deposits of the Emery Mining District Powell County Montana

Salah Al-Khirbash
The University of Montana

Recommended Citation

Al-Khirbash, Salah, "Geology and mineral deposits of the Emery Mining District Powell County Montana" (1982). *Graduate Student Theses, Dissertations, & Professional Papers*. 7088.
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GEOLOGY AND MINERAL DEPOSITS OF THE EMERY MINING DISTRICT, POWELL COUNTY, MONTANA

by

Salah Al-Khirbash

B.Sc Sana'a University
Yemen Arab Republic

Presented in partial fulfillment of the
requirements for the degree of

Master of Science

UNIVERSITY OF MONTANA

1982

Approved by:

Chairman, Board of Examiners

Dean, Graduate School

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Date

ABSTRACT

Al-Khirbash, Salah A., M.Sc., June, 1982 Geology

Geology and Mineral Deposits of the Emery Mining District, Powell County, Montana

Advisor: Dr. Ian Lange

The Emery Mining district is approximately 19 km. (12 miles) southeast of Deer Lodge, Montana. Hydrothermal mineralization is hosted by the late Cretaceous, basaltic to andesitic Elkhorn volcanic lavas. The paragenesis of the epithermal-mesothermal mineralization, from older to younger, is quartz/arsenopyrite → pyrrhotite/pyrite → spalerite/galena → chalcopyrite + quartz → carbonate. Argillic, sericitic and propylitic alteration are common in the country rocks of the district.

Metal analyses (Pb, Zn, Cu, Sb, Ag, Au, Co) of underground and surface exposures* were done. Lead and copper increase relative to zinc with depth. Galena and sphalerite are important Ag-bearing minerals. Arsenopyrite, pyrrhotite and pyrite may be Au-bearing.

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*Selected samples were run for Ag and Au analyses.

ACKNOWLEDGMENTS

Financial assistance for this study was made possible by the U. S. Agency for International Development, by my father, and by Mr. Mohammed Majid of Al-Khirbash Company in Yemen.

Special thanks is given to my advisor Dr. Ian Lange for his indispensible comments and advice, and to Dr. Wayne Van Meter and Dr. Jack Wehrenberg for their comments. I acknowledge Mr. Eric Brown of the Exxon Company (Minerals Department) for suggesting the area, Mr. Jaswant Jiwan for helpful points during the study, and Mr. John Cuplin for his advice in photomicroscopy.

Finally, I appreciate my wife, Fatima, for her cooperation during the field and laboratory work of this study, and Mrs. Shirley Pettersen for her typing.

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CHAPTER I

INTRODUCTION

The Emery Mining district was a most important area in southwestern Montana for its gold, silver and probably lead and zinc production. The district was discovered in 1888 by John Renault (prospector). The total value of the district lode deposits was estimated to be not less than $2,100,000, and for placers $75,000 from 1928 until 1949 (Robertson, 1953). Productive activity in the district from 1894 to 1940 was summarized by Robertson in 1953. The Emery district lies in sections 1, 2, 3, 10 and 11 of T7N, R8W in southern Powell County, about 12 miles southeast of Deer Lodge (Fig. 1).

The mineralization of the Emery Mining area is in the late-Cretaceous Elkhorn Mountain lava flows which flank the western side of the Boulder batholith (Klepper, et al, 1957). The lavas overlie undifferentiated Cretaceous sediments composed mainly of poorly consolidated sandstone, shale and siltstone (Robertson, 1953). However, within the mineralized area itself no sedimentary rocks were observed. Andesitic to basaltic lavas are the most abundant type in the district. Smedes (1966) suggested that the volcanics cover about 10,000 square miles (25,900 sq. km) and have a total thickness greater than 3,000 m. Robertson believed that the total thickness of the volcanic rocks below the Emery district is about 600 m (Figs. 2 and 3).

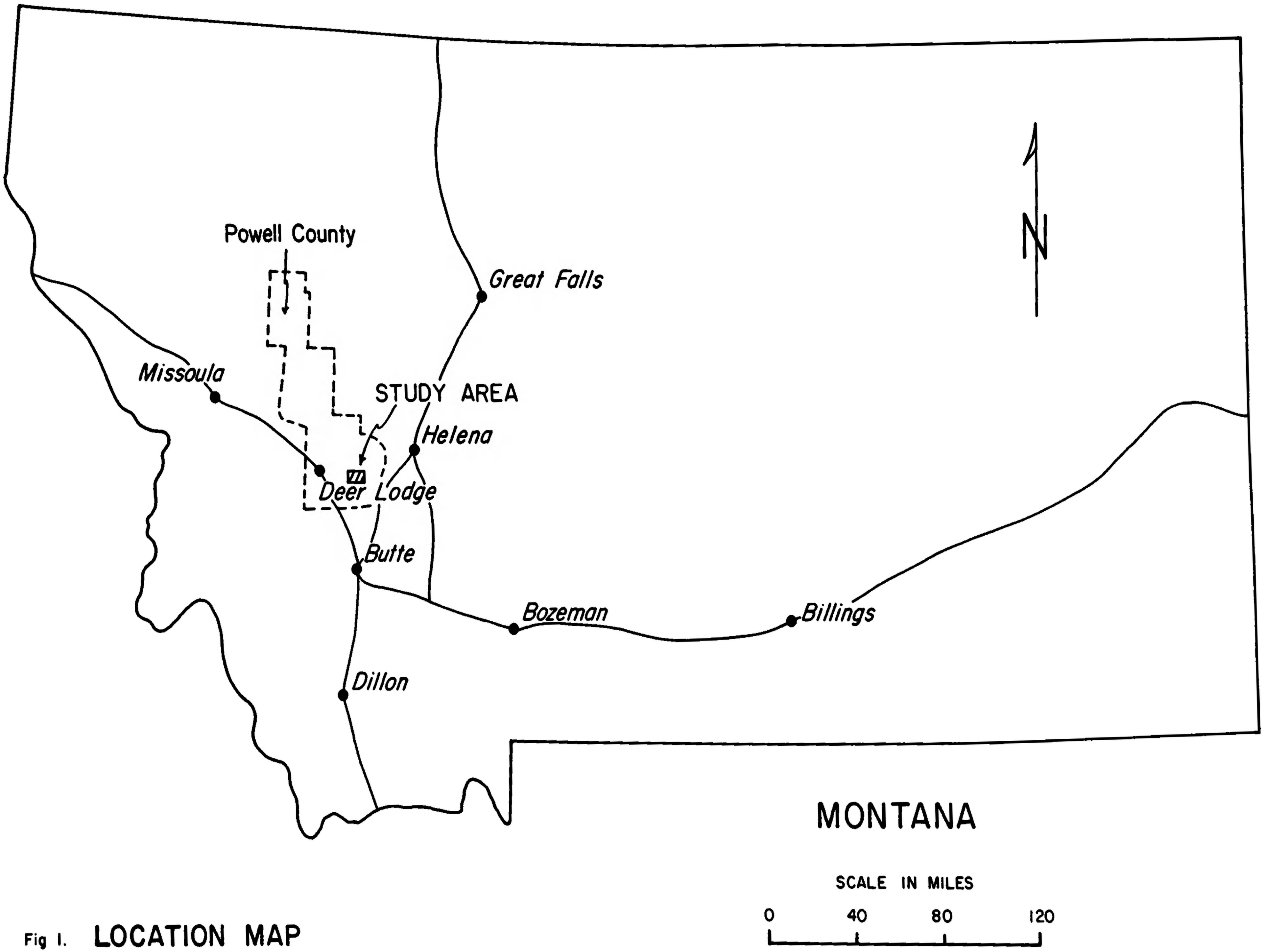


Fig 1. LOCATION MAP

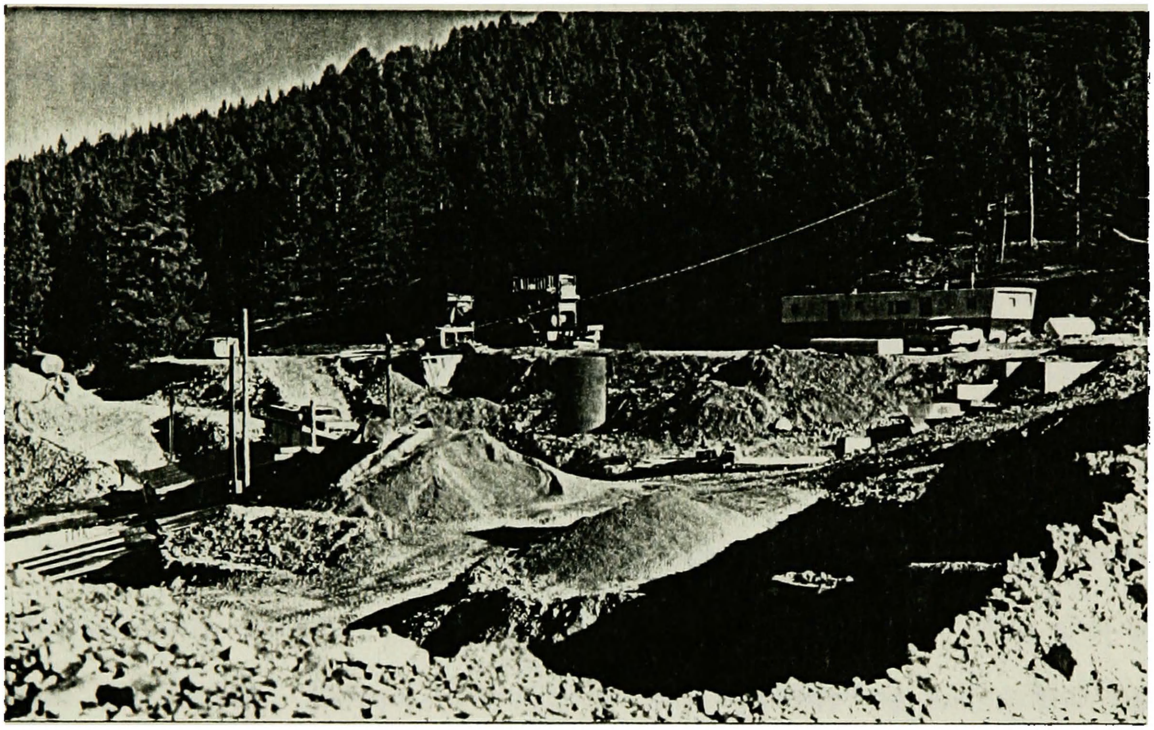


Fig. 2. A view of the Emery mine.

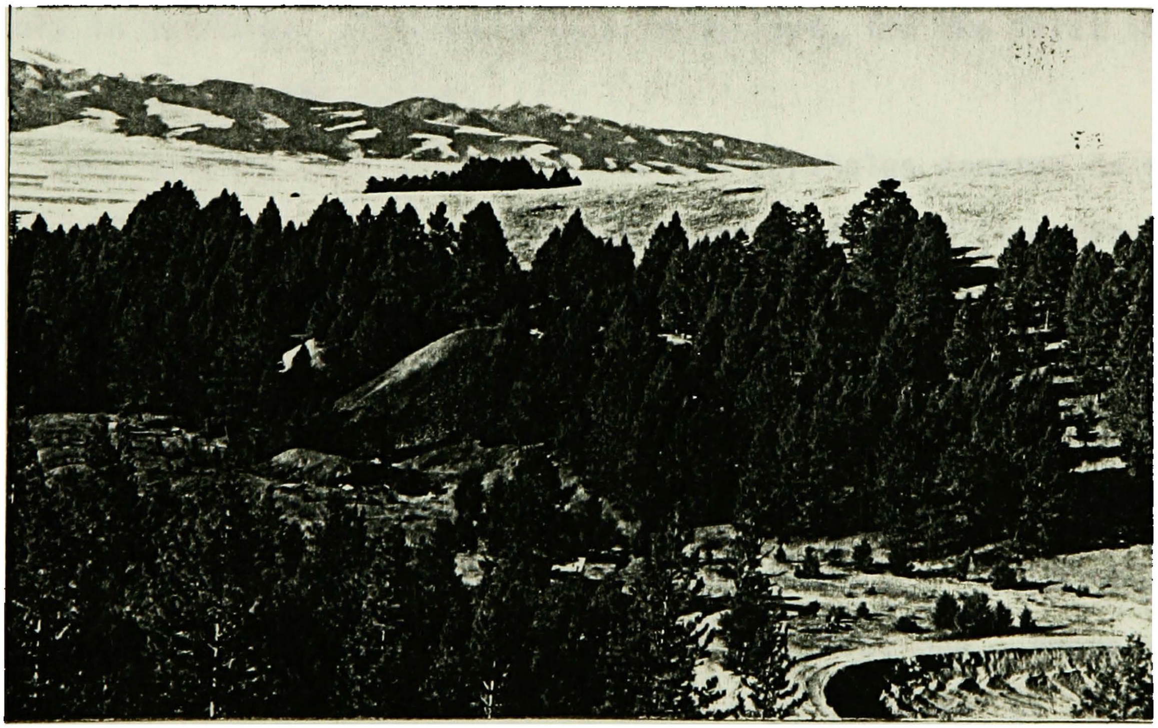


Fig. 3. Late Cretaceous volcanics of the district, looking west towards Deer Lodge.

The lodes in the Emery district are found in a nine kilometer square area, which are hosted by the subaerial volcanics. Mineralization is in small, simple to branched inclined veins cutting the inclined host rocks. Generally, the mienralization is found in three different structural elements. They include: (1) veins in low angle reverse fractures, (2) in normal faults, and (3) in post-mineralization faulting (Robertson, 1953). Disseminated replacement sulfides in the wall rock were also recognized by the writer.

The mineralogy of the orebody is simple. Lead, zinc, silver, arsenic, and copper were often present in significant amounts. The ore minerals include spalerite, galena, chalcopyrite, Ag-bearing tetrahedrite and Au-bearing arsenopyrite. Vein gangue minerals include pyrrhotite, pyrite, quartz, calcite. Chlorite, epidote, and chalcedony were found mainly in vesicles. Pyrrhotite was recognized, for the first time in the district, by the author.

Core samples were collected from two coreholes donated to the Montana Bureau of Mines and Geology in Butte during 1976/1978 (location of coreholes is shown in the geological map).

The present study examined two drill holes, No. 1 in detail. No. 1 has a total depth of 2902 ft. (870.5 m.). It was logged at a scale of 1 inch = 20 ft., and respresentative samples from the core were analyzed for their metal contents (summary is in Appendix 1). The second hole (No. 2) was examined and correlates with the first one. There are essentially no mineralogical differences. In addition, 21 samples were selected for analysis for areas where outcrops are available and from the dumps of the major shafts in the district.

The present investigation concentrated on the mineralogy, paragenesis, wall-rock alteration and the possible origin of the mineralization in the district. Mineralogical and metal variation through the different shafts as well as through depth will be reviewed.

The field work was carried out during late summer 1980 and early fall of 1981. The microscopic and analytical work were done during the winter and spring of 1982.

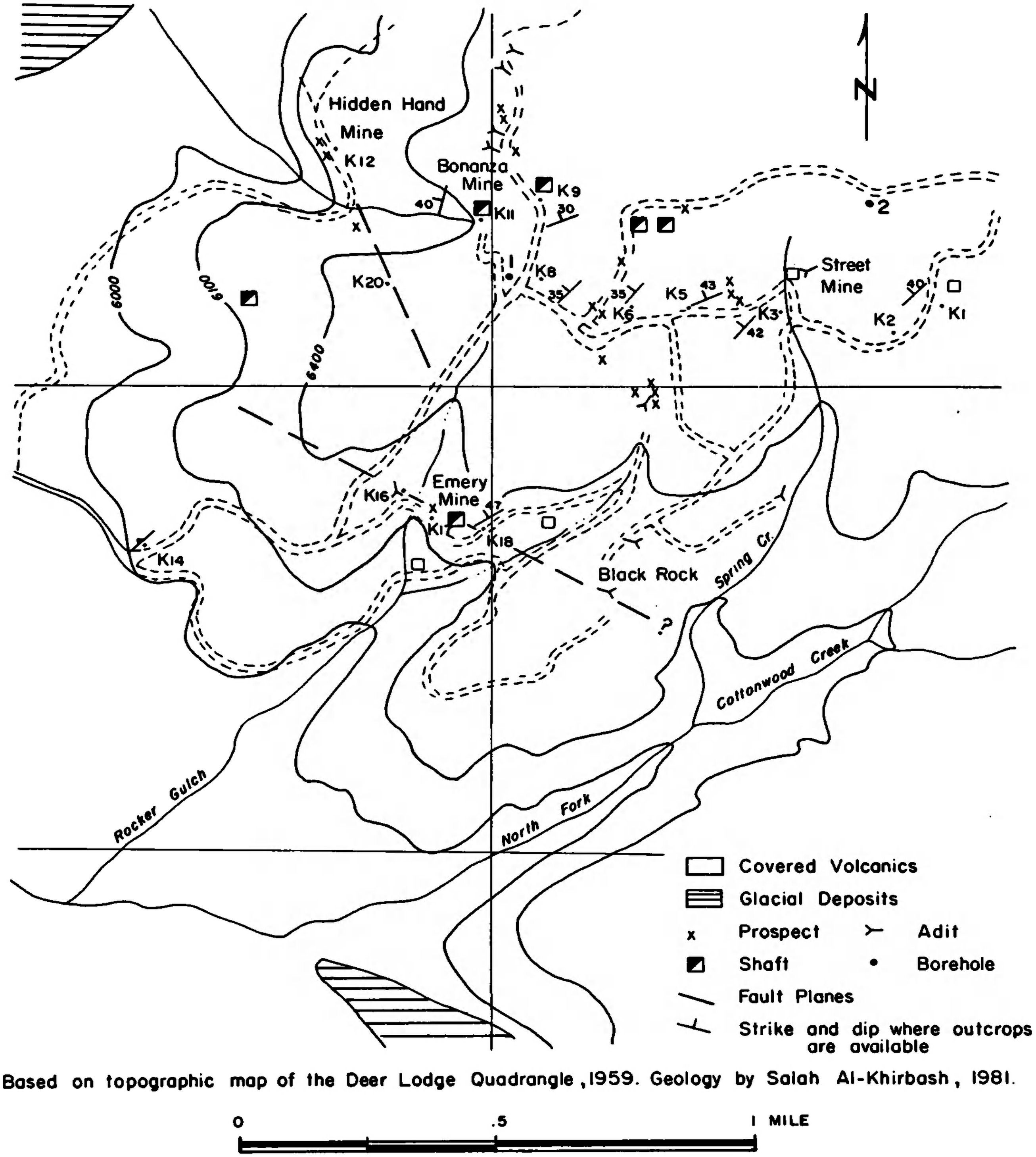
CHAPTER II

GENERAL GEOLOGY

The Emery mine district lies in the late-Cretaceous age Elkhorn volcanics and is located just west of the Boulder batholith. These volcanics cover about 7770 sq. km. around the batholith (Smedes, 1966). The geology of the district is relatively simple; andesitic to basaltic lava flows are the predominant rocks in the area. The oldest rocks exposed in the region are undifferentiated Cretaceous-age siltstones, Sandstones, and shales. However, within the mineralized area no sedimentary rocks were observed.

Description of rocks, based on the lithology rather than the stratigraphic position, has been mentioned by Robertson (1953). In the present study, structural relationships of the volcanic flows were studied by mapping the area and measuring the strikes and dips of the lavas where outcrops are available (Fig. 4.). The lava flows strike 30° - 35° N-NE and dip between 30° - 40° NW.

No major differences exist between rocks exposed on the surface and at depth except that rocks on the surface show more weathering than those observed underground. Examination of rocks revealed that porphyry basalt and prophyry andesites are the predominant rocks in the district. Pyroxene-bearing basalts are also present. Porphyritic basalts contain phenocrysts of calcic-plagioclase (An 50%) embedded in a slightly altered fine-grained matrix of plagioclase and pyroxenes



Based on topographic map of the Deer Lodge Quadrangle, 1959. Geology by Salah Al-Khirbash, 1981.

Fig. 4 Geologic Map of the Emery Mining District, Powell County, Montana

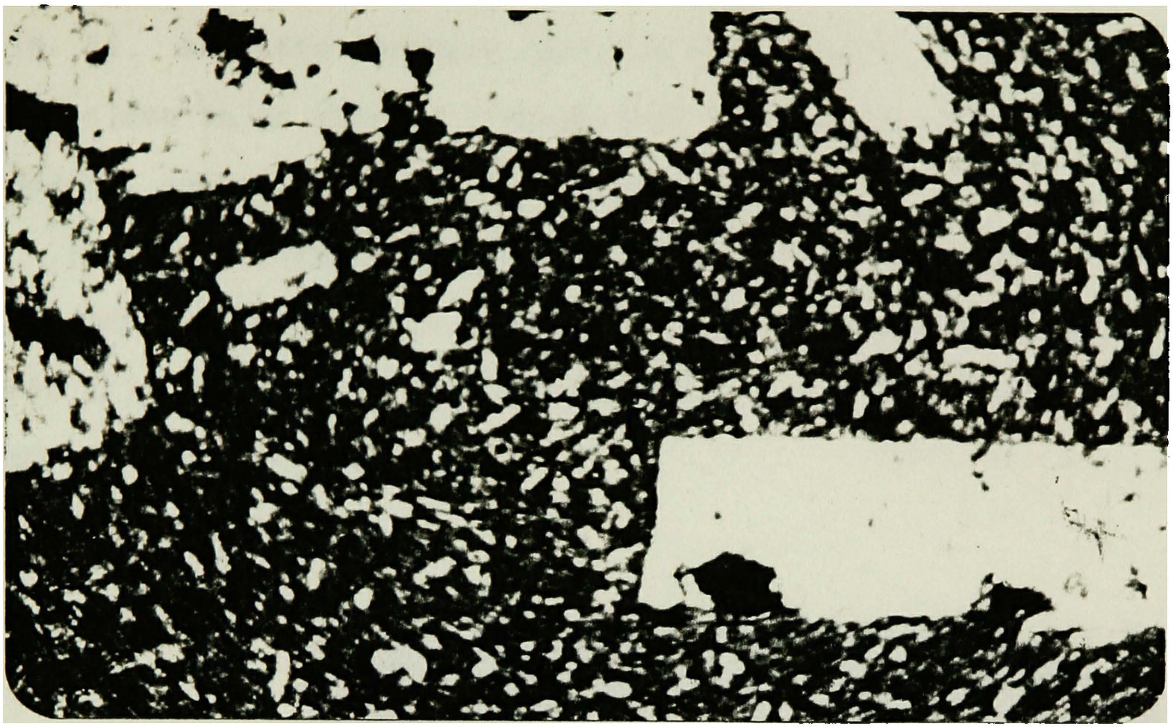


Fig. 5. Basalt porphyry. Calc-plagioclase in altered matrix, inclined shaft, (X2.5).

Fig. 6. Plagioclase andesite porphyry, 1527, (2.5).

(Fig. 5). Andesite porphyry contains fresh phenocrysts of calc-plagioclase in an altered fine-grained groundmass of plagioclase, pyroxene, and some quartz (Fig. 6).

The stratigraphic relationship between the individual volcanic units was not recognized. However, field observation at the inclined shaft (Fig. 7) suggest that intermediate composition rocks tend to be higher in the section.

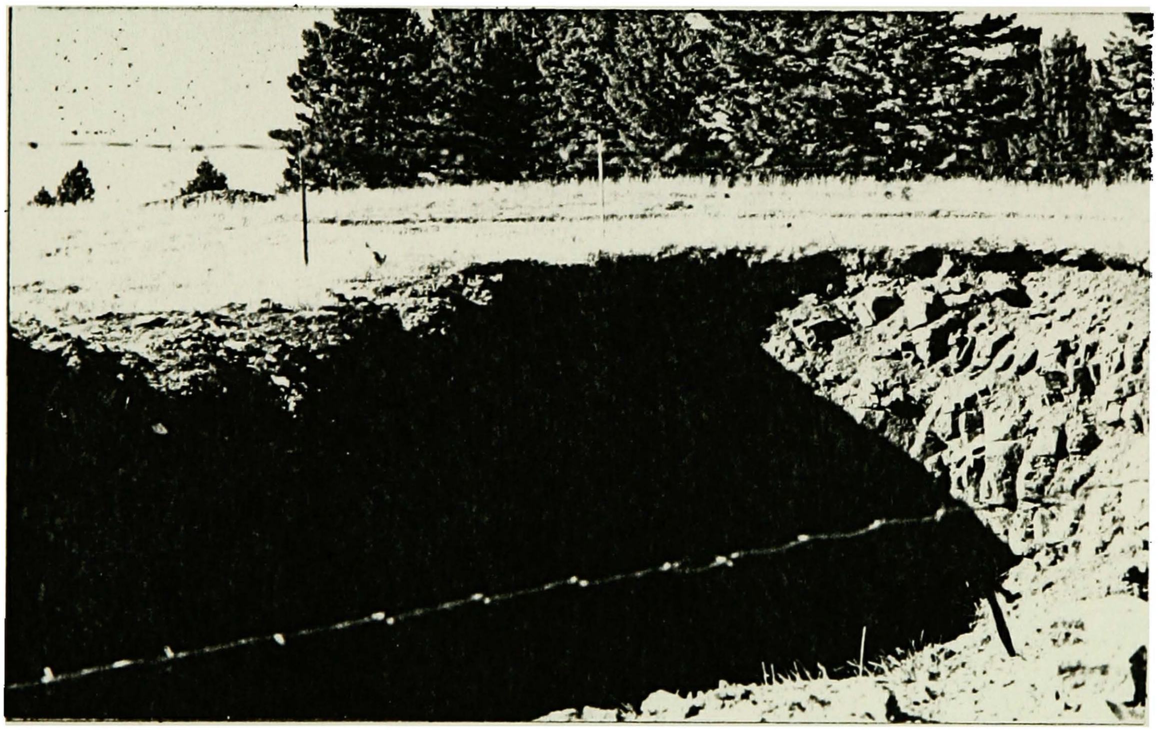


Fig. 7. Photo showing that the intermediate rocks of the district are higher in the section, inclined shaft.

Chemical analyses were run on 21 samples for their major element concentrations. The results are summarized in Table 1.

The precision of analyses is given below:

Fe_2O_3	± 1.2%
CaO	± .3%
MgO	± .7%
Na_2O	± .92%
K_2O	± 1.0%
MnO	± 1.4%

Table 1. Chemical Analysis of Rocks From the Emery Mine District

(Values are in wt %)

Sample No.	SiO_2*	Al_2O_3*	Total Iron as Fe_2O_3	CaO	MgO	Na_2O	K_2O	MnO	Rock description
K_1	--	--	20.16	8.68	3.28	2.74	1.85	0.166	not available
K_2	--	--	27.00	5.98	3.17	2.07	3.18	0.179	not available
K_3	54.61	15.23	15.59	3.97	4.08	3.75	2.20	0.179	porphyry andesite
K_5	43.00	14.70	20.70	4.41	4.73	2.32	2.59	0.211	pyroxene-basalt
K_{6a}	54.61	15.23	6.51	0.80	0.42	0.38	4.49	0.040	amygdaloidal andesite
K_{6b}	54.61	15.23	16.22	1.57	0.88	0.76	4.31	0.386	basaltic andesite
K_{6c}	54.61	15.23	14.87	1.54	0.79	2.08	4.32	0.186	basaltic andesite
K_8	--	--	19.72	1.61	3.16	2.42	2.59	0.131	altered andesite
Ka	--	--	20.14	7.62	3.69	4.21	1.12	0.164	altered andesite
K_{11a}	54.00	13.80	19.72	1.51	3.48	2.41	2.02	0.131	pyroxene andesite
K_{11b}	--	--	25.43	0.41	0.18	4.02	1.57	0.031	silicified rock
K_{12a}	47.40	13.80	15.38	10.47	3.45	2.47	4.58	0.531	porphyry basalt
K_{12b}	--	--	20.59	8.89	4.5	2.76	2.27	0.225	altered rock
K_{12c}	--	--	15.29	7.17	3.22	0.71	6.13	0.322	altered rock
K_{14}	47.40	13.80	13.38	9.38	2.82	2.27	4.66	0.247	porphyry pyroxene basalt
K_{16a}	--	--	18.42	8.93	4.00	2.82	2.28	0.184	amygdaloidal andesite
K_{16b}	47.40	13.80	18.42	8.68	4.40	4.88	2.21	0.209	porphyry basalt
K_{17}	54.00	11.60	19.00	5.20	4.52	3.73	1.80	0.183	pyroxene andesite
K_{18a}	--	--	26.25	1.82	0.47	6.78	1.63	0.170	qz-sulf. vein in silicified and.
K_{18b}	--	--	19.56	4.00	3.53	7.26	2.42	0.242	porphyry andesite
K_{20}	--	--	19.25	5.36	4.00	2.90	2.44	0.166	porphyry andesite

* = Values were taken from previous work by Robertson, 1953, due to difficulties in measuring Si and Al by using AAS instrument.

See Fig. 4 for sample location

CHAPTER III

MINERALOGY AND PARAGENESIS OF THE MINERALIZED ZONE

Mineralogy

The mineralogy in the Emery mining area is relatively simple. Samples collected from both underground and surface were studied microscopically and chemically. The analytical procedures will be discussed later. Study using reflecting and transmitted light microscopes revealed the presence of the following primary minerals, arranged in decreasing abundance: sphalerite, galena, chalcopyrite, arsenopyrite* and tetrahedrite+. Vein and dissiminated gangue minerals include pyrrhotite, pyrite, quartz, calcite; chlorite, sericite, epidote and chancedony as secondary wall rock alterations.

Pyrite and pyrrhotite are commonly found in small veinlets and fine to coarse grained massive aggregates, sometimes as well developed cubes and pyritohedron crystals (Fig. 8). Moreover, these two minerals were found as disseminated replacements concentrated on ferromagnesium minerals of the host rock and as pseudomorphs after carbonate rhombs. Pyrrhotite is more common underground than in surface exposures. Pyrrhotite veins sometimes are up to 6 cm thick. These veins contain a little sphalerite, galena and quartz.

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*Arsenopyrite is important for its Au-content.

+Tetrahedrite for its Ag content.

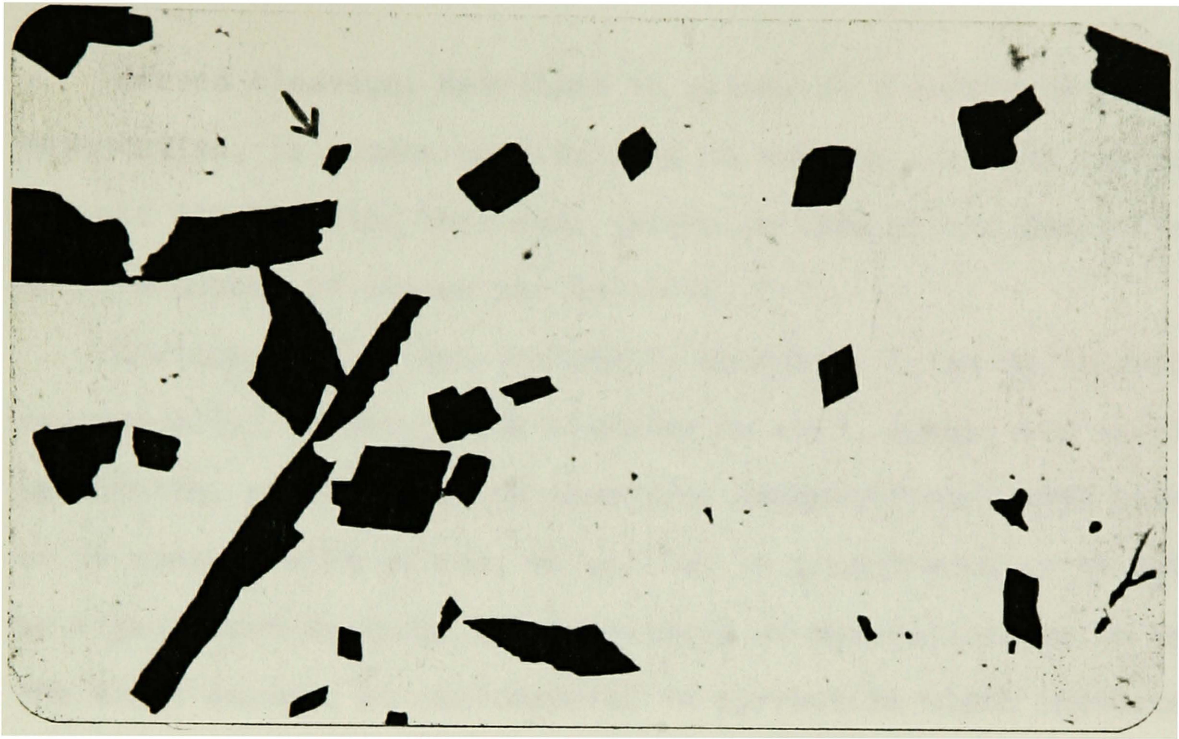


Fig. 8. Cubes and pyritohedron (arrow) of pyrite in a matrix of quartz. Also pyrite pseudomorphically after carbonate rhombs. Emery mine (X2.5).

Sphalerite is present in fine aggregates and as disseminations replacing the country rock and the earlier formed sulfides, such as pyrite and pyrrhotite. However, sphalerite is always associated with pyrrhotite in veins.

Galena is found in massive cubes and disseminations, as well as in veins associated with and replacing pyrrhotite, pyrite and sphalerite. Most commonly galena is associated with pyrite rather than pyrrhotite. These veins range from a few millimeters to a few centimeters in thickness.

Curved cleavage, developed in galena as a result of post-depositional deformation, is common particularly in surface and near surface samples. Elliott (1939) noted that some galena in vugs at the Emery contained up to 59.4 ounces of silver per ton (Fig. 9).

Chalcopyrite is too limited in abundance to be an important mineral economically. However, its presence as rods, blebs, and veinlets in sphalerite, pyrrhotite, and sometimes codepositional with quartz within or in contact with galena, as well as in microfractures in galena could be significant in terms of the history of mineralization in the district. The trace amounts of chalcopyrite in pyrrhotite might indicate that the pyrrhotite precipitated Cu-sulfides from subsequent Cu-bearing fluids. Alternatively chalcopyrite and pyrrhotite may have formed together. Weed (1900) noticed the same situation in pyrite in many orebodies of the southeastern states. Further discussion about the textural relationship between sphalerite and chalcopyrite will be given later. Chalcopyrite represents the final stage of metallic mineralization.

Arsenopyrite is found mostly embedded in a quartz matrix in near surface samples. This mineral could be of economic importance due to its gold content (Robertson, 1953).

Tetrahedrite was noticed by Elliott (1939) and by Robertson (1955) in the form of blebs and veinlets within the rest of the sulfides, particularly sphalerite. A sample of chalcopyrite which contained considerable amounts of tetrahedrite was analyzed by Elliott (1939) for its silver content. It contained 72 ounces of silver per ton. Quantitatively, the author of this investigation considers galena and possibly sphalerite

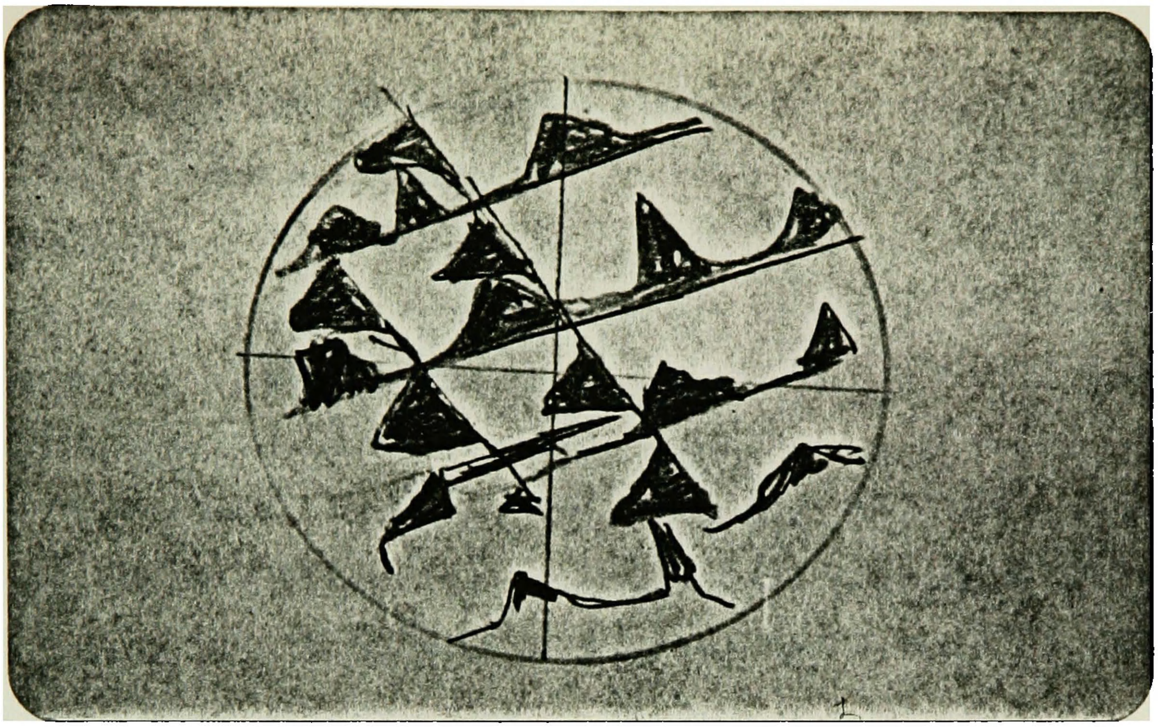


Fig. . Sketch showing a curved cleavage pits that developed in galena as a result of post-mineralization deformation, Emery mine (X4).

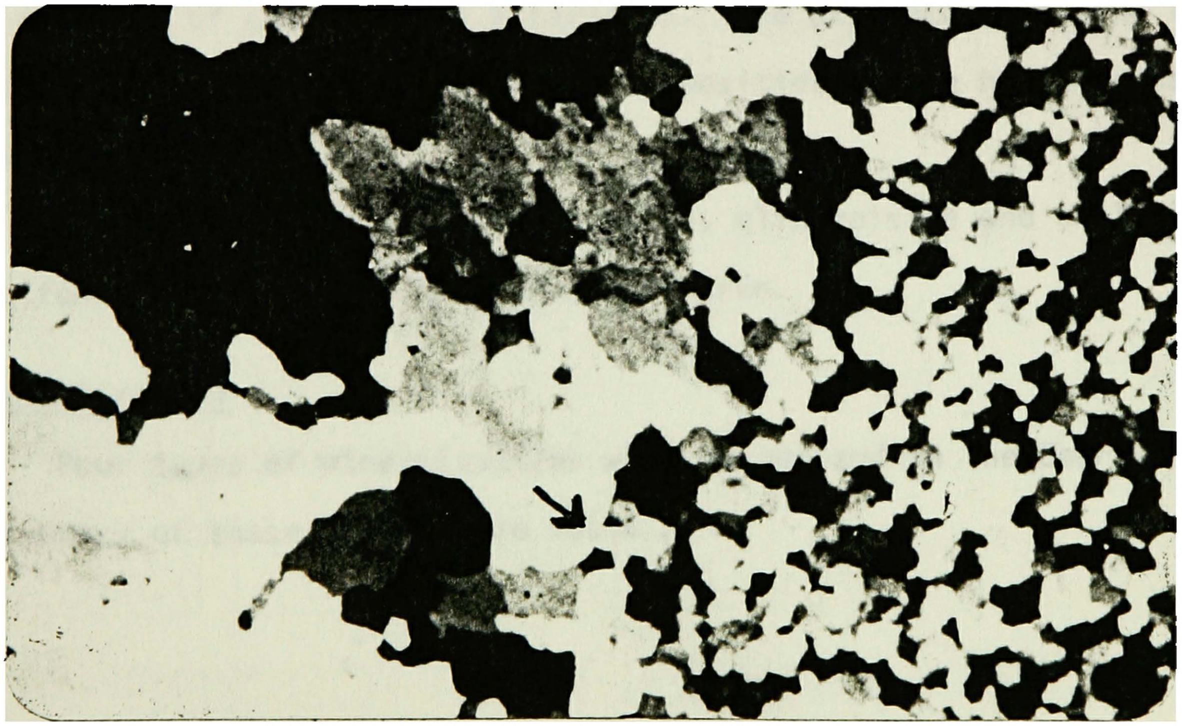


Fig. . "Massive or Bull Quartz" formed at the expense of the country rock, 2318. (X2.5).

to be more important silver-bearing minerals than tetrahedrite due to the lack of abundant tetrahedrite. (I tried unsuccessfully to find tetrahedrite crystals for analysis.)

Quartz is found in veins often as open space filling material associated with sulfides and carbonates. Sulfide-free stages of quartz formation also are present. Massive, crystalline aggregates, referred to as "Bull quartz" (Anderson, 1940) in the matrix of the country rock was noticed and could be a result of the silicification of the country rock (Adams, 1920) (Fig. 10). Most quartz-sulfide veins are parallel to each other (Fig. 15).

Calcite-like quartz is a common gangue mineral throughout the district. It was deposited in open space fractures and in the country rock, as a result of hydrothermal alteration. The presence of zoning in calcite indicates the changing of chemical composition of the hydrothermal fluids (Fig. 11).

Quartz, calcite, chlorite, epidote, clinozoisite and chalcedony are found filling voids throughout the area.

Mineralization

Four types of mineralization were recognized in the Emery district. A summary of these is given in Table 2.

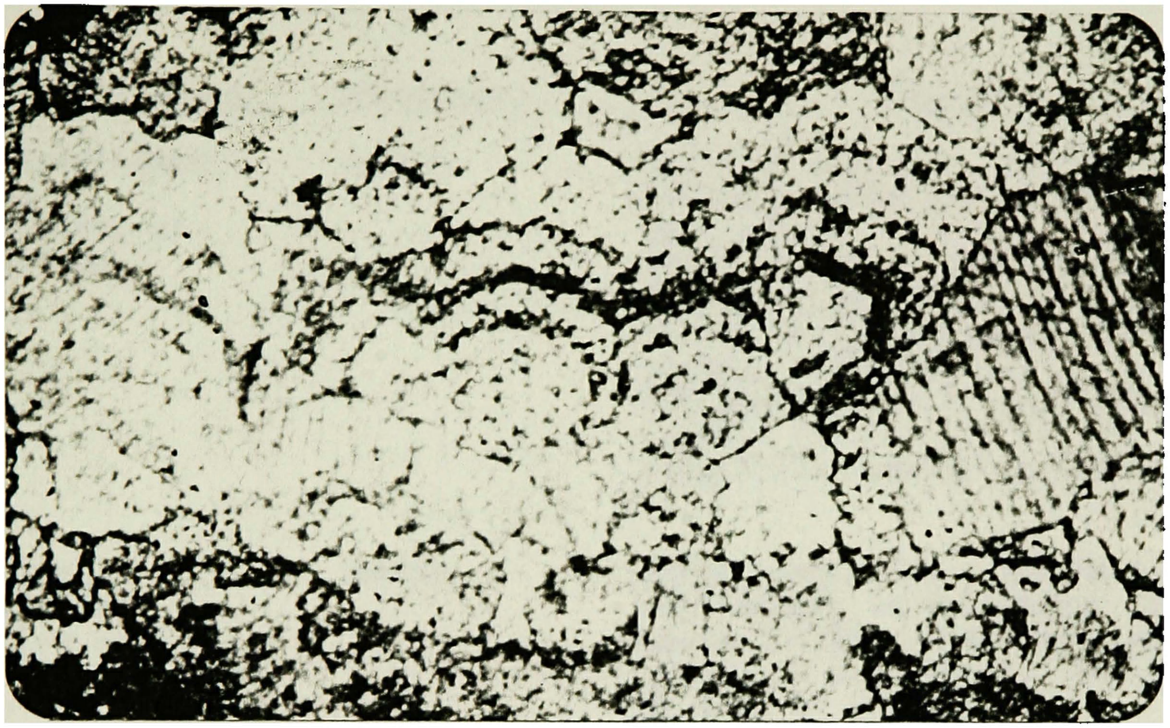


Fig. 11. Zoning in calcite, 929, (X16).

An unsuccessful attempt was undertaken to find the genetic relationship between the different veins. However, from the mineralogical and paragenetic studies, it is clear that some of these veins have been subjected to more than one generation of movement during material deposition (fracturing, deposition and then re-fracturing) (see Fig. 33).

Table 2.

Type of Mineralization	Abundance	Remarks
Disseminated and veinlets of sulfides	common	Sulfides are pyrr, py, sp, gn±, cp. sulfides replacing material of the host rocks. Mineralization controlled by small fractures as well as by the distribution of mafic minerals of the country rock. Two generations of some sulfides (pyrr) Parallelism and discontinuity of veins
Quartz-sulfide veins and filled voids	common	Veins range from a few mm to a few centimeters in thickness; of open space filling. Sulfides replacing quartz in some veins. The opposite is true in others. Parallel veins controlled by close space fractures.
Quartz-calcite veins. No sulfides	less common	Result of open space filling, replacement of quartz by calcite is often the case. Veins sometimes reach widths of 14 cm. This stage could represent the final (barren) stage of deposition.
Calcite-quartz-sulfide veins and filled voids	less common	Formed partly by open space filling (veins can reach 04 cm wide) and partly by replacement of each other (normal sequence of deposition).

Some veins (particularly quartz-sulfide) exhibit irregularities in width. This could be due to the relative movement of one wall past the other in the district without any noticeable displacement (Bateman and Jensen, 1981) or due to cutting of the sample.

Taber (1920), has considered in detail the mechanism of the various processes by which veins may be formed. Hulin (1929), summarized the result of Taber as vein growth by replacement of the adjacent country rock, as deposition in open fractures, and as deposition in openings produced by the force of crystallization of the growing vein minerals. Also, Hulin postulated that veins might have formed by the repeated fillings of small openings produced by intermineralization fault movements.

More investigation is needed to determine how the veins formed in the district. However, I believe, after studying many samples that most of the veins formed by open space filling in the fractured country rocks. Then the veins reopened and deposition of additional material occurred (see Fig. 25 and 32).

Paragenesis of Sulfides and Gangue Minerals

Hundreds of papers have discussed the theories which may cause mineral depositional sequences in orebodies (Bandy, 1940; Craig and Vaughan, 1981; Barton and Skinner, 1979). However, the interpretation of paragenetic sequences in mineral deposits is generally not without problems. Craig and Vaughan (1981) described in some detail the basic concepts that help in the study of the paragenesis of ore minerals.

In the present study a number of thin and polished sections were studied under both transmitted and reflected light in order to identify and determine the paragenesis of sulfides and gangue minerals. The paragenetic results given below were interpreted from diagnostic replacement, open space filling, crosscutting relationships as well as from the crystal morphology and mutual grain boundary relationships.

I summarized the results of the study in table 3. Minerals are arranged from older to younger, the sample number for each core sample indicates the depth in feet within the core (see Fig. 4 for surface sample locations).

Partial replacement of the late-Cretaceous rocks of the district, by ore minerals, particularly, near veins, took place at many small centers. Such centers join together to form masses of high grade material near the vein. This relatively "high grade" core is flanked by a "low grade" disseminated zone (Fig. 12). The same situation was shown by Bateman and Jensen (1981). Another common mode of replacement that was noticed is termed "multiple center growth" (Bateman and Jensen, 1981) on foci of ferromagnesium minerals of the host rock. This is important in controlling the distribution of disseminated sulfides (pyrite and pyrrhotite) in the district. (Fig. 13).

Discussion

The mineralization in the Emery mining district is the product of replacement and open space filling. Many ores of this type show a complex paragenesis sequence in which multiple episodes of deposition and replacement are observed. Multiple episodes of mineral deposition are

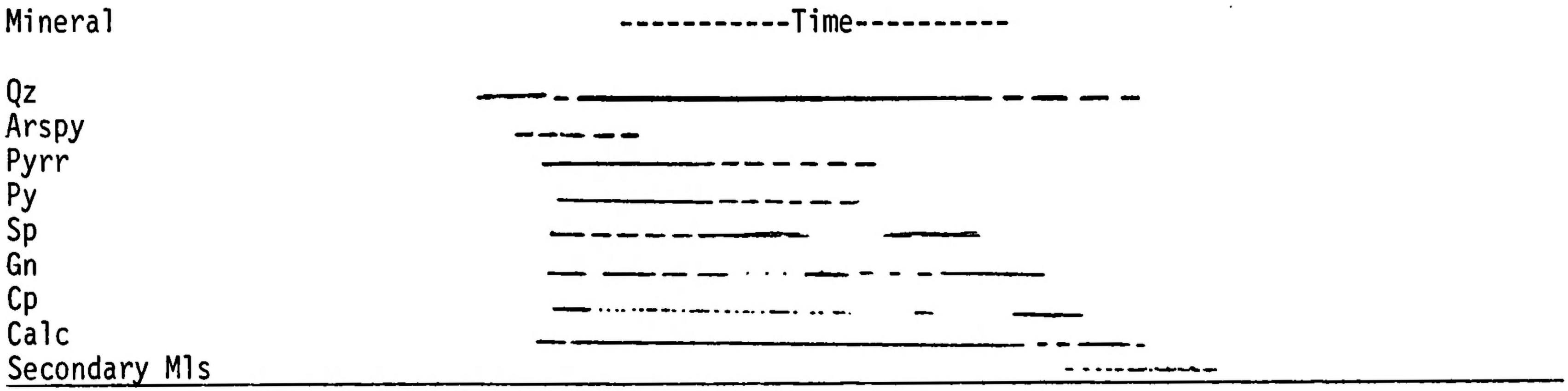
Table 3. Paragenesis of Mineralization

Paragenesis (Older-----Younger)	Sample No.(Transmitted light)
Sulfides---Qz--Calc.	526,558,585,615,618,929,1267,1781,2584 1051,1209 (except for sulfs.) K_7,K_{11},K_{12} (mostly py)
Py---Sp---Qz	618,2663
Qz---Sulf.	762,894,2318,2361,2381,2367
Py/Pyrr---Gn---cp	929
Qz---calc.	986,2518,2626
Qz---Py/Prr---sp---gn---Qz--calc	1011,2408,2516
Pyrr---cp--calc	1236
Pyrr--sp---cp---gn---cp	1267
Pyrr---sp---cp(?)---calc	1888,2190,2381,2410,2881,2367,2276
Chlorite--Chalcedony---carb.---chlor---epidote	K_4

Table 4. Paragenesis of Mineralization

Paragenesis (Older----Younger)	Sample No. (Ore Microscops)
Qz---Arspy/Pyrr---sp---gn---cp---(Qt+CP)---Cal	2276,2382,slab from Emery dump, K-18a, K-18c
Py/sp---cp---gn---Qz	1011, K-18F
Py---Qz---calc	K-18a, K-18b
Py---sp	K-18b, K-18c

SUMMARY OF TABLES



Qz = quartz, Arspy = Arsenopyrite, pyrr. = pyrrhotite, py = pyrite, sp = sphalerite,
Gn = galena, cp = chalcopyrite, calc = calcite

indicated from the presence of two parallel quartz-bearing veins (Fig. 14) which show deposition of sulfides in veins with quartz and as an individual block. Parallel quartz-sulfide veins may be explained by replacement controlled by closely spaced parallel fractures in the country rock, which were affected by a relative (?) movement of opposite walls of curved fissures (Fig. 15).

As summarized in Tables 3 and 4 quartz was deposited first through the district filling open fractures, voids and showing subsequent replacement by sulfides (Figs. 16, 17). This phase may have continued throughout the period of mineralization as indicated by the cross-cutting relationships of veins, and replacement of sulfide by younger quartz (Figs. 18, 19).

Euhedral arsenopyrite crystals were found in a matrix of quartz. However, whether arsenopyrite is earlier or the same age as the quartz is not known (Fig. 20). Arsenopyrite crystals were found by Joyce (1951) cutting pyrite crystals (Joyce, J.P., 1951).

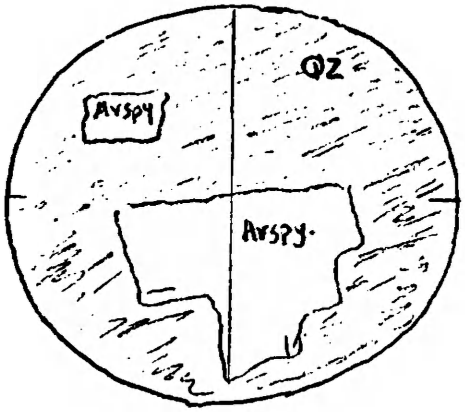


Fig. 20. Euhedral crystals of early formed arsenopyrite (arspy) embedded in a matrix of quartz, Emery mine, (X4).

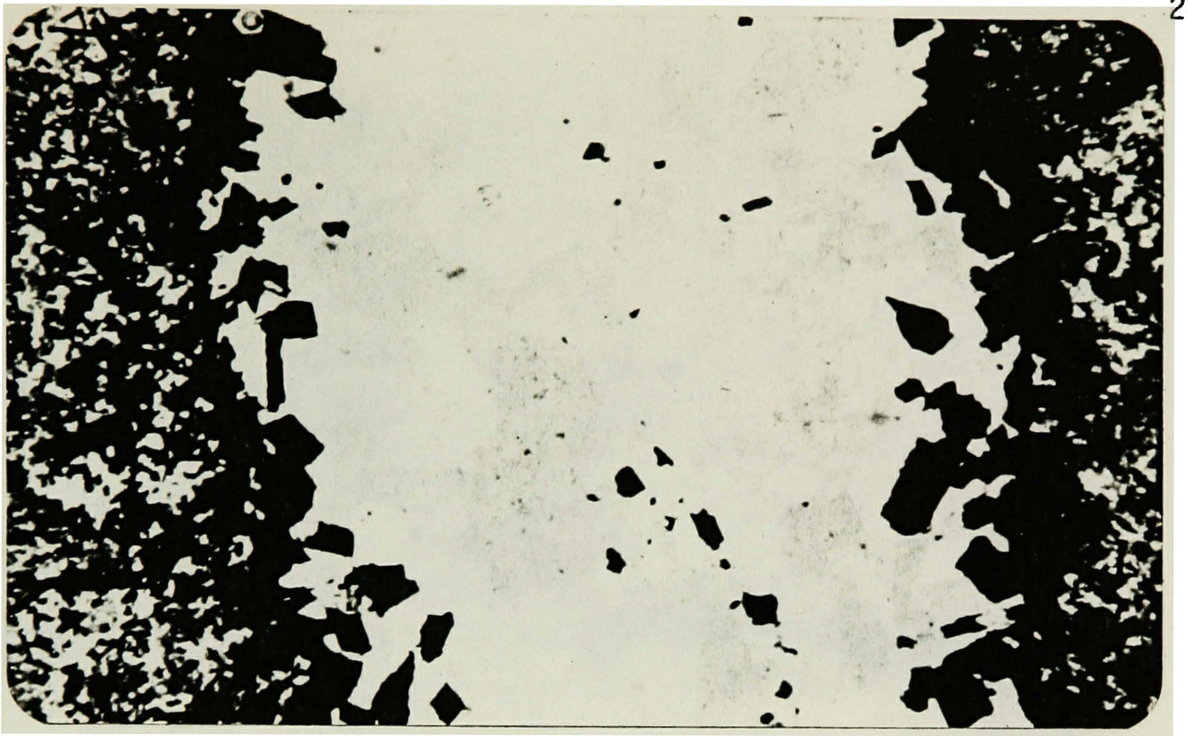


Fig. 12. Concentration of pyrite along both sides of the vein, K18, (X2.5).

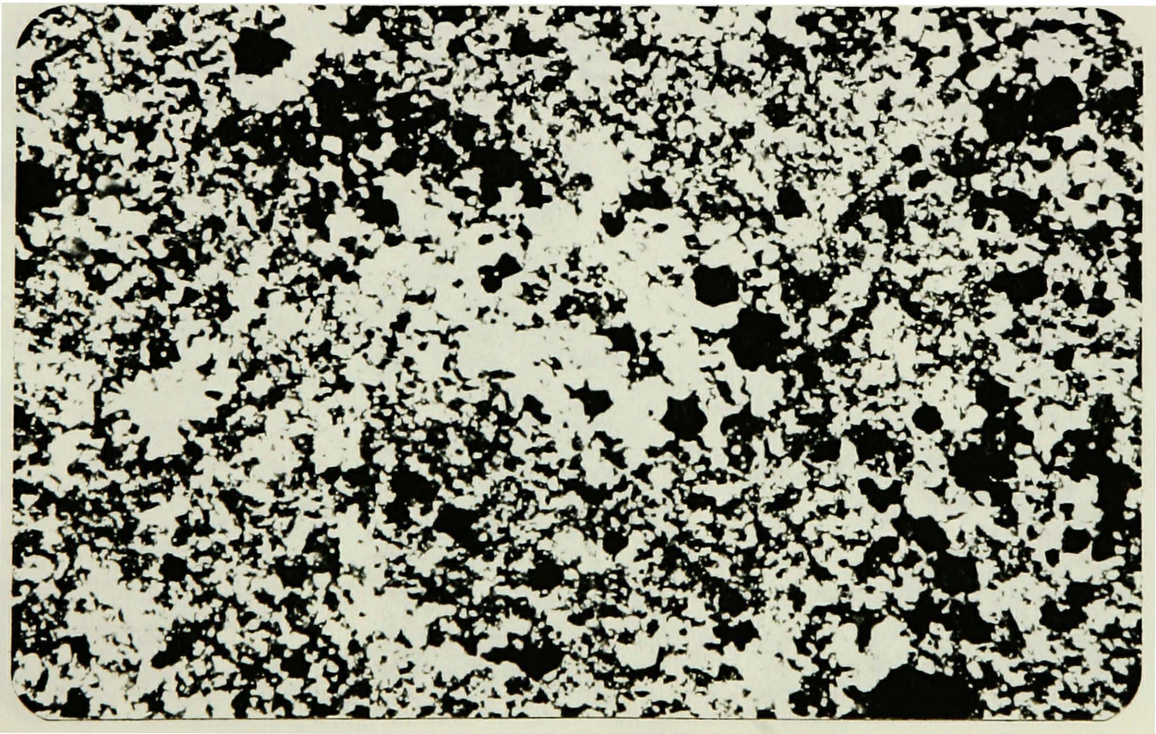


Fig. 13. "Multiple centre growth" due to partial replacement of mafic minerals by pyrite, K18, (X2.5).

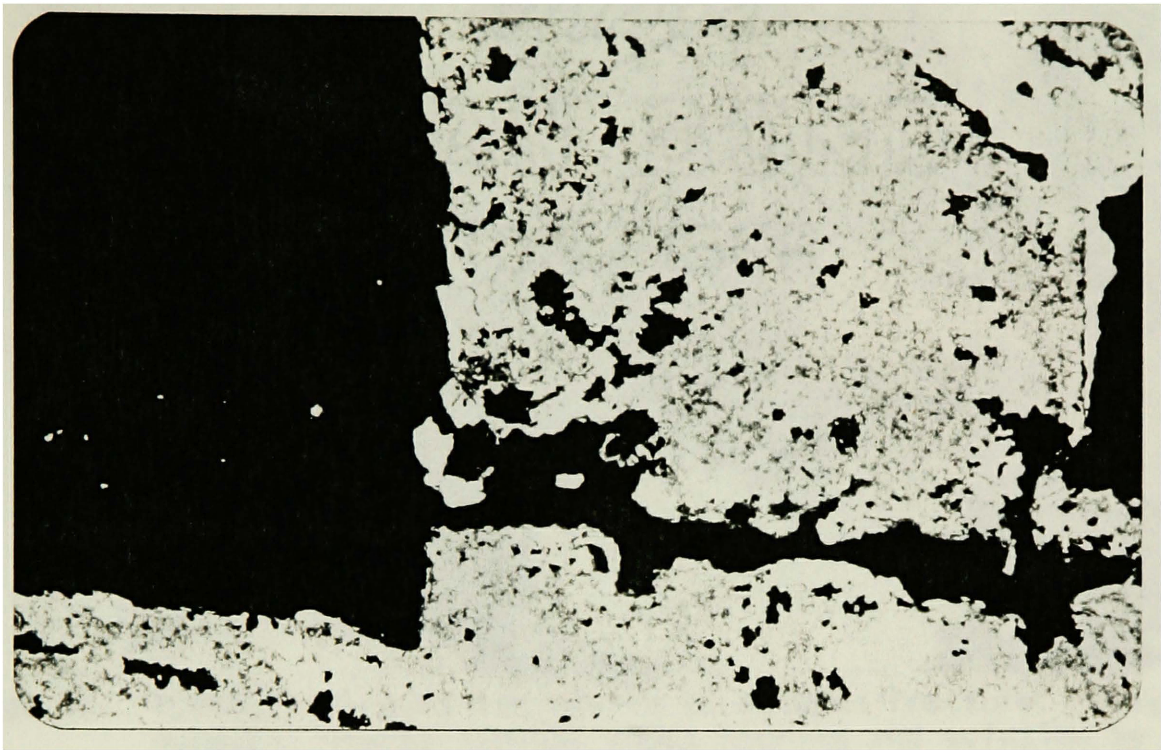


Fig. 14. Multiple episode of sulfide deposition, 2361, (X2.5).

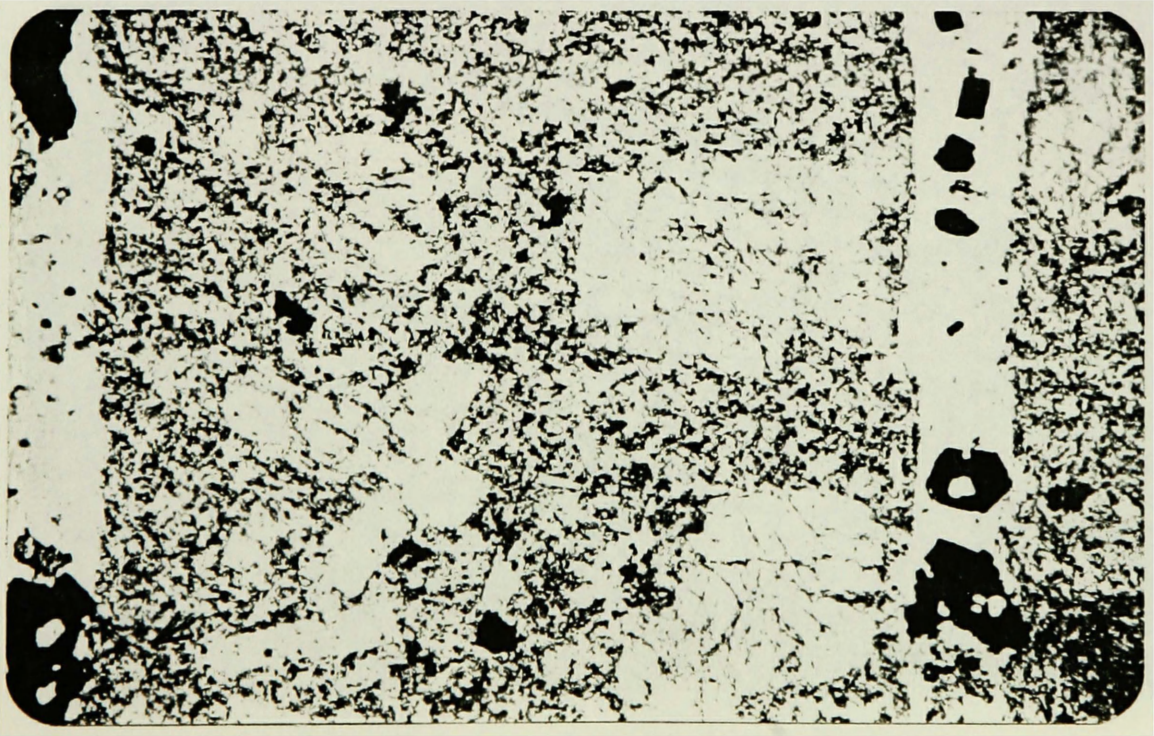


Fig. 15. Parallel fractures subjected to a relative movement of opposite walls of curved fissures, 645, (X2.5).

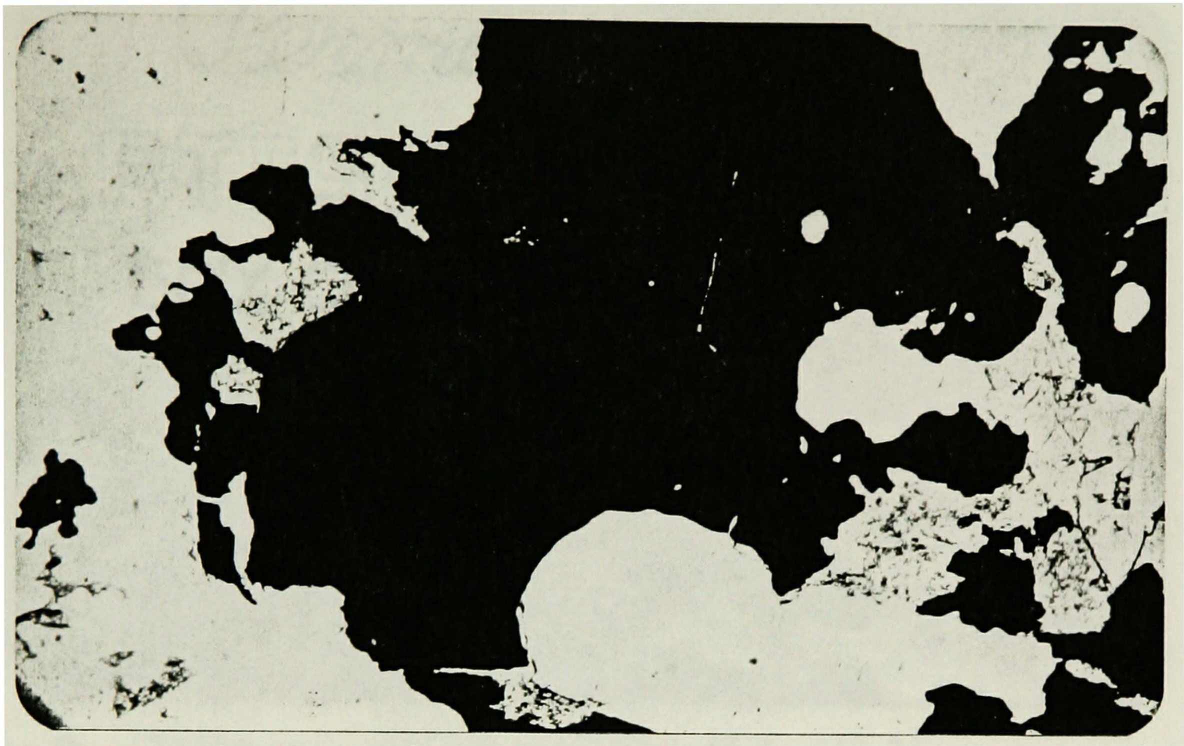


Fig. 16. Pyrrhotite replacing quartz in an open fracture. Original euhedral quartz crystal shows etching and solution by younger pyrrhotite, 762, (X2.5).

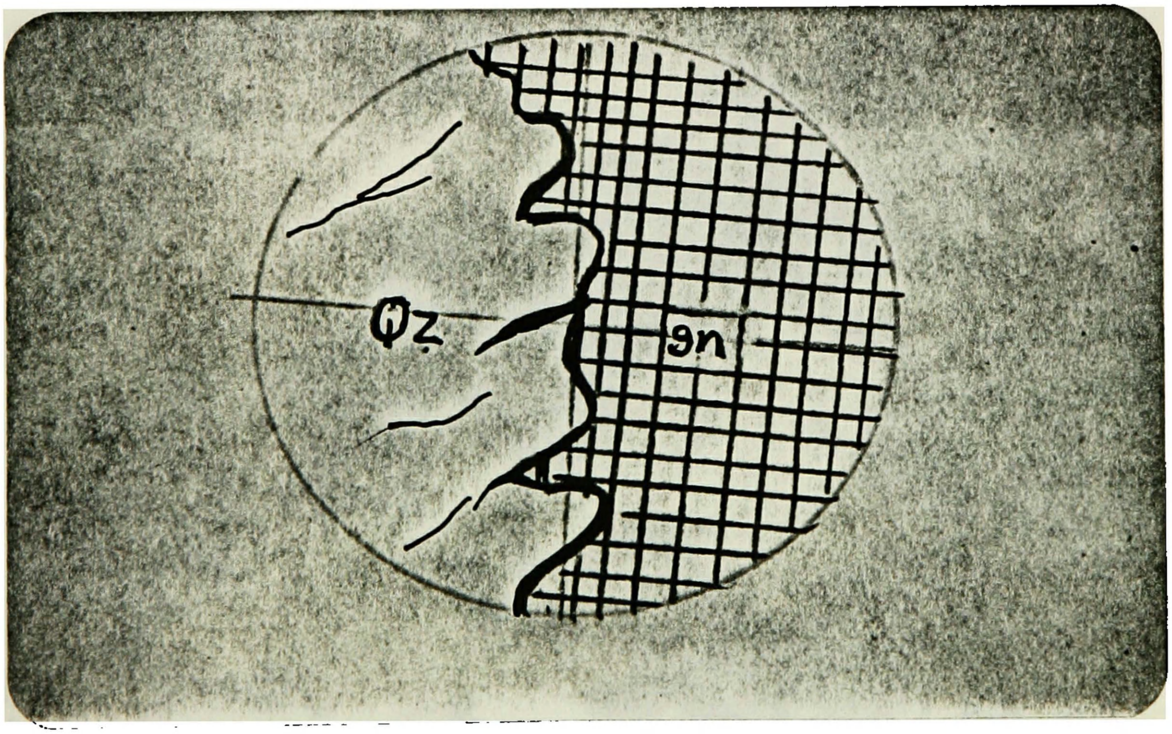


Fig. 17. Sketch of polished section showing replacement of quartz (qz) by galena (gn) along grain boundaries. Note the eroded quartz grains, Emery mine, (X4).

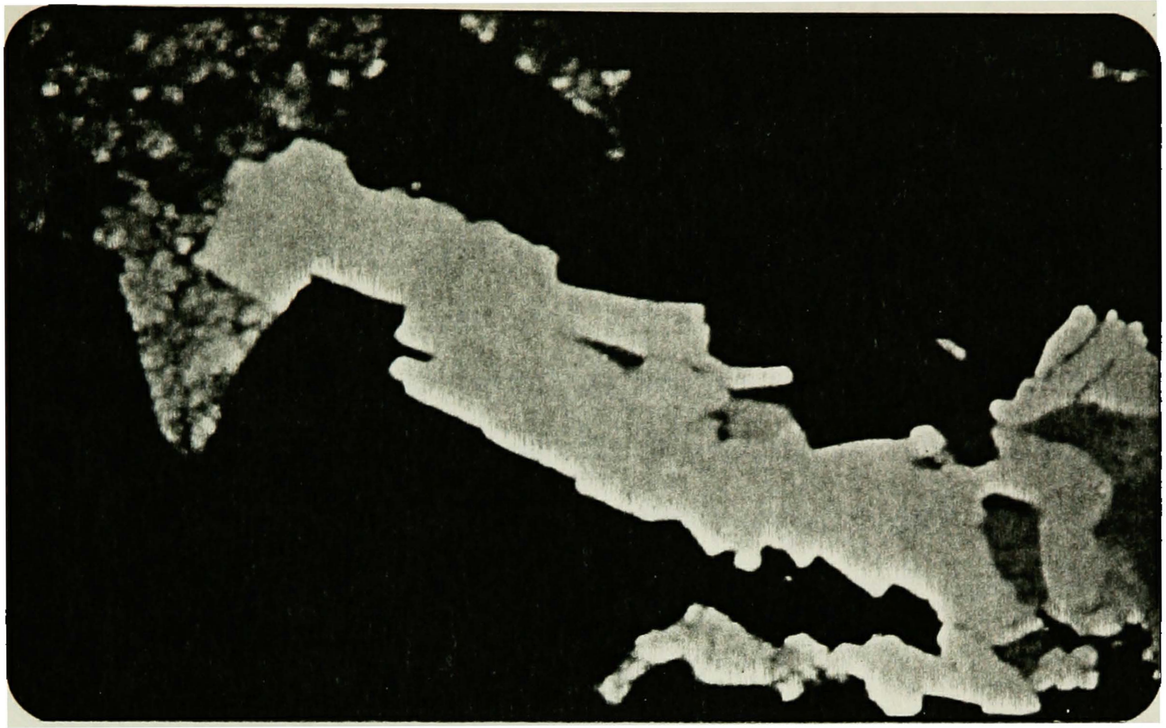


Fig. 18. Quartz vein cutting sulfides, 1011, (X2.5).

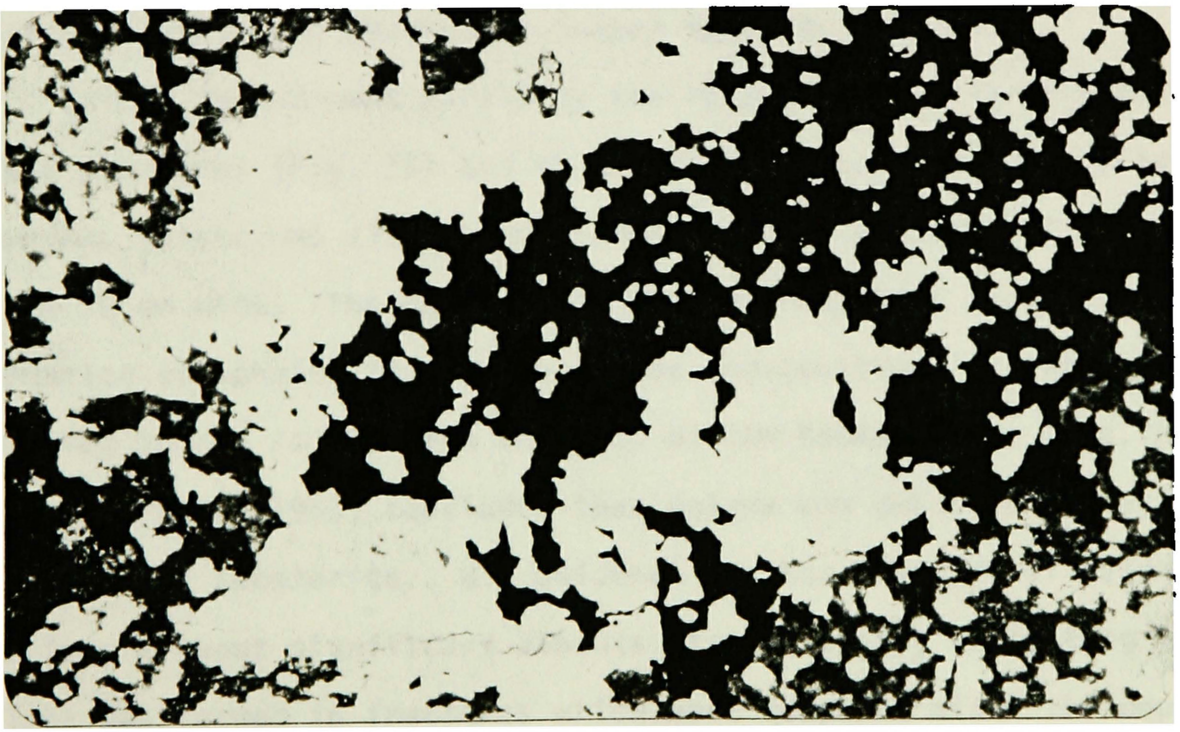


Fig. 19. Quartz replacing sulfide in open spaces, 2318, (2.5).

Pyrrhotite and/or pyrite were the next minerals formed. Surface and underground samples showed replacement of quartz by pyrrhotite (see Fig. 16). No clear paragenetic relationship between pyrrhotite and pyrite was observed. Two generations of pyrrhotite are indicated by distribution of big blocks of pyrrhotite which are connected by small veinlets of quartz and pyrrhotite of the second generation (Fig. 14). Euhedral crystals of pyrrhotite and pyrite are present and apparently formed early (Fig. 21). Both minerals also replaced pyroxene crystals completely.

Sphalerite was deposited next, as massive aggregates in open fractures and in pre-existing minerals such as pyrrhotite and quartz (Fig. 22). However, in many samples sphalerite is found in mutually interpenetrating pyrrhotite masses (Figs. 23, 24) which may indicate that sphalerite and pyrrhotite formed together.

Galena formed next partly by the replacement of early sulfides, along fractures (Fig. 25) and as crystals in open fractures (Fig. 26). However, galena was also found in more massive concentrations ranging up to 10 cm wide. The deposition of galena may have occurred during the formation of sphalerite because of the codepositional relationship observed in one sample from the dump of the Bonanza Mine (Fig. 27).

Robertson (1953) concluded that galena was deposited after the formation of sphalerite. His evidence was the presence of galena fissure fillings without significant amounts of sphalerite, suggesting that the galena was formed in fractures which were reopened after the deposition

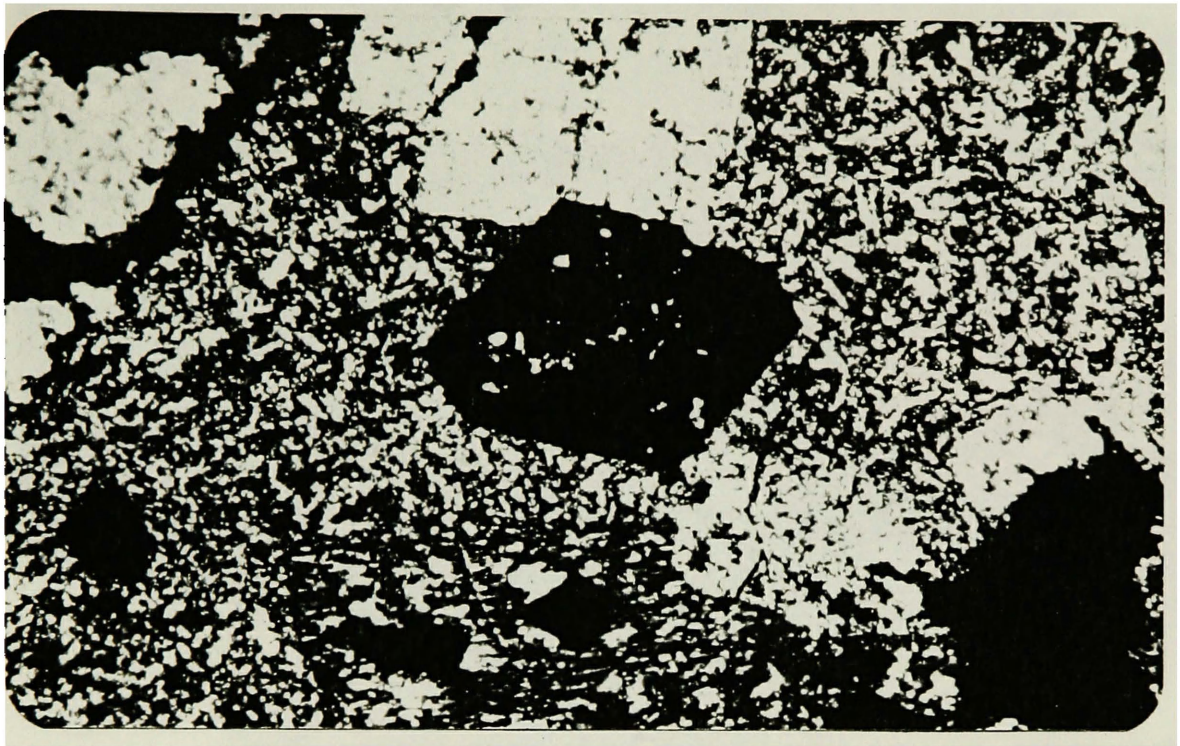


Fig. 21. Cubes of early formed pyrite, K7, (X2.5).

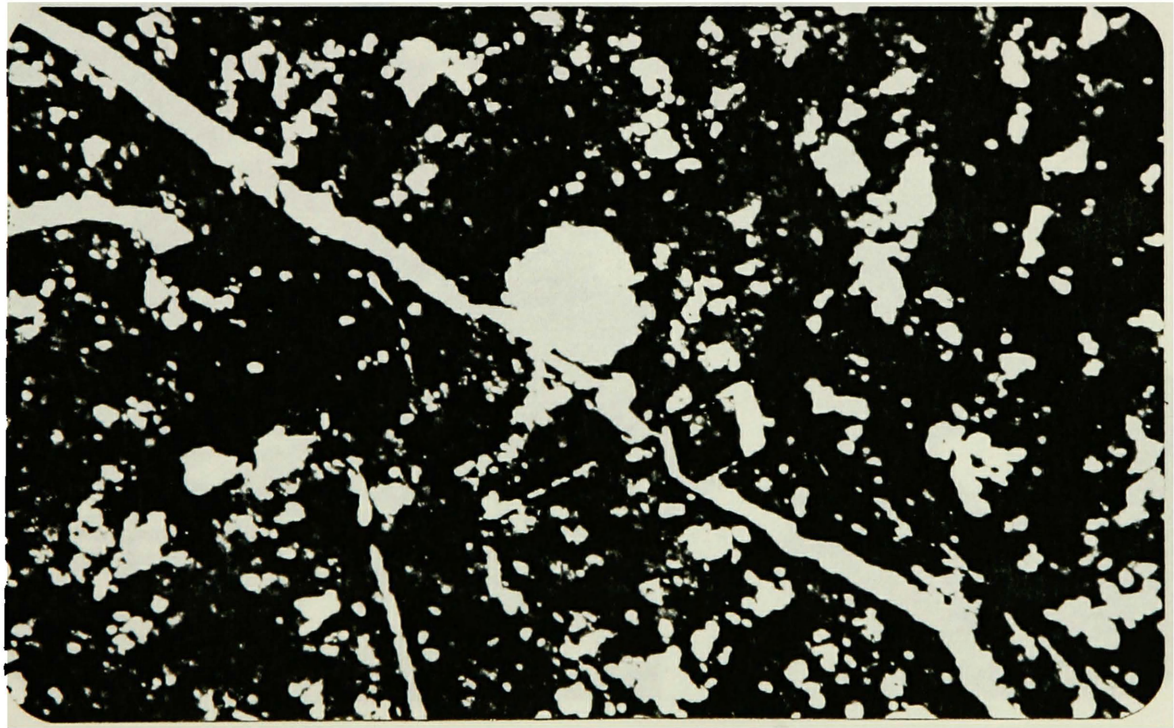


Fig. 22. Incomplete replacement of pyrrhotite by sphalerite. Both cut by a carbonate vein, 2381, (X2.5).

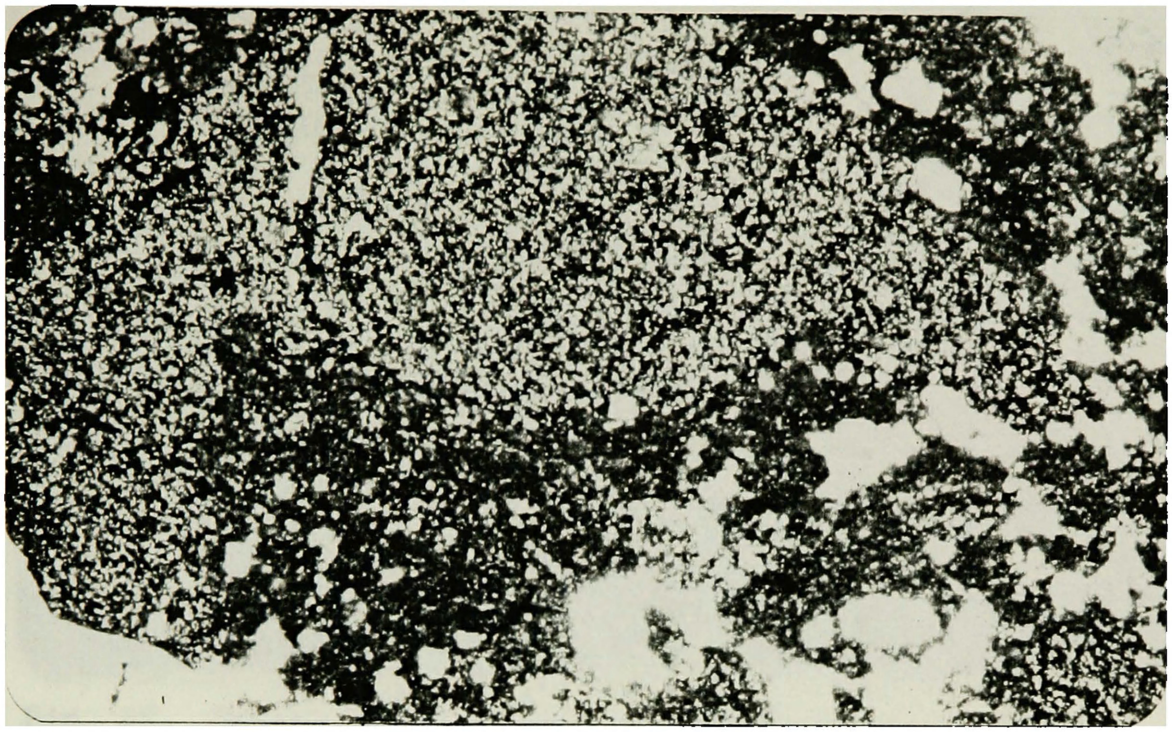


Fig. 23. Mutually interpenetrating grains of pyrrhotite (pale brown) and sphalerite (red-brown). Photo taken under reflected light, K18, (X2.5).

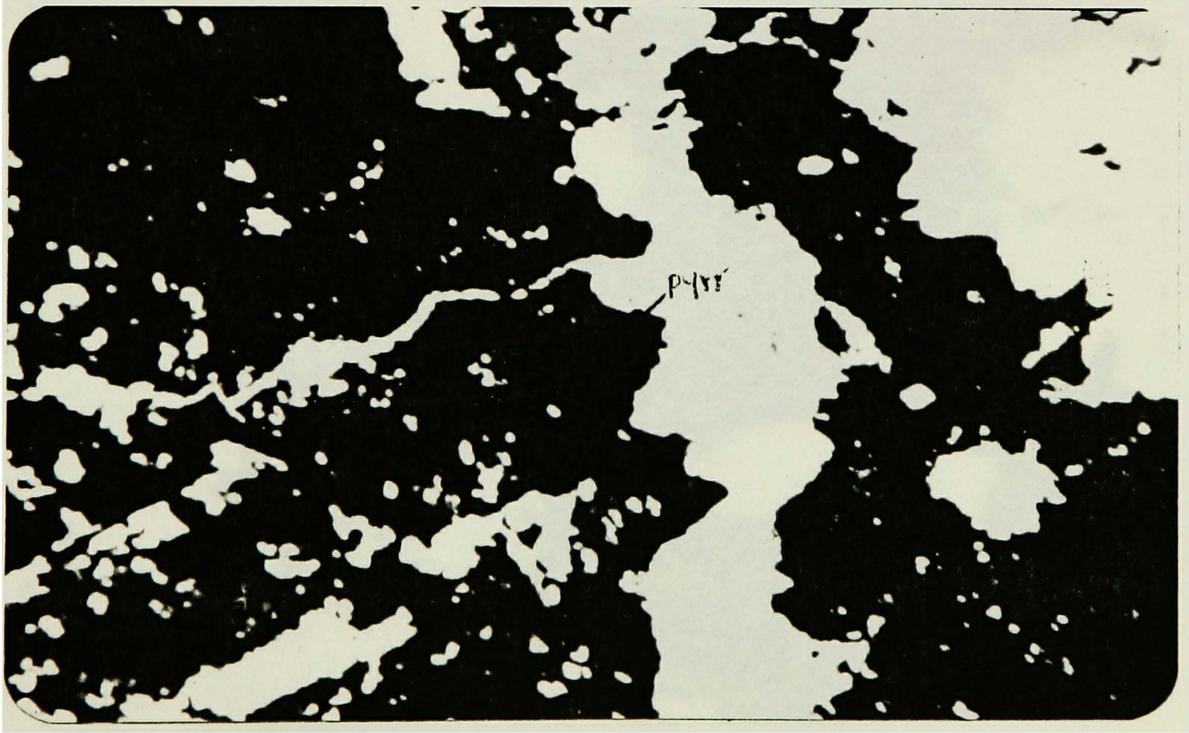


Fig. 24. Same as above, sphalerite (lower) and pyrrhotite (upper) on the left side of the photo. Both are cut by a carbonate vein, 2381, (X2.5).

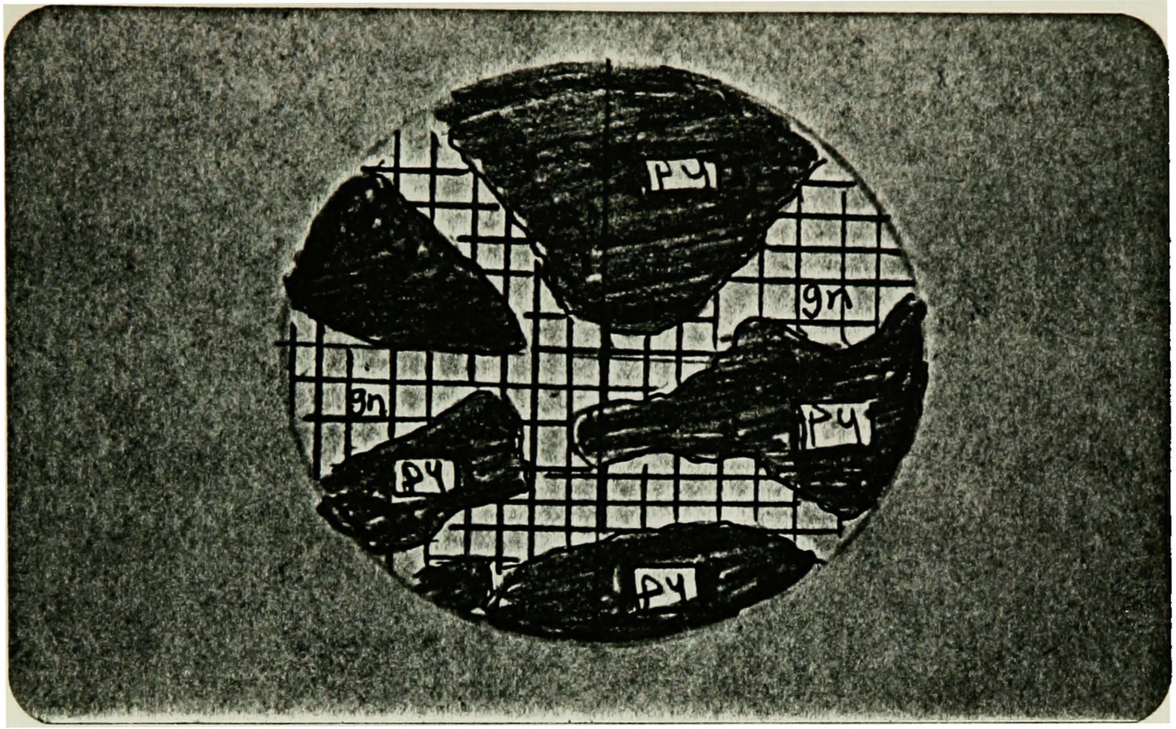


Fig. 25. Galena (gn) has been introduced into a fractured matrix of pyrite (py), and replaced the pyrite. Hidden Hand Mine, (X4).

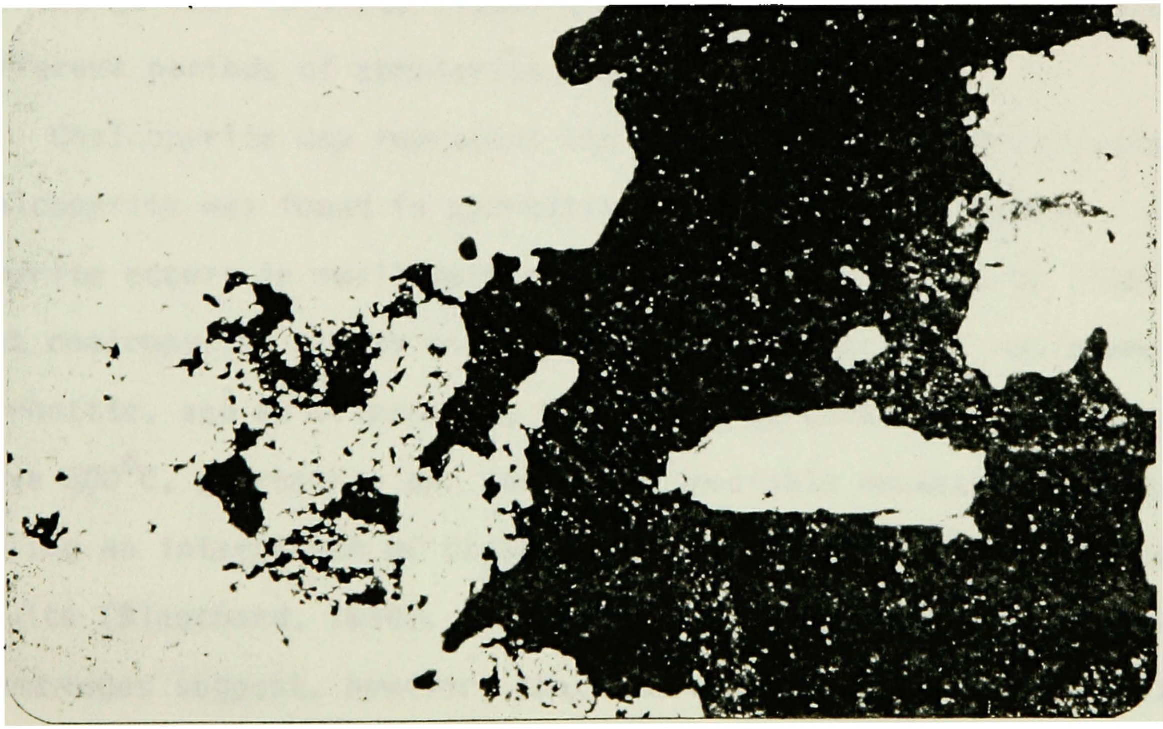


Fig. 26. Open space filling of pyrrhotite (pale brown), sphalerite (red-brown), and galena (silver-white), K18, (X2.5).

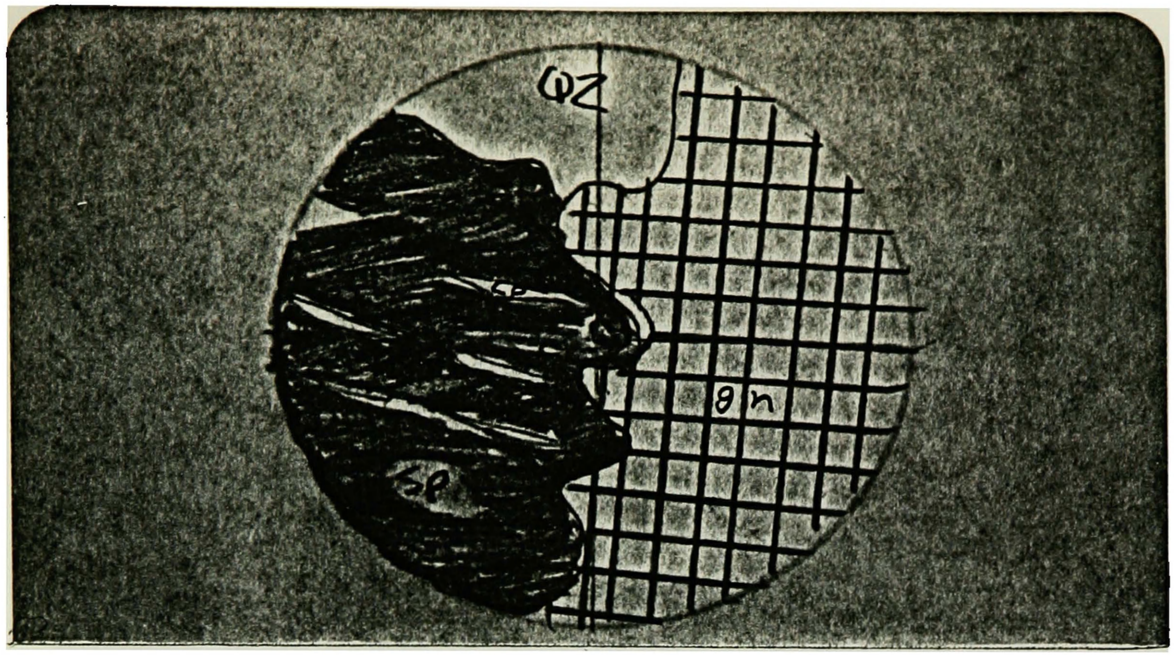


Fig. 27. Sketch showing codeposition of galena (gn) and sphalerite (sp), with a little replacement of sphalerite by the former, Bonanza Mine (X16).

of sphalerite. However, I did not see any fractured sphalerite containing galena. Elliott (1939) also was not able to distinguish the different periods of sphalerite and galena formation.

Chalcopyrite may represent the final stage of mineralization. Chalcopyrite was found in pyrrhotite, sphalerite, and galena. Chalcopyrite occurs in small veinlets in pyrrhotite. Schwartz (1959) stated that chalcopyrite occurs as veinlets in pyrrhotite; as replacements in pyrrhotite, and as alternating bands with pyrrhotite. At temperatures above 300°C, pyrrhotite can contain appreciable amounts of copper, upon cooling an intergrowth of chalcopyrite and chalcopyrrhotite in sphalerite results (Blanchard, 1938). The type of mineralization and alteration assemblages suggest, however, that the temperature of mineralization in the district did not exceed 300°C.

Very tiny blebs and veinlets of chalcopyrite also occur in sphalerite (Fig. 28).

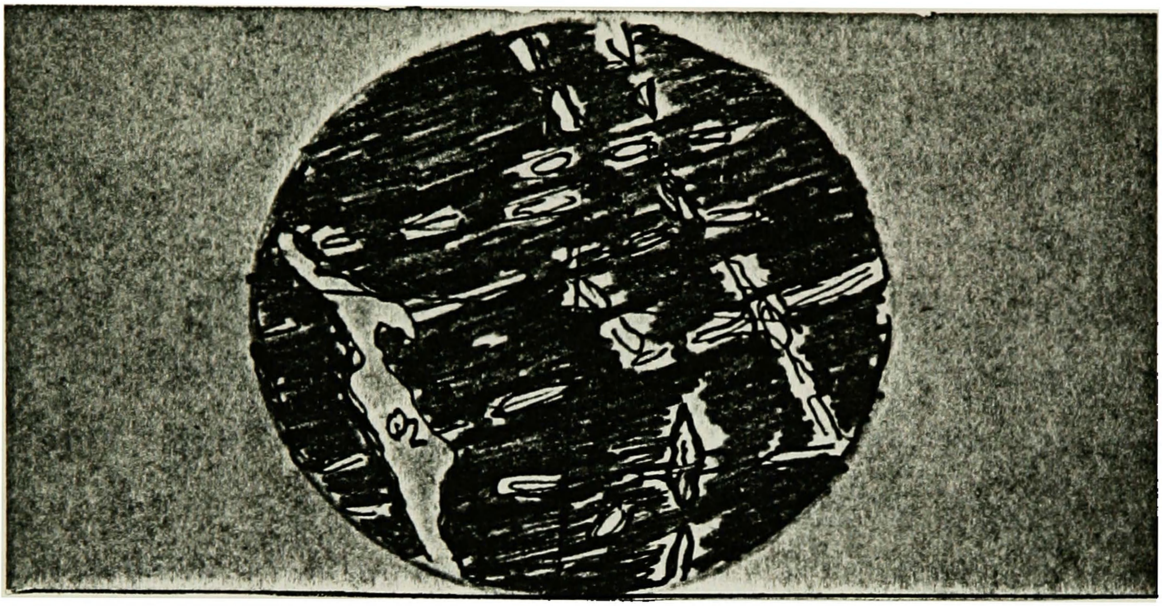


Fig. 28. Sketch showing oriented chalcopyrite veinlets in sphalerite as a result of replacement, Emery Mine, (X16). (See text for discussion)

These veinlets (less than 1 milimeter in thickness and reach up to few milimeters in length) in most cases, follow the crystallographic planes (cleavage) of the hosted mineral. The chalcopyrite in sphalerite has been interpreted by previous workers as the result of exsolution* at temperatures of less than 400°C (Buerger, 1934). However, experimental work by several authors (Craig and Vaughan, 1981) illustrate that copper will not dissolve in sphalerite unless the temperature of sphalerite

---

*Exsolution: The process whereby an initially homogeneous solid solution separates into two (or more) distinct crystalline phases without addition or removal of material to or from the system. It is generally, not necessary, occurs on cooling. (Gary, M. McAfee, R. and Wolf, C.L., (eds.), 1974).

formation is at least 500oC. The type of mineralization and alteration suggests that the temperature of mineralization is much lower than 500°C (perhaps 200-300°C maximum) (Dr. Ian Lange, pers. communication, 1982).

Study of this intergrowth texture showed that these small cleavage-controlled lamellae thicken at their intersections (Fig. 29). Barton, P.M. and Berhke, P. M. (pers. communication by Craig and Vaughan, 1979) concluded that "this intergrowth could form by 'epitaxial growth' during sphalerite formation or by replacement as copper-rich fluids reacted with the sphalerite after formation:. (In case of exsolution intergrowth of minerals depletion of veinlets at their intersection is the case. For more discussion see Craig and Vaughan, 1981, p. 123-138.)

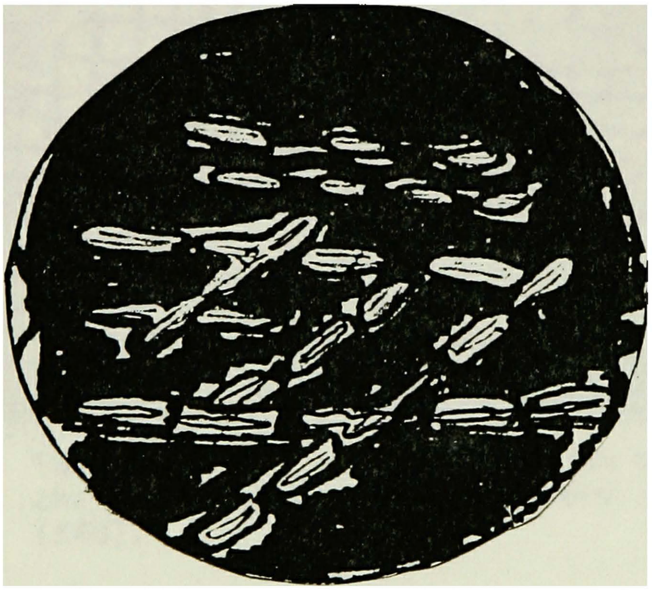


Fig. 29. Sketch showing oriented rods and blebs of chalcopyrite (cp) within and replacing spalerite (sp), 2382, (X16). (See text)

Therefore, the chalcopyrite may have formed either contemporaneously with the sphalerite or as a later replacement of the sphalerite along cleavage planes. Further study of the sphalerite-chalcopyrite intergrowth phenomena may yield the answer.

Chalcopyrite was found in galena (commonly) as unoriented blebs and stringers. This situation can be explained as a co-depositional process of the two minerals and/or by filling microfractures in galena. No obvious replacement textures were noticed between the two minerals (Fig. 30). In some cases chalcopyrite was found with quartz in larger fractures.

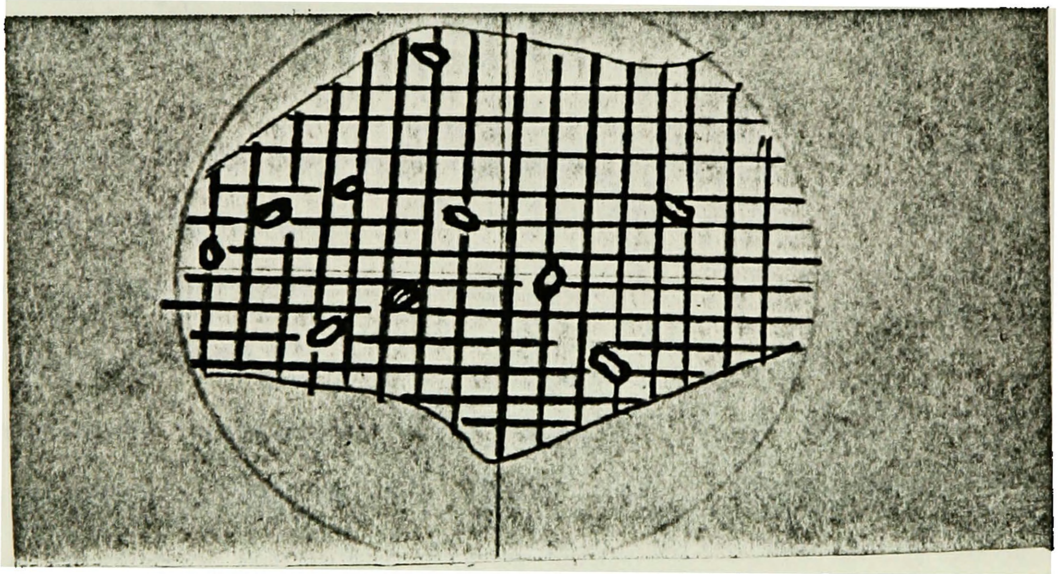


Fig. 30. Sketch showing unoriented blebs of chalcopyrite (cp) within galena (gn). 1011 (X40).

The introduction of chalcopyrite into galena could have happened after the deformation of the galena (Fig. 32).

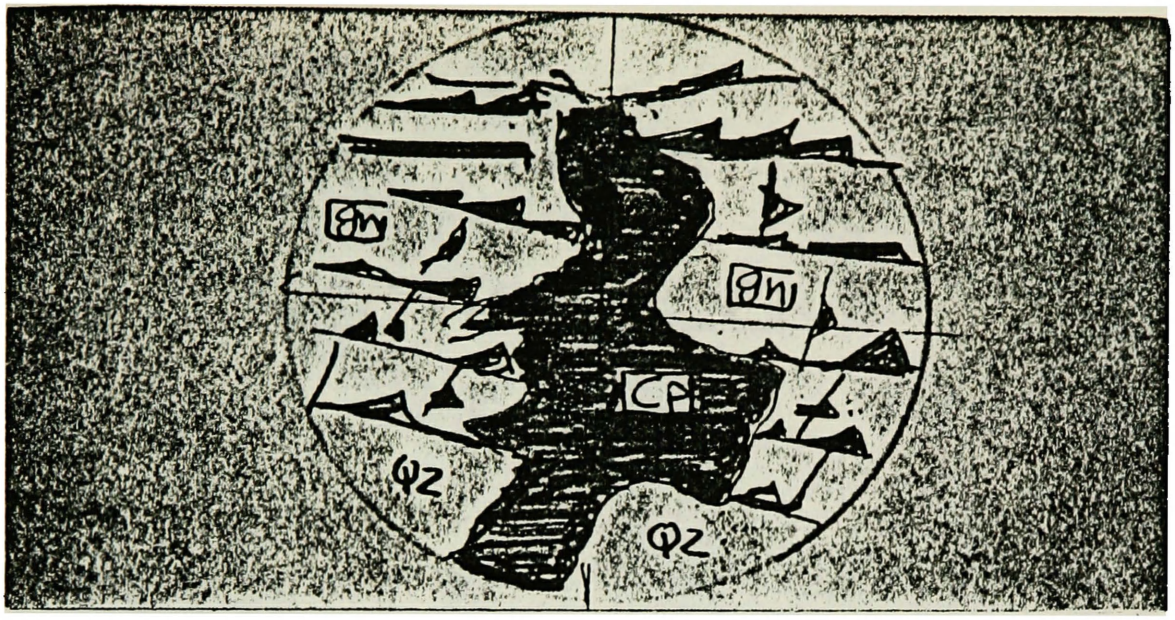


Fig. 31. Introduction of chalcopyrite (cp) into deformed cleavage galena, probably after the deformation process, Emery Mine (X4).

Tetrahedrite is an important economic mineral in the district (Elliott, 1939 and Robertson, 1953). However, it was not observed by the author. Elliott (1939) and Robertson (1953) conclude that tetrahedrite is younger than galena.

As previously mentioned quartz continued to be deposited throughout the entire mineralization period. Some samples showed two different grain sizes of quartz including coarse-grained quartz which in most cases shows replacement by sulfides (refer to Fig. 16). The other variety is a **fine-grained** quartz which usually but not necessarily replaces early sulfides (Fig. 19).

Microscopic study revealed that calcite deposition is the last in the main stage of mineralization. Calcite filled early formed fractures in the district (Fig. 32, also see Fig. 41).

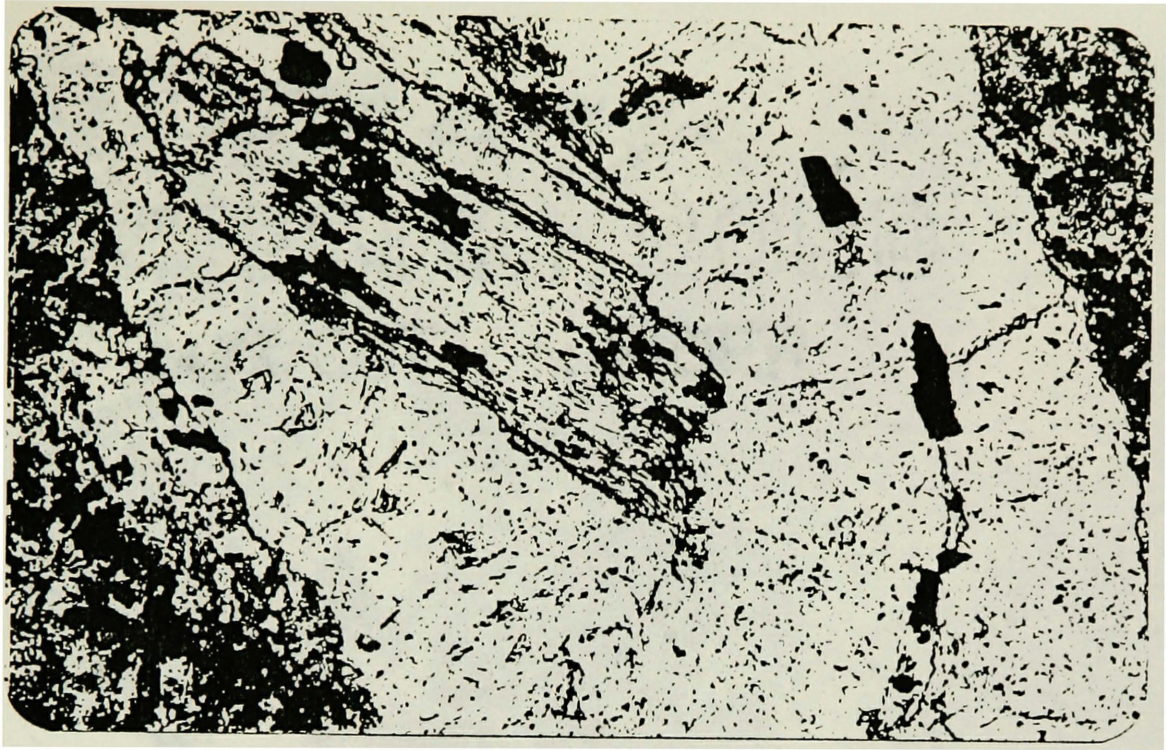


Fig. 32. Calcite filled a fractured rock, 469 (X2.5).

Calcite replaces most of the early formed minerals. Small calcite veins cut and replaced early sulfides and quartz leaving small blocks "islands" of unreplaced sulfide behind (Fig. 32).

Microscopic observations were done to see whether the carbonate veinlets in sulfides replaced the sulfides or filled fractures in the sulfides. Craig and Vaughan (1981) discussed the two possibilities and concluded that in case of replacement irregular vein sides are produced that do not match both sides. In case of infilling, the walls match (Fig. 34).

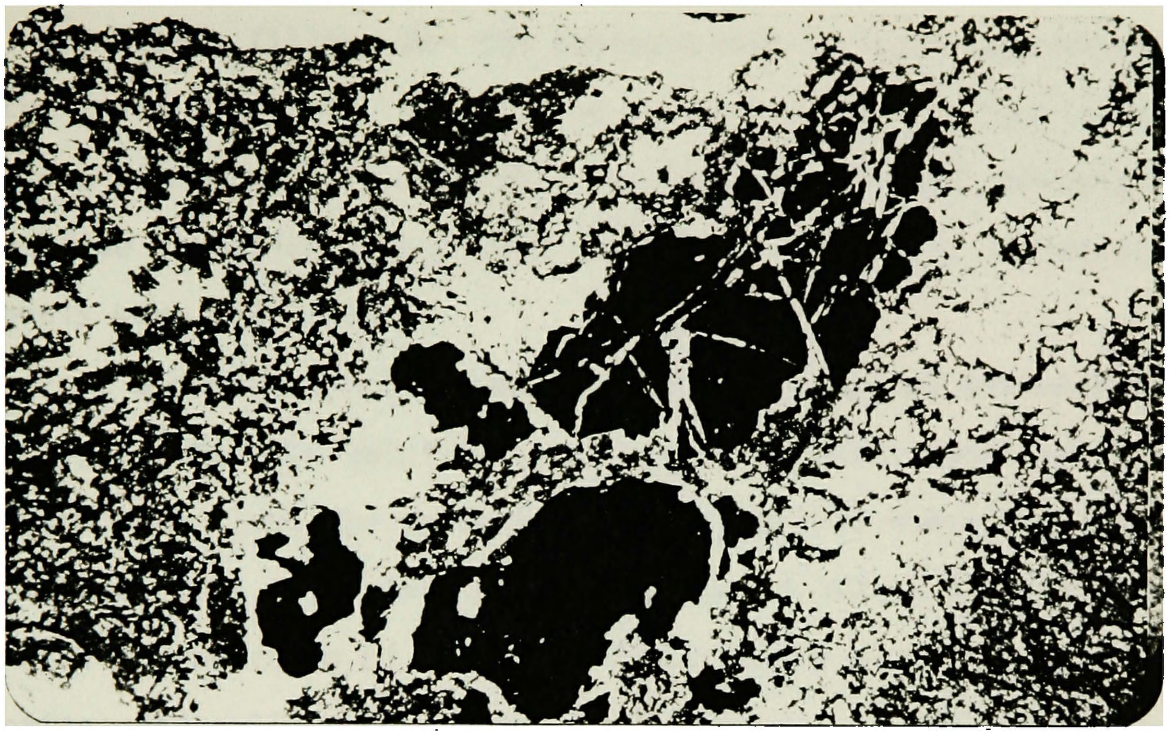


Fig. 33. Calcite veins replacing sulfides. Islands of unreplaced sulfides left behind, 585, (X2.5).

Fig. 34. Branched calcite vein cutting and replacing sulfides, 2276, (X2.5).

Open space filling was the dominant mode of vein type mineralization in the Emery district. Replacement of the original sulfide phases, however, did occur (Fig. 35, 36). Replacement was the dominant mode of sulfide formation in the wall rock where especially ferromagnesium minerals were replaced.

Post mineralization movement is indicated by the presence of cross-faulting of the main vein and the presence of small veinlets of sericite and carbonate along the vein-country rock contact where they cut the sulfides as well as by the curved cleavage of galena as mentioned earlier.

The introduction of the rest of the gangue minerals such as chalcedony, chlorite, and epidote were found filling voids and replacing the mafic minerals of the country, and they are younger than calcite.

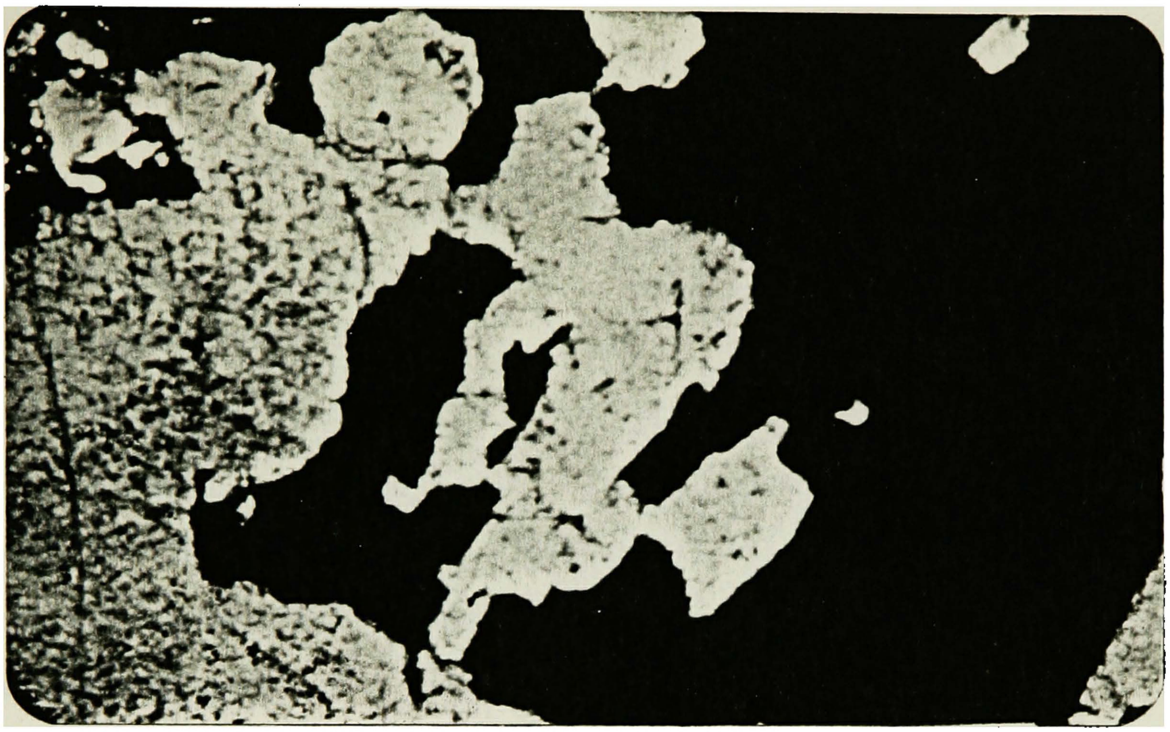


Fig. 35. Calcite-vein replacing pyrrhotite, 1145, (X2.5).

Fig. 36. Galena (gn) being replaced by calcite (cal) along fractures, 2381, (X8).

CHAPTER IV

ANALYTICAL METHODS AND RESULT OF ANALYSIS

In the past, analyses of the country rock in the mine area were performed only for the major elements. In addition, analyses of minor elements were done on specific minerals, rather than the bulk of the country rock. These data were summarized by Elliott (1934) and Robertson (1955). Moreover, analyzed samples were restricted to material from surface or near surface exposures because there was no access for underground workings at that time.

In the present study analyses were run on surface and underground samples. Twenty samples were collected from dumps of different mines and available outcrops. The area sampled covered about 6 km^2 around the Emery shaft. Sample locations are shown on Fig. 4. In addition, 6 core samples from a vertical borehole (No. 1) were selected at different depths; 14 contain disseminated sulfide, two samples are of veins. The sample number indicates the depth in feet from the surface.

Each sample was cut into two havles, one half for microscopic work and the other one was prepared for atomic absorption spectrophotometer analyses (varian AA6). Equipment used for crushing and grinding the rock is described by Fletcher (1981). The procedure of decomposition and dissolution of the samples was given by Shapiro and Brannock (1962) and Fletcher (1981). The aim of these analyses was to study the geochemical trends of elements and their distribution.

Underground Samples

Seven elements were measured and include Pb, Zn, Cu, Sb, Co, Ag, and Au (Table 5). Several attempts carried out to show the geochemical relationship between the above elements, using a simple linear, statistical method. The results are summarized below.

Lead-silver (Fig. 37). The analyses show that as the lead content increases, silver increases. Correlation coefficient is 0.79). As mentioned earlier, Ellitt (1934) assayed a galena sample from the Emery mine for its silver, and it contained 59.4 ounces Ag/ton. The highest Ag content in this study (0.35 oz/ton) was found from a disseminated sulfide sample (depth = 2463 ft.). Sulfide-vein (2594 ft.) has 0.39 ounces Ag/ton.

Zinc-silver (Fig. 38). The Zn-Ag plot shows that as the Zn content increases, Ag increases (correlation coefficient 0.71). A sphalerite sample picked up from the Emery mine by Elliott (1934) had 9.9 ounces of Ag/ton (Robertson, 1953).

Copper-silver (Fig. 39). The plot of the Cu and Ag relationship shows that as the Cu content increases, Ag increases also. The correlation coefficient is 0.64.

Antimony-silver. The Sb-Ag plot did not show a good correlation.

Gold-metals. Gold concentrations do not correlate well with the other metals. Therefore it may be associated with arsenopyrite,

Table 5. Chemical Analysis of Selected Core Sampled from Borehole No. 1, Emery Mining District - values in ppm

Sample No. (Depth) in Ft.	Pb	Zn	Cu	Sb	Ag	Au	Co	ounces/ton Ag	ounces/ton Au	Remarks
430	683.28	128.94	4.68	1697.50	5.21	0.34	87.03	0.166	0.010	
620	817.41	224.45	76.81	1790.20	6.01	0.34	84.06	0.180	0.010	
819	1180.34	583.41	143.97	1635.70	13.22	0.34	90.00	0.396	0.010	
929	912.04	502.96	137.29	1728.40	6.01	0.32	69.21	0.180	0.010	
972	699.06	107.48	198.33	1759.30	6.01	0.37	107.83	0.180	0.011	
1051	722.73	146.39	33.75	1790.20	6.81	0.30	84.06	0.204	0.008	
1145.5	722.73	101.87	52.28	1882.90	6.81	0.39	87.03	0.204	0.011	
1318	912.09	214.44	35.93	1052.00	7.61	0.42	110.80	0.228	0.012	
1527	699.06	112.72	67.54	2006.50	7.61	0.43	107.83	0.228	0.012	
1888	738.51	124.32	29.39	1759.30	6.81	0.39	90.00	0.204	0.011	
2190	643.84	99.25	54.46	1790.20	6.81	0.40	110.80	0.204	0.011	
2382	1448.60	623.81	69.44	2191.90	8.42	0.45	134.57	0.246	0.013	vein
2462	1038.33	507.83	101.33	1882.90	10.82	0.37	90.00	0.326	0.011	
2594	2300.70	543.37	313.86	2408.20	12.42	0.43	134.57	0.372	0.012	vein
2663	864.75	224.22	90.43	1790.20	6.01	0.39	95.95	0.180	0.011	
2902	722.73	93.64	72.99	1604.80	6.01	0.41	104.86	0.204	0.012	

Precision of Analyses: Pb, ± 3.9%; Zn ± 5.6%; Cu ± 4%; Sb ± 7.7%; Ag ± 4.3%; Au ± 0.02*; Co ± 7.3%
Percent of the values
*Au of the amount

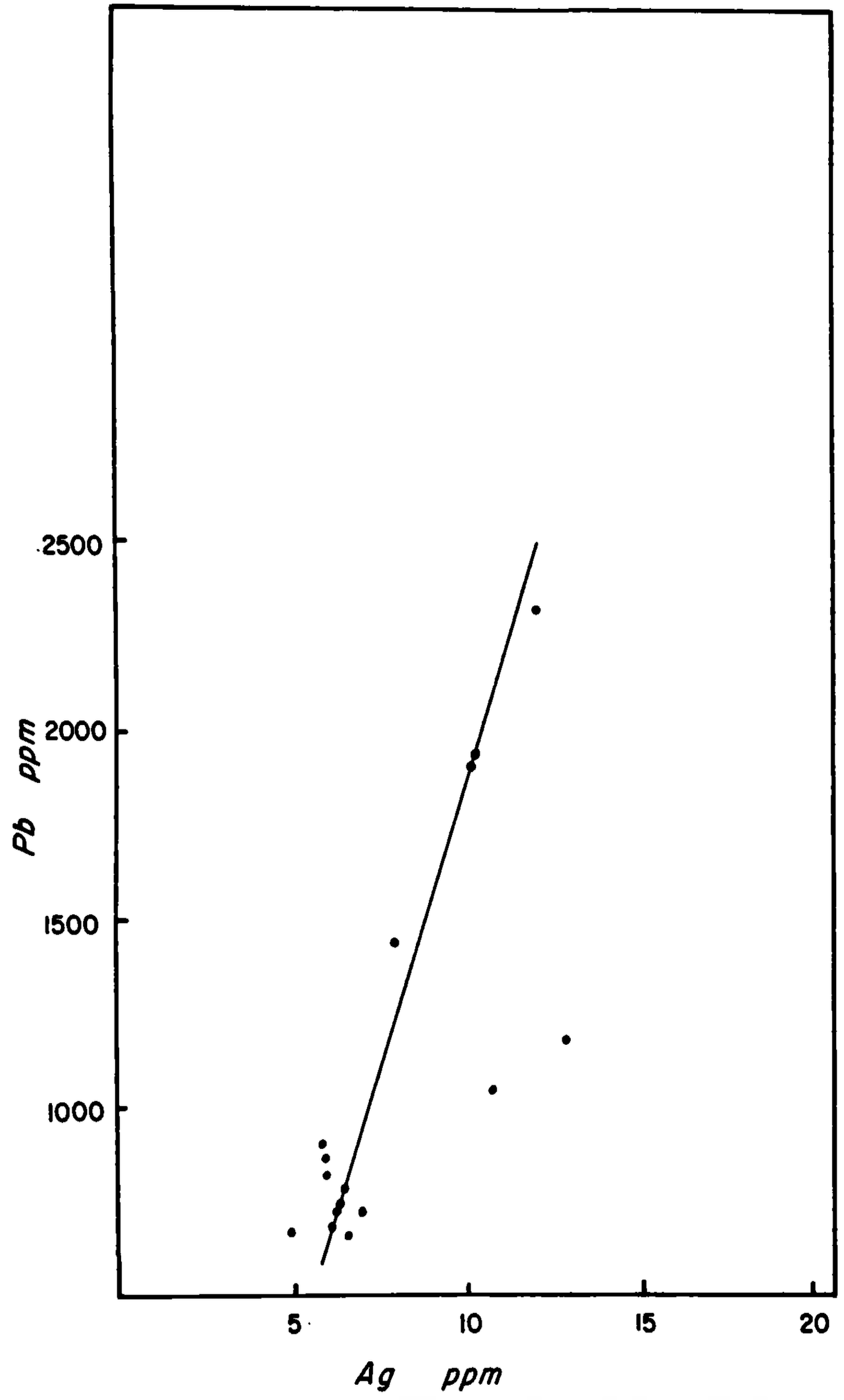


Fig. 37 Plot of lead versus silver of underground samples. Correction coefficent = 0.79

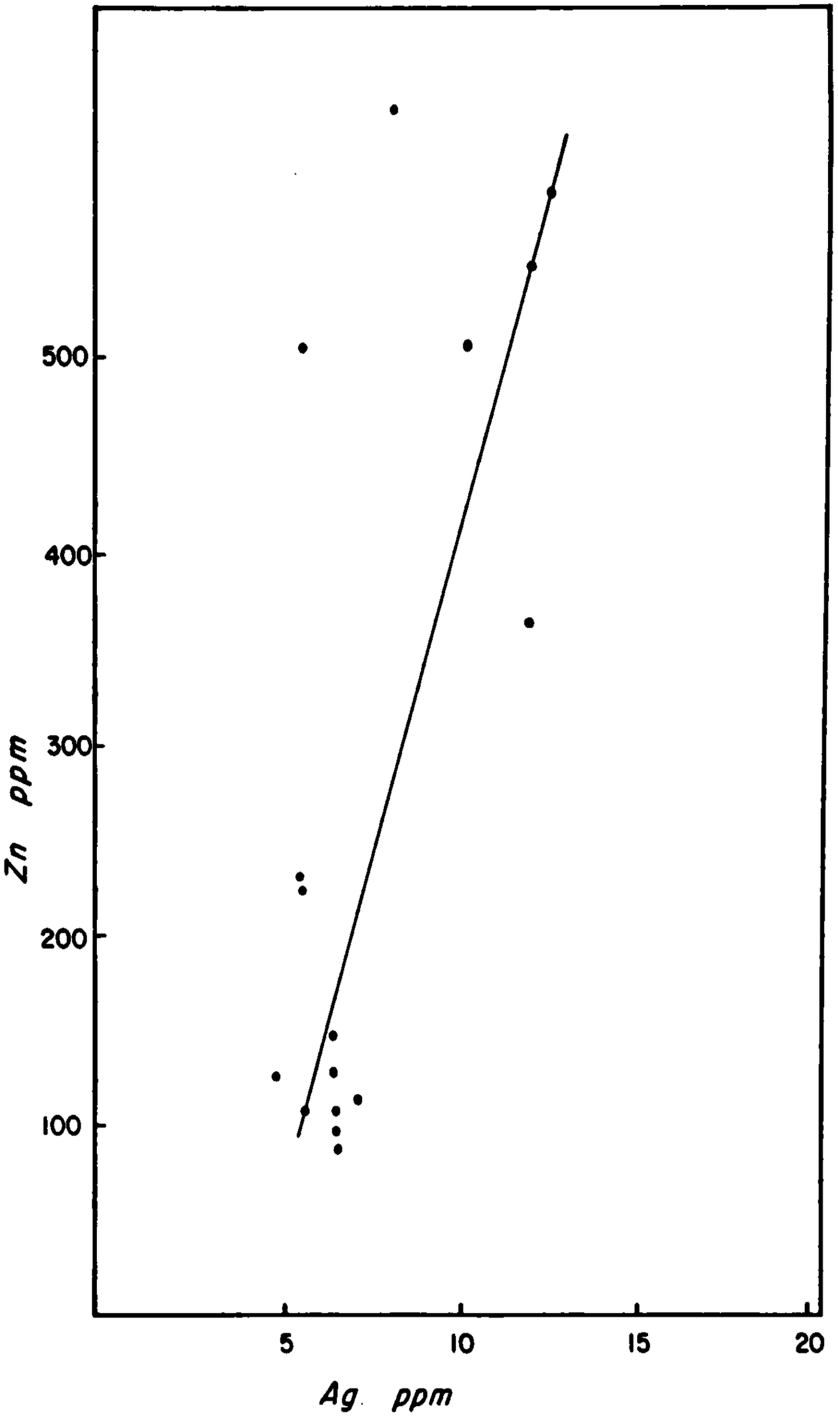


Fig. 38 Plot of zinc versus silver of underground samples. Correction coefficent = 0.79

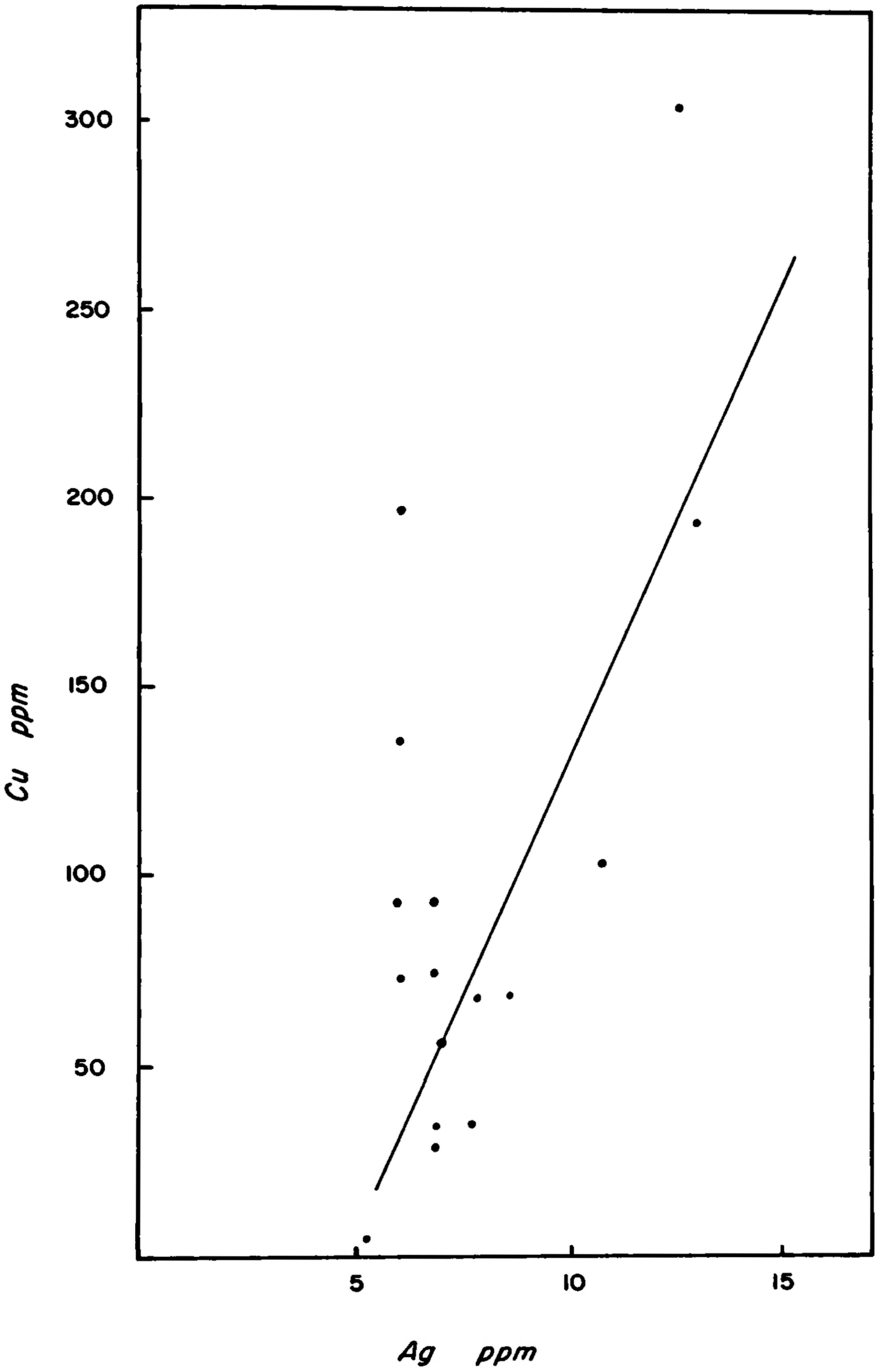


Fig. 39 Plot of copper versus silver of underground samples. Correlation coefficent = 0.64

pyrite, and/or pyrrhotite. A value of 0.013 ounces/ton was found from a pyrrhotite vein at 2381 feet.

Conclusion

The above relationships show that silver is associated with at least sphalerite and galena. Tetrahedrite and boulangerite probably contain silver but were not observed in this study. In zinc sulfide minerals with homogeneous composition Gaudin et al. (1951) concluded that a rapid ion exchange of Ag for Zn occurred, followed by a solid state diffusion reaction in which the Ag replaced Zn in the open sphalerite structure or was included in the interspace.

Recent work showed that Ag_2S has a great solubility in PbS (0.4 mol-1%) (Frueh and Vincent, 1974). VanHook (1960) found that the presence of Sb increases solubility of Ag in galena (as Miargrite $AgSbS_2$ form). Elliott (1934) found that boulangerite ($5\ PbS.2\ SbS_3$) contains 51.8 ounces of Ag/ton.

Zn/Pb, Cu/Zn, and Cu/Pb ratios were plotted against depth. A good correlation was not observed. However, relative comparison of these elements showed a little increasing of Pb and Cu over Zn with depth.

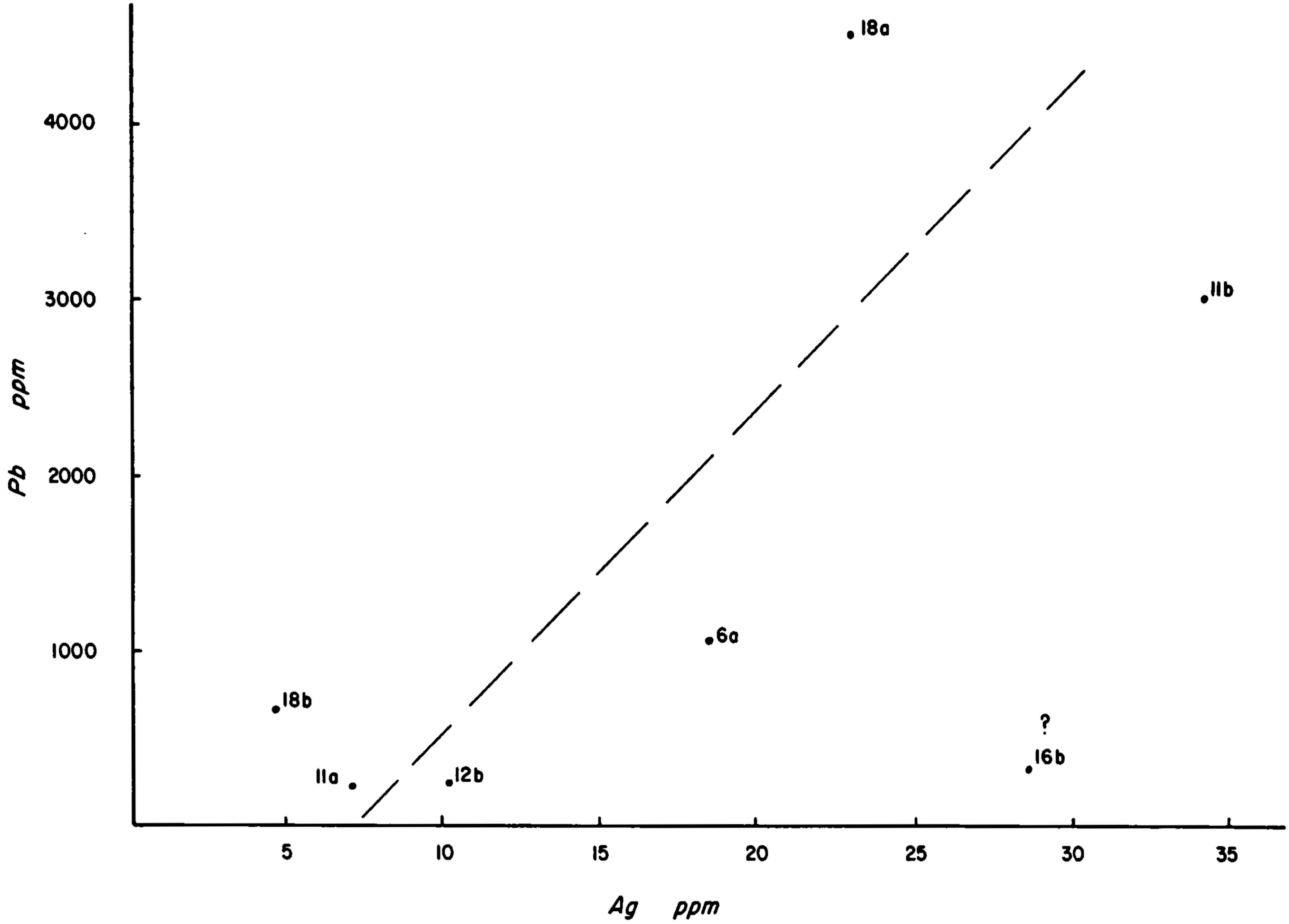


Fig. 40 Plot of lead versus silver of surface samples. Correlation coefficent = 0.55

Surface Samples

Twenty-one samples were analyzed for Pb, Zn, Cu, Sb, Ag* and Au*. The result of analyses is given in Table 6. Generally, silver increases as lead increases (Fig. 40).

The highest silver content (1.09 ounces/ton) was found in a dump sample collected from the Bonanza Mine (K_{11b}). All other metals show no apparent correlation with Ag.

The highest concentration of gold occurs in the underground workings. Because pyrrhotite is known to host Au and microscopic observations showed that pyrrhotite is more abundant in the underground than the surface outcrops, pyrrhotite may be the most important Au-bearing mineral in the district. The highest Au value (among the surface outcrops) was obtained from the Emery shaft ($\leq$ 0.009 ounces/ton).

Note: My original gold analyses show unexpected high values. Therefore, a few samples were sent to TSL Laboratories for additional check. My values are about 300 times higher. Therefore, I reduced my gold values accordingly. The error of the analyses may be due to the gold standard used (pers. comm., Jack Wehrenberg and Janet Roemmel, 1982).

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*Selected samples were run for Ag and Au.

Table 6. Metal Analysis of the Country Rock, Emery Mine District (values in ppm)

Sample No.	Pb	Zn	Cu	Sb	Ag*	Au*	Ounces/ton Ag	Ounces/ton Au
K_1	299.95	156.40	87.65	571.50				
K_2	276.30	149.75	77.25	553.50				
K_3	110.90	141.45	61.70	482.15				
K_5	134.55	143.15	92.85	464.25				
K_{6a}	1174.10	221.10	144.80	571.50	18.50	0.19	0.59	0.005
K_{6b}	1103.20	1857.30	576.00	464.30				
K_{6c}	1221.35	1870.55	326.65	517.83				
K_8	205.45	173.00	259.15	535.70				
K_9	158.20	131.50	269.50	553.70				
K_{11a}	277.00	187.90	253.45	500.00	7.24	0.26	0.23	0.007
K_{11b}	3064.20	328.95	14.90	553.55	34.00	0.24	1.09	0.007
K_{12a}	87.30	60.15	4.50	535.70				
K_{12b}	347.20	169.70	25.30	589.30	10.14	0.21	0.32	0.006
K_{12c}	394.45	267.60	20.15	517.84				
K_{14}	134.57	68.45	14.90	500.00				
K_{16a}	299.05	131.50	40.90	535.79				
K_{16b}	394.45	151.40	108.45	625.00	28.85	0.22	0.92	0.006
K_{17}	418.10	161.35	30.55	642.85				
K_{18a}	4458.10	2114.45	186.40	678.55	22.93	0.31	0.73	0.009
K_{18b}	630.70	299.10	25.30	642.85	4.99	0.29	0.16	0.008
K_{20}	323.60	166.35	150.00	571.40				

* = Ag and Au analyses run on only selected samples. See Fig. 4 for sample's location.

Precision of Analyses: Pb, ± 5.0%; Zn ± 2.3%; Cu ± 15%; Sb ± 17%; Ag ± 23%; Au ± 0.07** Percent of the values

**Au of the amount

CHAPTER V

HYDROTHERMAL WALL ROCK ALTERATION AND SURFACE WEATHERING

Wall Rock Alteration

The term hydrothermal alteration is defined by the Glossary of Geology as "alteration of rocks or minerals by the reaction of hydrothermal water with pre-existing solid phases".

Hydrothermal alteration is a useful guide to mineralization and indicates the character of ore forming fluids. An excellent review of the physical, chemical and mineral changes during hydrothermal alteration was discussed by Schwartz (1959), and Meyer and Hemley (1967).

Study by Robertson (1953) showed that argillization and carbonization are the common hydrothermal alteration products in the Emery district. In this study work was based on surface outcrop samples, dump samples, and two cores.

Uncertainty in locating the boundaries of the main vein in the Emery district made the study of wall rock alteration associated with the vein difficult. However, from field observations, thin sections study and chemical analyses of the country rock, four types of alteration were found. They include: 1) argillization, 2) sericization, 3) propylitization, and 4) silicification.

(a) Argillic alteration (Fig. 41). Results in the development of clay minerals through complex hydrothermal processes which result in the subtraction of calcium, and sodium from the feldspars of the country rock

(Stanton, 1971). Chemical analyses of rocks ($K6_a$, $K6_b$) show depletion in calcium and sodium. However, enrichment of Na occurred in some rocks from the Emery shaft ($K18_{a,b}$) and of Ca in rocks from the Hidden Hand shaft ($K12_a$).

Fig. 41. Argillic alteration of Ca-plagioclase near a quartz-carbonate vein, K15 (X2.5).

(b) <u>Sericitic alteration</u>. Sericite, pyrite and quartz are predominant minerals of this type of alteration. Feldspars and pyroxenes (chlorite) are destroyed by the hydrothermal solution; sericite, pyrite, and quartz result. Iron combines with S-bearing solutions forming pyrite. A typical reaction of this type (below) is discussed by Meyer and Hemley, (1967) and mentioned by Stanton (1972).

$$2\ Al\ (Mg,Fe)_5AlSi_3O_{10}\ (OH)_8 + 5Al^{+3} + 3Si^{(OH)}{}_4 + 3K^+ +$$

chlorite

$$2H^+ \rightarrow 3KAl_2\ Al\ Si3O_{10}\ (OH)_2 + 10\ (Fe,Mg^{++}) + 12\ H_2O$$

sericite

Fyfe (1978) concluded that K^+/H^+ in "alteration-controlled system" acts as a buffer solution in assemblages of muscovite-quartz-K-feldspars. Sphalerite solubility in KCl-HCl-bearing solutions is 65 ppm Zn at 300°C and 13,000 ppm Zn at 500°C. 13 ppm occur at 300°C and 196 ppm are found at 500°C in non-buffered solutions.

(c) Propylitic alteration (Fig. 42). This type of alteration involves the formation of "propylite" by complex processes in which an assemblage of minerals such as chlorite, epidote group, quartz and carbonate result. The assemblage is also characterized by lack of much cation metasomatism or leaching of elements (Rose and Burt, 1979).

At the Emery Mine pyroxene crystals show partial to complete chloritization and sulfurization (pyrite) associated with magnetite. Hematite was also observed and is probably an alteration product formed after magnetite.

A typical example of the conversion of andesine to clinozoisite is mentioned by Stanton, R.L. (1972) and is given below (Note: SiO_2 and Na^+ are liberated on the conversion of albite to chlorite) (Fig. 43).

$$2\ NaCaAl_3Si_5O_{16} + 2SiO_2 + Na^+ + H_2O \rightarrow$$

$$Ca_2Al_3Si_3O_{12}\ (OH). + 3\ NaAlSi_3O_8 + H^+$$

clinozoisite

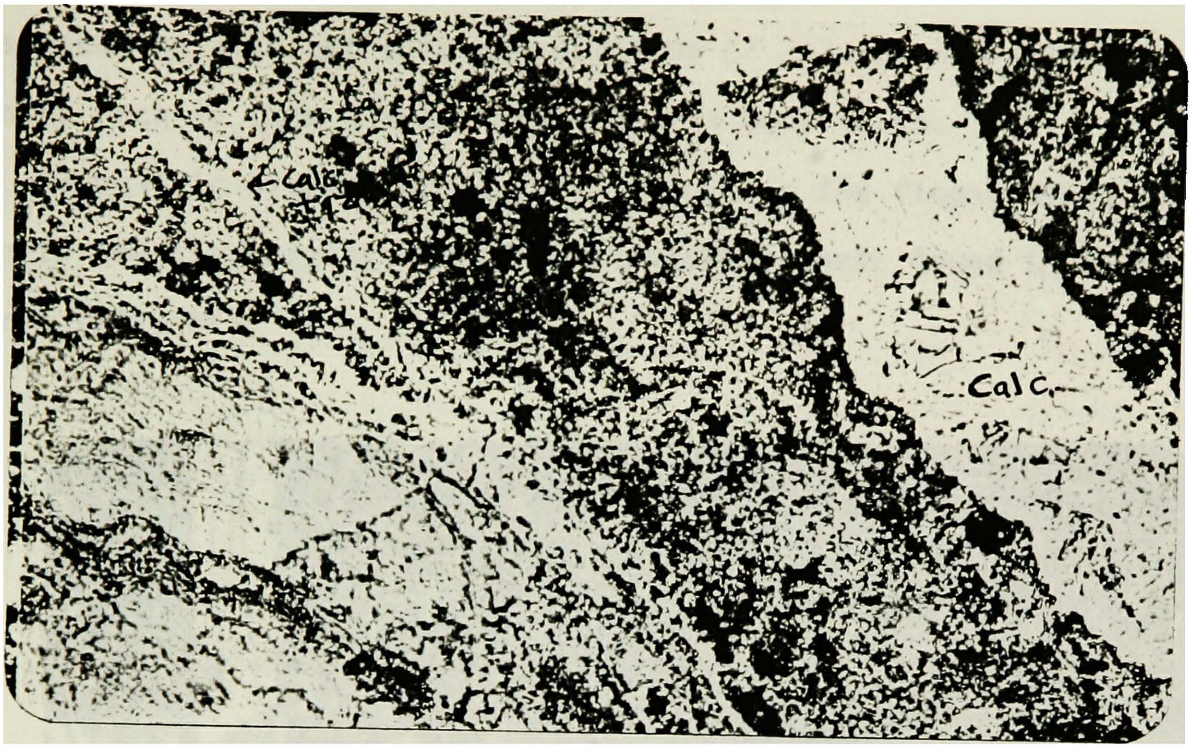

Fig. 42. Propylitic alteration composed of chlorite, calcite, particularly abundant along veins, 558, (X2.5).

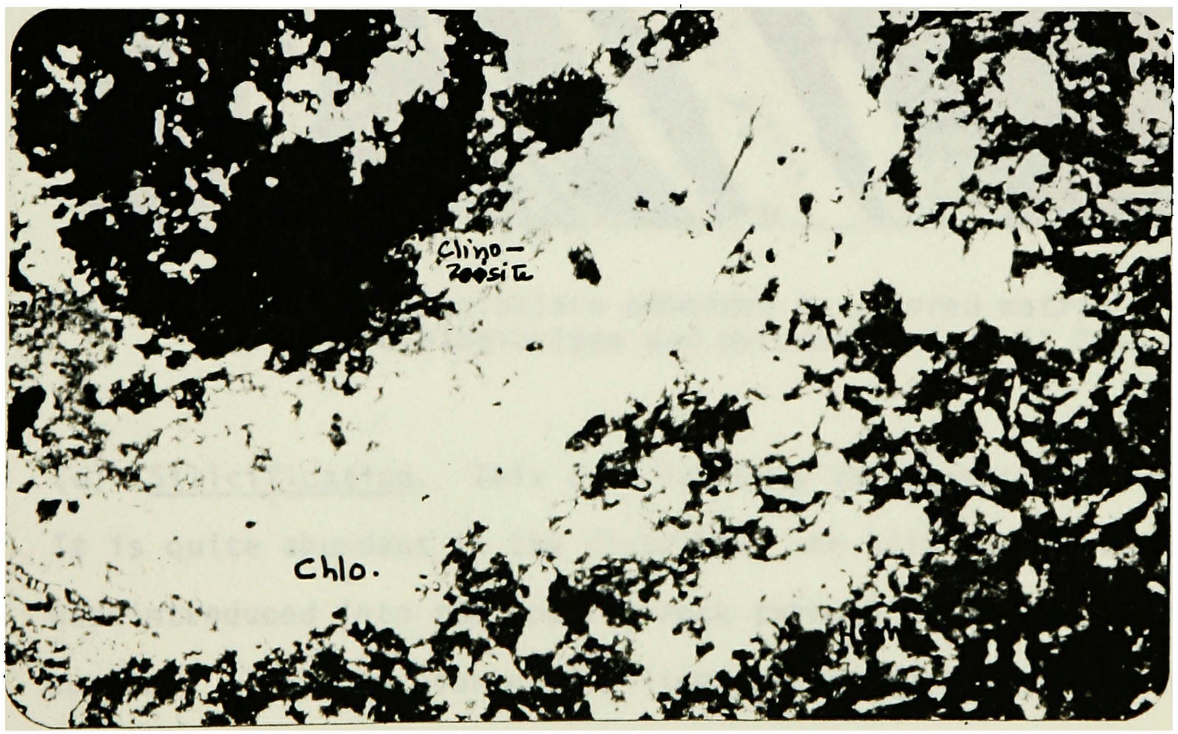

Fig. 43. Chlorite, quartz (white) and clinozoisite filling voids, K5, (X2.5).

This equation also explains the addition of calcium and sodium of the country rock in some places, particularly near veins.

Propylitic alteration is more intense in the fine-grained matrix than in the phenocrysts; fresh Ca-plagioclase were found in altered matrix (Fig. 44).

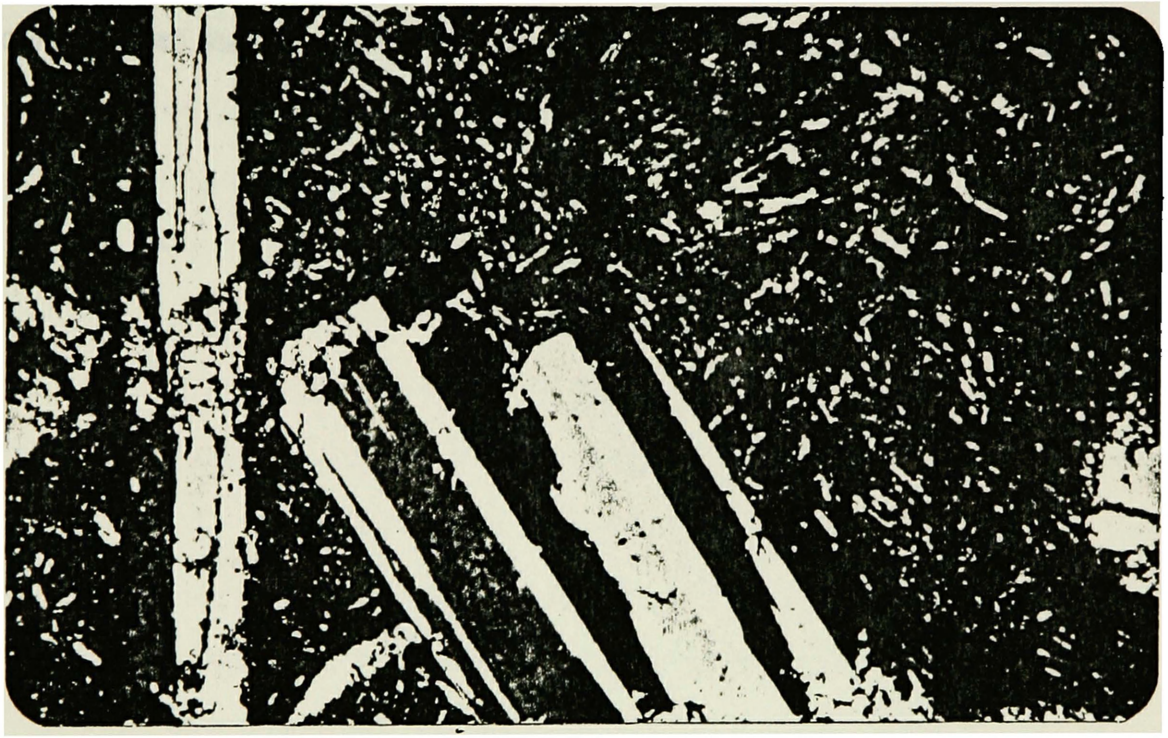

Fig. 44. Fresh Ca-plagioclase embedded in altered matrix of calcic-plagioclase and pyroxenes, K_{12}, (X 2.5).

(d) Silicification. This type involves the formation of quartz. It is quite abundant in the district. The silica-bearing solution was introduced into the country rock through fractures, from deep source. Also, the source of siliça was the destruction of minerals of the country rock.

Surface Weathering

The term gossan refers to the "iron-hat" that has been left after the weathering of minerals. The gossan at the Emery district are "barren gossan" because they are economically unimportant. The gossans were derived mostly from pyrite and pyrrhotite. Robertson (1953) mentioned that the oxidation has proceeded to a depth of about 15 m. No supergene enrichment was noted by me in my study of subsurface samples.

CHAPTER VI

ORIGIN OF THE MINERALIZATION

The mineralization in the Emery Mine is of hydrothermal origin and consists of open space filling in fractures and disseminated replacement in the adjacent wall rock. The solutions may be related to the magma of the Boulder batholith. Meteoric waters probably dominated in the system. Ore-forming fluids including sulfur and Cu, Pb, Zn and arsenic-bearing complexes, penetrated fractures and openings of the country rock. During their migration the chemical and physical condition of the solution changes causing a sequential deposition of the minerals.

Mineralogical and textural relationships of minerals listed below suggest that the temperature of formation was below 450°C.

(a) the presence of chalcopyrite blebs in pyrrhotite indicate that the temperature is around 300°C (see p. 32),

(b) by the study of sphalerite-chalcopyrite intergrowth which showed that the temperature is much lower than 500°C (see p. 34), and

(c) the presence of the final carbonate stage suggests a low temperature of mineralization (Robertson, 1953).

However, Robertson (1953) concluded because of the presence of tourmaline crystals at the Hidden Hand Mine that the initial temperature of mineralization exceeded 500°C. Recent work on the formation of tournaline suggests that tourmaline may be found associated with carbonates (Boyle, R.W., 1979). which is other evidence in the district suggesting that mineralization occurred at temperature of less than 300°C.

The sulfide mineral assemblages consists of sphalerite, galena, pyrrhotite, pyrite, chalcopyrite and small amounts of tetrahedrite, arsenopyrite; and silver and gold, and the type of alteration includes argillic; sericitic and pyropylitic suggested that the mineralization of the Emery area is mesothermal in character (200-300°C) (based on Lindgren's classification, 1919).

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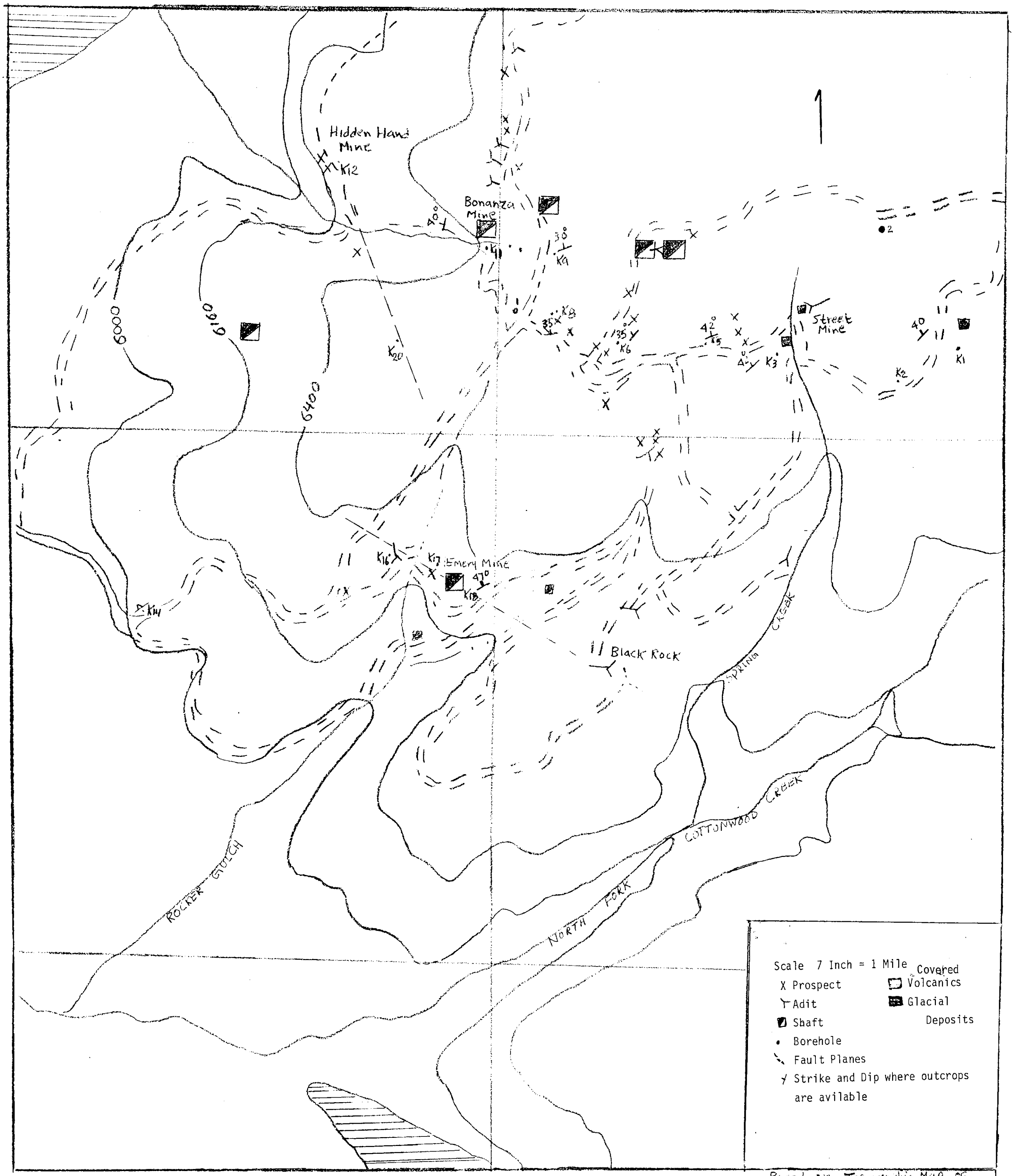
APPENDIX



Based on Topographic Map of Deer Lodge Quadrangle, 1959
Geology by Salah Al-Khirbash
1981

GEOLOGIC MAP OF THE EMERY MINING DISTRICT,

Powell County, Montana.

P1 of 17

EMERY (Zosell) Mining District

Borehole No. 1.

Described by Salah Al-Khirbash, Summer, 81

Notes

① less mineralized areas with respect to the whole sequence

② Zn decreases by depth

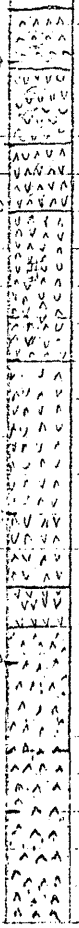
INDEX	
Andesite porphy. & nonporphy.	^^^^
Basaltic comp.	vvvv
And. basalt (?)	v^v^

Scale 1" = 20'

Company GMRIC Gulf mineral Resources Co.

KEY AND ABBREVIATIONS

AL-ALASKITE
AP-APLITE
ARG-ARGILLITE
ARS-ARSENOPYRITE
AZ-AZURITE
BAS-BASALT
BOR-BORNITE
CALC-CALCAREOUS
CAL-CALCITE
CPY-CHALCOPYRITE
CHL-CHLORITE
COV-COVELLITE
CUP-CUPRITE
DOL-DOLOMITE
EP-EPIDOTE
PbS-GALENA
GAR-GARNET
HNFLS-HORNFELS
LST-LIMESTONE
MAL-MALACHITE
MONT-MONTMORILLONITE
PY-PYRITE
PYR-PYRRHOTITE
Qtz-QUARTZ
Qtz. DIOR-QUARTZ DIORITE
QTZITE-QUARTZITE
QM-QUARTZ MONZONITE
RH-RHYOLITE
SH-SHALE
ZnS-SPHALERITE
TET-TETRAHEDRITE



FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION	Ft	Remarks
	NX						
			No Core		No Core	400	
			Black And.	massive ; Small Fissures	Dissiminated py. , W/ Veinlets of Py and PbS(?) highly Silicified (415'), No alter.	420	Samples & Depth ① — 430 ② — 455 ③ — 470 ④ — 490
X			Mostly dark Basalt	Massive , " "	Diss. & Veinlets of py. Hem. is present		
			Andesitic Basalt, thin layer of $CaCO_3$	massive	Diss. Py. , Veinlets of py and PbS(?) Gross-, The Core size. Cubes of Py is also present	440	
			Porph. And-Basalt; Phenocrysts of pyrx.	Massive Bedding-planes are common	V.Fine – medium diss. of py. Veinlets are present in cross-cutting relationships Chlorite is present		* 455'
			Do	Fractured, filled w/ $CaCO_3$* Bedding-planes are common		460	
Y.			DO ; greenish material (Chlorite?) is common	Highly Fractured Zones filled w/ Coarse grained of $CaCO_3$; Some evidences of movement. Bedding planes of dark mls. are common.	Dissimination of py , Veinlets of py & Probably ZnS are also present.* Clay mls are common as alt. products.		* Mineralization replaced by $CaCO_3$
			Do; grayish	Fractured filled w/ Crystals of $CaCO_3$	less mineralized	480	
			Mostly dark, porphy. basalt	less fractured			
			Mostly, greenish And.	Massive Some fractures filled w/ grains of $CaCO_3$	mineralized mostly controlled by small fissures	500	
			Do	DO	Do plus coarse crystals of py clay mls alt. products	510	

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KEY AND ABBREVIATIONS

AL-ALASKITE	BOR-BORNITE	CUP-CUPRITE	LST-LIMESTONE	Qtz. DIOR-QUARTZ DIORITE	TET-TETRAHEDRITE
AP-APLITE	CALC-CALCAREOUS	DOL-DOLOMITE	MAL-MALACHITE	Qtzite-QUARTZITE	
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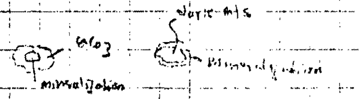
AZ-AZURITE	CHL-CHLORITE	GAR-GARNET	PYR~~R~~-PYRRHOTITE	SH-SHALE	
BAS-BASALT	COV-COVELLITE	HNFLS-HORNFELS	Qtz-QUARTZ	ZnS-SPHALERITE	

FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION	Depth	Remarks
						540	
			Slightly weathered And.	Broken	Chlorite & clay mls(?), diss. py		
			Porph..., Highly weathered Andesite, grayish [illegible]-bas, grayish silicified	Do. (crashed)	Pale-grayish rock, mostly $CaCO_3$ (Ankerite?), there are some spots of py.		
				massive	Host rock slightly altered, diss. of py. & replaced by $CaCO_3$	560	
			Do.	Do., fissures are filled w/ $CaCO_3$ (predom.)	Do.		
			mostly Bas.	Do, " "	Do.		
			porphy Andesitic, black-grayish in color, phenocrysts * comprised of feldspar pyx.	mostly massive, w/ some fractures filled w/ $CaCO_3$ * # Somewhere at 588' evidence of movement (?)	Spots of py blebs ranging from fine to coarse grained & ZnS also present (?) veinlets of most commonly py.	580	* reaction w/ HCl gives greenish soln.
			Do.	Do. *	Do, w/ v. [illegible] diss of cpy.		* fractures mostly goes // w/ the core axis & and some filled w/ mineralization
			Do.	Do.	py & ZnS filled fractures *	600	* ZnS replaces py. * ZnS content increased at ≈ 600'
			Andesitic-bas. blackish in color,	Do.	PbS is present, fractures-filling, bedding-plane veinlets, py also present. * ZnS diss.		* Veins cross-relationship is a good evidence that PbS deposited after py.
			DO, grayish-black in color	Do.	Do, except less PbS		
						640	
						660	
			Basaltic, blackish in color	Do.	Do, chlorites are present, spots of a very bright ml. are present		
					Do, 2ry $CaCO_3$ fissures-fillings are present *	680	* nearly I mineralization zones in some losses.

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KEY AND ABBREVIATIONS

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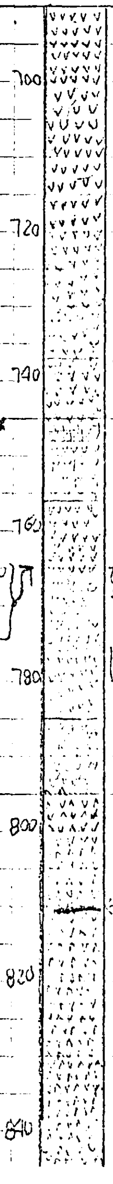

FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION	
			Do.	Do		
			Do,	DO	DO, Veinlets mostly goe, parallel & normal to the core sample.*	Sample No. 736' Shows a Sort of displacement
			Do		— large thin layers replacing the original rock*	*very little or mostly NO Sulfides are present
				Do, filling-fissures are present	Do, veinlets make about 45° w/ the core length	* See Sample 745'
			Do	Do	Do, less alteration, long veinlets making 45° to each other ⊛ Some are ⊥ CaCO3 is mostly common (764'-768') ⊛	⊛ Sample No. 762'
					Do, bedding-planes are common (dark bands)* disseminated py (at least) is common.	less mineralized zones ⊛ See sample * See Sample No. 785'
			porph. andesitic in character	Do.	Do, mineralization is common in a set of blebs*	* See Sample No. 797'
			Do	Do.		
					Mostly dissimination py, py Veinlets are less common	([illegible]) Big fracture filled with uncrystallized [illegible] (see chart 820
			Do.	Do.	less mineralized Zone Fissure-filling w/ CaCO3 *	* See Sample No. 846'

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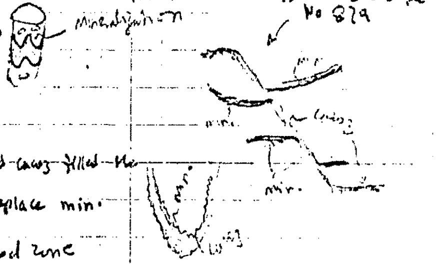
FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION		
			Do.	Do.	Do; less mineralized Zone* ZnS is present*	850	* less mineralized zone compared to the hole section described before * See Sample No. 853'
				Broken		860	Broken
			Do,	Massive	Do; Wavey mineralized fissures are diagonistic rounded dissimination of Py	880	Fractures filled w/ about 0.1" Caco3 & good evidence for that Caco3 ppt after the sulfide(?) zone See Sample No 879 & Folding after ?? the dep. of host rock * See Sample No 891'
			Do.	Do ; (Slightly Weathered) Bedding planes are common in the unweathered Zones. Fractures are filled w/ Caco3 in a wavy pattern, rocks broken along the fractures (No. 898)*	ZnS probably present (891')* PbS is present 894'	900	* Well crystalized Caco3 filled the Fractures. Caco3 start replace min.
					Do; No galena observed		
			Do.	Do, more fractured 2-2.5" thick Fracture filled w/ Caco3 and nearly unmineralized is present at 914'*	Do; less mineralized (910'), PbS is present (915')		less mineralized zone * See Sample (914')
			Do; more greenish in color.	Do ; (Wavey pattern fractures)		920	
					PbS, ZnS are present controlled by a curved fractures (924')		less min. Zone.
			Do; blackish, smooth surfaces rock	Do, less fractured			less mineralized Zone
					Small veinlets, but v. less mineralization Zone (could be barren zone)	940	" " "
			Do.	Do, Fractures filled w/ uncrystallized Caco3.			" " "
			Andesitic rock, porph.	Do.	less mineralized Zone, where found is dissimination.	960	" " "
					diss. Py & Cpy.*		* See Sample No. 972'
						980	
					Fracture filled w/ Caco3 seems controlling the ppt of sulfides.		less mineralized Zone
			Do; a black material is present ●			995	● Sample 996' ★ serpentinite (less mineralized Zone (up to 1002')



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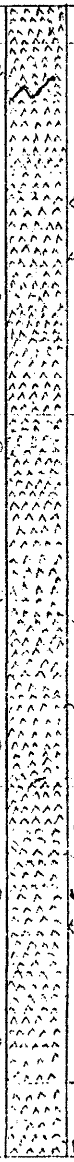
QTZITE-QUARTZITE
QMz.-QUARTZ MONZONITE
RH-RHYOLITE
SH-SHALE
ZnS-SPHALERITE
TET-TETRAHEDRITE

FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION		
			Do.; porphyry, adesitic, greenish pbs are a phenocryst	Do; less Fractured	Zns & chalcocite (?) are present* other ml. is presnt		* see Sample 1006' (in a small amounts).
				Do.	Zns, pbs are present as a dissimination & as a fillings in a wavey fractures ; CaCO3 replaces them*		& See Sample No. 1011 See paragenesis & cleavage of galena
			Do	Do	Do. 1020		
					Disseminated (?) Zns, pbs & pyr. are common Sy.		Sample 1027'
			Do.	Do; bedding planes are common (as above)	DO.		Sample 1034'
			Do	Do (" ")	Do. 1040		
							Notise: I noticed that the beautiful crystals of pbs and Zns concentrated more in the porphyritic type of rocks
					Do; a beautiful crystals of py are present associated w/ a well crystallized CaCO3*, No pbs is clear (1051').		* See Sample 1051'
				Do; bedding planes are common &	Do. & 1060		& See Sample 1063' " more description for the distribution of min.
							pyr.
					1080		
			Do.	Do; fractures filled w/ CaCO3 and less mineralized (than before); bedding-planes are present	Do.		Sample 1083'
							see Sample 1094'
					1100		
			Do	Do; a less mineralized of quartz vein is present at 1104'	DO.		py.
							see Sample 1114' less mineralized zone
					1120		see Chunk Sample no 1124' : for reddish material.
				Do.	Do; less py		
					1140		
					Do; Replacement process are common between sulfide min.		See Sample 1145.5'
							less mineralized zone (1153- 1163.5')



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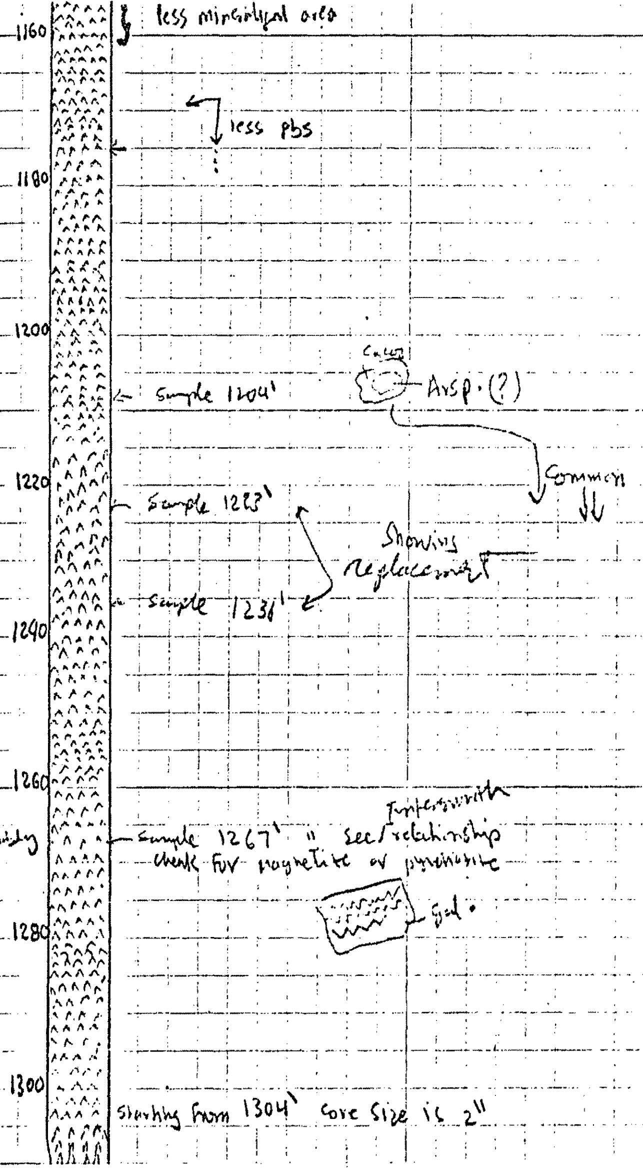
BAS-BASALT	COV-COVELLITE	HNFLS-HORNFELS	Qtz-QUARTZ	ZnS-SPHALERITE	

FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION
			DO; slightly weathered (1174')	DO	DO, less PY
			DO; blackish in color.	Do.	
			DO	DO	DO.
			DO.	DO.	DO; large amounts of PbS, ZnS, Py, ARS. and probably magnetite
					DO; less PbS
	2"				



less mineralized area

less pbs

Sample 1204'

Arsp. (?)

Common

Sample 1223'

Showing replacement

Sample 1236'

Sample 1267' " see relationship Intergrowth
check for magnetite or pyrrhotite

gal.

Starting from 1304' core size is 2"

Cont' ZHL
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CAL-CALCITE
CPY-CHALCOPYRITE
CHL-CHLORITE
COV-COVELLITE

CUP-CUPRITE
DOL-DOLOMITE
EP-EPIDOTE
PbS-GALENA
GAR-GARNET
HNFLS-HORNFELS

LST-LIMESTONE
MAL-MALACHITE
MONT-MONTMORILLONITE
PY-PYRITE
PYR-PYRRHOTITE
Qtz-QUARTZ

Qtz DIOR-QUARTZ DIORITE
QTZITE-QUARTZITE
QMz-QUARTZ MONZONITE
RH-RHYOLITE
SH-SHALE
ZnS-SPHALERITE

TET-TETRAHEDRITE

FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION		
			Do	Do; bedding-planes are common	Replacement are common*		* See Sample No. 1318'
						1320	
			Do.	Do;	Do; fractures are less mineralized than dissemination type		
						1340	
			Do; slightly weathered	Do	Do.		
			Do; more blackish				← Sample No. 1346'
							← Sample No 1350'
						1360	
							← Sample No 1376'
						1380	
			Do, slightly weathered	Broken (crushed) [1384']			
					Pyrrhy is present (?)*		* See sample No 1391'
						1400	← Sample No. 1404'
			Do; massive, greenish (Porphy.)	massive	Do. Porpylitic alteration*		* See sample 1414'
					Do, qtz. is present. Silicification is common along fractures Zns is abundant.	1420	
							← Sample 1425' see mineralization's control.
							← less Mineralized Zone * see sample 1438' ??
			Do.	Do.	Do; Calcite filled fractures control mineralization* qtz. is present	1440	← *Sample 1439'
							← Sample No 1455'
			Do.	Do	Do	1460	

Ext. 3H1
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KEY AND ABBREVIATIONS

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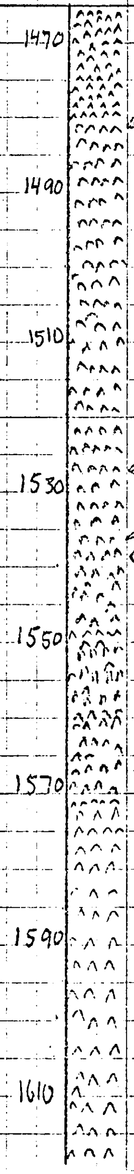
AP-APLITE	CALC-CALCAREOUS	DOL-DOLOMITE	MAL-MALACHITE	QTZITE-QUARTZITE	
ARG-ARGILLITE	CAL-CALCITE	EP-EPIDOTE	MONT-MONTMORILLONITE	QMz-QUARTZ MONZONITE	
ARS-ARSENOPYRITE	CPY-CHALCOPYRITE	GLS-GALENA	PY-PYRITE	RH-RHYOLITE	
AZ-AZURITE	CHL-CHLORITE	GAR-GARNET	PYR-PYRRHOTITE	SH-SHALE	
BAS-BASALT	COV-COVELLITE	HNFLS-HORNFELS	Qtz.-QUARTZ	ZnS-SPHALERITE	

FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION
					Do; qtz is present.
			Nonporphyritic andesitic rock	Do, highly weathered &	
			Do.	highly fractured, but less weathered	Calcite-filling fractures present (well crystallized), 1572'



← See sample 1481'

← Less mineralized zone (1527')

← sample see relationship between min. & qtz.
& Mineralization is not clone see sample 1540'

Less mineralized zones

Core Z41
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BAS-BASALT
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CHL-CHLORITE
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CUP-CUPRITE
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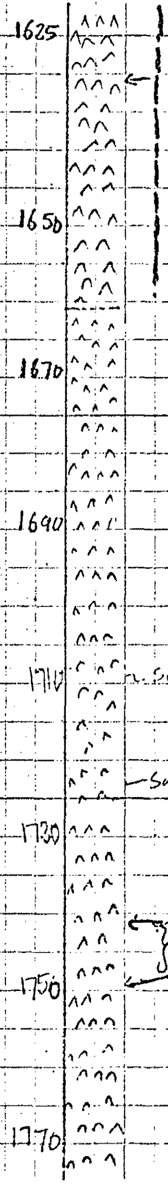
FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION
			Porphy. andesite rock	bedding planes are common	
			D.O.	D.O	Qtz is present Qtz. surrounded by mineralization
			Do, non porphy. Slightly weathered (1741-49) Massive, fractured andesite, porphy.	bedding-planes uncommon	



← Sample 1631' (less mineralized zone)

NOTE Mineralization concentrate in the porphyritic andesite type.

Sample No 1709'

Sample 1723'

less mineralized zone see sample 1741'

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KEY AND ABBREVIATIONS

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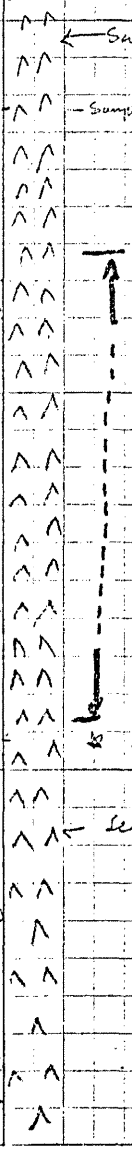
AZ-AZURITE	CHL-CHLORITE	GAR-GARNET	PYR-PYRRHOTITE	SH-SHALE	
BAS-BASALT	COV-COVELLITE	HNFLS-HORNFELS	Qtz.-QUARTZ	ZnS-SPHALERITE	



FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION		
						1780	← Sample 1782' See vein controle
					Qtz is present as Phenocrysts in.		– Sample 1792' Qtz Phenocrysts
						1800	
				highly fractured, slightly weathered			
						1820	
				Do, (unweathered)			
							less Mineralized Zones
							Compositional
						1840	
						1860	
				Do.	dissemination and blebs more than veinlets type ~~Calcz-filling fractures unmineralized~~ less Qtz.	1880	See Sample 1878'
					Replacement is Characteristic ZnS, FeS & SiO2		← See Sample 1888' & Diagnostic Replacement (Texture)
						1900	
				Do.	Do.		
						1920	
				Calcz-vein (≈20'') long & 1/16 core sample			

KEY AND ABBREVIATIONS

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CALC-CALCAREOUS
CAL-CALCITE
CPY-CHALCOPYRITE
CHL-CHLORITE
COV-COVELLITE
CUP-CUPRITE
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FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION		
					1935	^ ^	
						^	
						^ ^	
					1950	^ ^	
						^	
						^ ^	
						^	
					1970	^ ^	
						^	
						^ ^	
					1990	^	
						^ ^	
						^	
					2010	^ ^	
						^ ^	
						^	
						^ ^	← Sample 2026' see relation between py & Mn
				More stretched fractures.	2030	^ ^	
						^	
						^	
						^ ^	
					2050	^ ^	
						^	
						^	
					Qtz veins are present	^ ^	← Sample 2065'
					Very fine crystals of py, sph. & possibly tetrahedrite 2070	^	
						^ ^	
						^	
						^ ^	

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CAL-CALCITE
CPY-CHALCOPYRITE
CHL-CHLORITE
COV-COVELLITE

CUP-CUPRITE
DOL-DOLOMITE
EP-EPIDOTE
~~FES~~-GALENA
GAR-GARNET
HNFLS-HORNFELS

LST-LIMESTONE
MAL-MALACHITE
MONT-MONTMORILLONITE
PY-PYRITE
PYR-PYRRHOTITE
Qtz-QUARTZ

Qtz DIOR-QUARTZ DIORITE
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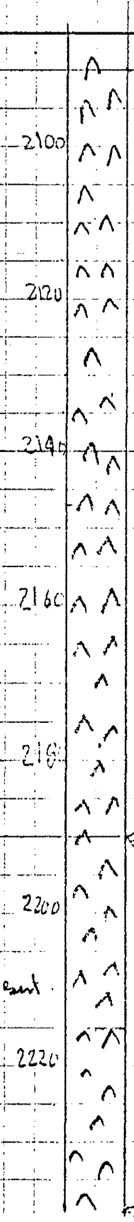
RH-RHYOLITE
SH-SHALE
ZnS-SPHALERITE

TET-TETRAHEDRITE

FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION
					less ZnS, Qtz veins common
				Crushed (broken)	
			Do, fine porphyro-ingots.	Massive, fractured	
			Do	Do.	Do.
				Do.	Veins in crossrelationship, sph., galena(?) present less pyrite, No Chalcopy.



Notice

Where the Porphyritic Rocks gone ?

← Sample 2190'

End of Box 200

← Sample No 2239'

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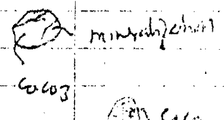
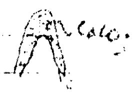
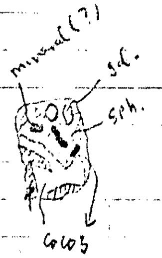
FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION		
			Do.	Do.	Do; CaCO3 along fractures see Replacement (?)* long CaCO3-filling fracture (15")	2250	Sample 2252' Sample 2257' → *
					DO, grenish ml. is present (?) CaCO3 fractures reach ½"–1¼" in width	2270	Sample 2267' " 2269'
					DO; an open space filling of sph & gal (?) 3½" width*		See 2276'
					DO also less long fractures (CaCO3); big CaCO3 crystals along fractures*		• See Sample 2287'.
						2290	
			Do.	Do.	Do, Py is present in ([illegible])		See Sample 2304'
						2310	See Sample 2318'
							See 2327' (black material along fractures)*
						2330	
							Sample 2347'* (Hyndman)*
			Do., more siliceous	Do.	Do, deep-blue color ml.*	2350	Sample 2352'
			unporphyritic And.		Do; Py forming thin layers along rounded fractures but uncommon. Notice controlling factor of mineralization* mineralization along fracture more common.		Sample 2361'* Sample 2365' Sample 2367'
						2370	
				crushed at 2386'	open space filling (sph., gal & CaCO3) are common* (1" width). Notice the sequence of deposition*		*Sample 2381' * " 2382'
						2390	

? Compare w/ core at depth







KEY AND ABBREVIATIONS

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AL-ALASKITE	BOR-BORNITE	CUP-CUPRITE	LST-LIMESTONE	Qtz. DIOR-QUARTZ DIORITE	TET-TETRAHEDRITE
AP-APLITE	CALC-CALCAREOUS	DOL-DOLOMITE	MAL-MALACHITE	QTZITE-QUARTZITE	
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AZ-AZURITE	CHL-CHLORITE	GAR-GARNET	PYR-PYRRHOTITE	SH-SHALE	
BAS-BASALT	COV-COVELLITE	HNFLS-HORNFELS	Qtz-QUARTZ	ZnS-SPHALERITE	

FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION- MINERALIZATION		
						2400	
			Do. Do, Slighty weathered	Notice, the Slickenside along fracture. Crushed @ 2411 – 2425'	Do; less zns. (generally less mineralized zones)		Sample 2408' Sample 2410'
						2420	generally less mineralized area
						2440	
			Do. Unporphyritic, grayish rocks more siliceous (Arg)	Crushed rocks massive, slightly fractured	Do. Disseminated Py, Arspy. are common	2460	Sample 2462' (fresh sample)
			unporphy, weathered Rs	Crushed	Unclear	2480	
			Do, fresh, brightly calcoveins rock 2490-91 Do; except blackish Do	massive, fractured Do, less fractured	Disseminated, veinlets (zns, py, Arsp?) are present CaCO3 fissures are present.	2500	Sample 2491' less min. area.
			Do.	Do.	Do; open space filling of CaCO3 (2-4½" width), growth of big crystals		Sample No 2516' Sample No 2518'
					Do, mineralization is very fine crystals	2530	
						2545	

KEY AND ABBREVIATIONS

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FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION		
						2555	
						2570	
	1.5" dia.		evengrained, whitishgreen rock	massive, less fractured	propylitic-type alt. could be present, v. fine diss. miner. are common, $CaCO_3$ Fis. fil. is present.		
							Sample 2584'
						2590	
					Do, veinlets also present ⊛		Sample 2594'⊛ (at least 5 type of mls are present).
			Do, more black	massive, more fractured	less mineralized are		less mineralized zone
						2610	
			Do	Crushed, weathered	Do		
			$CaCO_3$ (totally) 2622-27	massive, less fractured	$CaCO_3$ filled 1.5" dia fracture* $CaCO_3$ replacing the mineralizations		*Sample 2626'
	1.5" dia		even-grain, greenish rk.	massive, less fractured rock	Propylitic type alteration near $CaCO_3$-filling fractures. mineralization are common in diss. type	2630	Sample 2635'
			Do.	slightly weathered	less mineralized, $CaCO_3$ fractures are present.		
			Do, very fine grains	Massive, fractured, unweath	less	2650	less mineralized zone
			Do, grayish	Do	blebs of ZnS are common, $CaCO_3$ fillings are less common (sometimes none)		Sample 2663'
			Do, more silicified			2670	
						2690	
			very fine bluish rock	highly Do fractured, unweathered	Very less mineralization (could be very fine diss.)		

Trend is generally less mineralized compared to the whole sequence

Mismatch 2624-2630

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FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION		
						2710	↑
							~ Sample 2712'
						2730	
				crushed 2732-2736'			less mineralized compared to the whole sequence
			Do, gray-dark gray	Crushed 2746-2747' massive, fractured.	blebs (ZnS) are common, ~~also~~ veinlets are present	2750	↓
					diss. type more common.		
						2770	
			Do, more blackish		min. are common in open space fillings ⓐ		
						2790	~ⓐ see sample 2789'
							↑ less mineralized zone ↓
						2810	
			porphy.; black, basalt; phenocrysts are flds & horn	massive, fractured rock	Diss. type are common, ZnS, py, ...?		~ Sample 2815'
			Non porphy., grayish black; Do, like 2815	Do.	veinlets (subs ‖ w/ core sample) common* Do, Diss also present		~*sample 2820'
						2830	
			Do, like 2815		Do, but veinlets less mineralized	2850	

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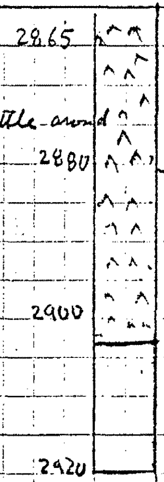
FOOTAGE	CORE SIZE	RECOVERY	LITHOLOGY	STRUCTURE	ALTERATION-MINERALIZATION
			Nonporphyry., very fine, black rock	massive, less fractured	less mineralized mass; except a very little around [illegible] filling fractures.
			Do.	Do	Do, Fracture filling more common



Sample 2881'

END Sample 2902'