AN EXAMINATION OF SOME LEAD ORES

from the

COEUR d'ALENE DISTRICT, IDAHO.

by

William Albert Waldschmidt

S.B.,E.M. South Dakota School of Mines

1920 - 1921

Submitted in Partial Fulfillment of the Requirements

for the

Degree of

MASTER OF SCIENCE

from the

Massachusetts Institute of Technology

1922

Signature of Author

Certification by the Department of

Mining, Metallurgy and Geology

CONTENTS

AN EXAMINATION OF SOME LEAD ORES
FROM THE
COEUR d'ALENE DISTRICT, IDAHO.

INTRODUCTION.

General Statement.- The ores examined microscopically were collected in 1920 by Professor Waldemar Lindgren at the Hecla East Vein, the Star Mine, and the Morning Mine. Because many of the ore samples assayed high in silver, the main purpose of this examination was to determine the state of occurrence of the silver. In this paper the general features of the lead-silver veins of the Coeur d'Alene district will be outlined, and then the ores from each deposit will be discussed in detail with special emphasis on the occurrence of the silver, and the order of deposition of the minerals.

LEAD-SILVER DEPOSITS OF THE COEUR D'ALENE DISTRICT.

As described by Ransome (1), "the lead-silver ores came principally from metasomatic fissures, which traverse the siliceous formations of the sedimentary series of the Coeur d'Alene. The deposits are lodes which have formed chiefly by the replacement of quartzite, or allied rocks, by galena and siderite along zones of fissuring."

The ore bodies occur in two quite well defined areas, chiefly in the Burke and Revett formations of pre-Cambrian age. One area extends along the south fork of the Coeur d'Alene River, northward to the head of Nine-mile Creek, and the other continues for some distance west of Wardner. These two areas have produced about 98 per cent. of the lead and silver of the district.

The vertical range of the ore is about 4,000 feet; that is from the deepest level of the lowest mine to the highest outcrop. Some of the mines have been worked to a depth of 2,000 to 2,500 feet, but it seems quite general that the grade of the ore becomes less with depth, usually increasing in zincblende and decreasing in galena.

---

(1) Ransome & Calkins: Geology and Ore Deposits of Coeur d'Alene District. U.S.Geol.Survey, Prof. Paper 62, 1908.

Although there are a few distinct contact metamorphic deposits in the district, the most were formed by ascending hot solutions during the intrusion of the Cretaceous monzonites.

HECLA EAST VEIN.

General Description.- The Hecla East Vein is situated about one mile northeast of Burke, Idaho, in an extremely rugged country. It is included in the large lead-silver area between the south fork of the Coeur d'Alene River and the head of Nine-mile Creek. The vein is very continuous, varies in width from 2 to 20 feet, dips about 70 degrees to the south and pitches sharply toward the west. It is entirely in the Burke formation of quartzitic slates. On the west side it is cut by the O'Neil fault against which the ore usually stops very abruptly, but on the east side, the vein either pinches out altogether or else gives way to quartz veins. Minor slips are present but are probably not of much importance in relation to the large O'Neil fault.

At the No. 3 Tunnel level, the vein splits but each branch continues downward, in some places the north branch being the most prominent, but they unite again at the 900 foot level.

The main tunnel, No. 3, starts about 50 feet above the creek bed at Burke, and intersects the vein at an elevation of 3,812 feet. Above this the ore has been worked to the 57th floor at an elevation of 4,312 feet. Below the tunnel they have followed the vein to the 900 foot level, which has an elevation of 2,923 feet. This gives the ore body a vertical range of about 1,390 feet. Immediately to the north of the Hecla East Vein is the Russel Tunnel, elevation 5,012 feet, which has intersected a vein 125 feet from its portal. This vein shows oxidized material from 16 inches to three feet in width, dipping 66 degrees to the south. It was followed for a distance of 500 feet, and geological examinations have shown it to be a part of the Hecla East Vein, which has been carried upward by a reverse fault. As this upthrown part of the vein outcrops above the Russel Tunnel, the vertical range of the Hecla East Vein would be greater than that already stated.

The upper portions of the Hecla East Vein, and the vein cut by the Russel Tunnel are oxidized and usually contain little or no sulphide minerals.

<u>O'Neil Fault</u>.- The O'Neil fault is a reverse fault of about 200 feet vertical displacement, and 80 feet horizontal displacement. It cuts the Hecla East Vein on the

west, strikes a little east of north and dips approximately 45 degrees to the west. Movement of the hanging wall, as indicated by striae, was about 60 or 70 degrees southeast. The fault is easily recognized by the presence of gouge, drag or oxidized ore.

Mining.- Mining has been carried on extensively in the Hecla East Vein, but it has been confined entirely to the downthrow side of the O'Neil fault. The ore is stoped out along the entire width of the ore body, but when the fault is reached it stops abruptly. Therefore the lateral extent of mining is determined on the north and south by the country rock, on the west by the O'Neil fault, and on the east by the size and grade of the ore vein, because as has already been stated, the vein pinches out toward the east. The vertical extent of mining and the No. 3 Tunnel have already been mentioned.

Minerals.- In order to avoid a repetition of the general characters of the minerals observed, in the descriptions of the ore samples from the different levels, each mineral will be briefly described below.

Galena occurs massive and constitutes the chief mineral of the deposit. The coarsest galena examined showed cleavage faces from 2 to 4 mm. square, but generally it is much finer grained than this. The fine-grained galena is commonly known as steel galena because freshly fractured surfaces have a steel-like luster. In all of the specimens examined, this steel galena appeared to be an intimate mixture of galena, tetrahedrite, sphalerite, pyrite, gangue, and other minerals present in the ore.

Boulangerite occurs in fine-grained, lense-shaped, masses in the flowage or schistosity planes of the coarser galena. In hand specimens, it is very likely to be mistaken for tetrahedrite, but a knife scratch will immediately show that it is too soft. In polished sections, it is difficult to distinguish from galena but careful examination will show that it has a slight creamy color and that the characteristic triangular cleavage of galena is absent. It is most readily found by etching the galena with ferric chloride, which blackens the galena and leaves the boulangerite unaffected as white masses. Microchemical tests showed that the boulangerite contained both silver and copper, indicating that some of the lead was replaced by those metals. Before the blowpipe, arsenic fumes were given off indicating a replacement of some of the antimony by arsenic.

Tetrahedrite is very abundant in some parts of the vein and always occurs in very small particles which have resulted from breaking and replacement. It was impossible to make microchemical tests on the tetrahedrite for silver, because the particles are so small that they can not be cleanly separated from the other minerals. Tetrahedrite is difficult to distinguish in the hand specimens, but its presence is sometimes shown by the blue color of some surfaces, due to the alteration of the tetrahedrite to covellite.

Freibergite occurs in small particles throughout the ore, and is closely associated with the tetrahedrite. It can not be readily detected in polished sections unless it is first etched with nitric acid or potassium cyanide. These reactions distinguish it from tetrahedrite.

Sphalerite occurs in relatively small amounts. It is massive and usually in small particles which have resulted from the crushing in the ore body. The breaking of the sphalerite is quite clearly shown by the numerous small particles which have been broken away from and remain near the larger particles of sphalerite.

Pyrrhotite occurs massive and usually is quite abundant. It is extremely broken into small particles and occurs scattered throughout the ore, and is also strung out in somewhat parallel rows in the galena flowage zones.

Pyrite occurs massive and quite abundantly, especially where the ore comes in contact with the gangue. Where it occurs in the galena ore it is usually in small individual cubic crystals. Many of the larger crystals have been broken and subsequently filled with galena and gangue. The smallest individual pyrite crystals were found included in the boulangerite lenses.

Chalcopyrite is quite abundant and occurs in stringers and large masses, replacing and cutting the other minerals of the ore. It is abundant near the contact of the ore and gangue.

Covellite was observed only in the partly oxidized ore where it occurred in very small amounts, replacing the galena. Some of the slightly oxidized surfaces of the steel galena have a blue tint due to the presence of covellite.

Cerussite occurs abundantly in the oxidized portions of the vein, both massive in the limonite-stained crushed ore and as well defined crystals in vugs. The massive cerussite shows that it is a direct alteration product of galena.

Limonite occurs finely divided in the oxidized portions of the vein and is the result of the oxidization of the pyrite and pyrrhotite.

The non-metallic gangue minerals are quartz, siderite, calcite, and chlorite. The latter occurs only as a chlorite rock where crushing and slipping has been greatest.

Ore Samples Examined.- In describing the various ore samples, it has been found convenient to discuss them in descending order of their occurrence in the vein, describing first, those of the upper levels, and lastly, those of the lowest level.

1. Sample from vein crossing vertical raise to surface, 300 feet above the top stope (57th Floor). The vein at this point consists of oxidized material about two feet in width, and is well defined by quartzite above and below it. The ore consists of broken gangue minerals, chiefly quartz, with considerable amounts of limonite, and calcium and lead carbonates. It has been so completely oxidized that there are no metallic sulphides remaining.

2. Sample from the 30th Floor close to the fault. On this level, the ore has been nearly completely stoped out. On the east side, the vein pinches out to a narrow fissure showing no ore but about two inches of quartz. On the west the vein is cut by the O'Neil fault.

The ore is a high grade silver ore, assaying 55.2 per cent. lead and 32.8 ounces of silver. Because of the oxidized character of the ore, only very poor sections could be obtained, but even these showed interesting features. The most characteristic feature was the alteration of galena to cerussite. This alteration could be seen in all stages, from nearly all galena with a small amount of cerussite or all cerussite with a few tiny residual specks of galena. When the galena was etched with ferric chloride, small rounded white unetched specks remained, which gave reactions similar to those of boulangerite but the particles were so small that the chemical tests may not be quite dependable. Where alteration has not greatly affected the galena, the ore has the characteristic steel luster. Where alteration has been active, the ore has a sooty appearance due to the presence of covellite. Other parts of the ore contain well developed cerussite crystals in vugs, while most of it is stained yellow by limonite. Sphalerite occurs sparingly as residual rounded particles. Pyrite usually occurs as unaltered individual crystals in the quartz, but some smaller crystals occur in the galena. As no tetrahedrite or chalcopyrite were observed, the small amount of covellite replacing the galena, may represent their alteration product.

The high silver values can only be accounted for by assuming that it is included in the remaining cerussite, and partly altered galena, as a result of the oxidization of freibergite, and silver bearing boulangerite, of which only a few minute particles remain. Just in what state it is can not be determined in this sample, but very likely it is metallic or as cerargyrite, and so finely divided that it can not be observed in polished sections.

3. Sample from the 31st Floor of the 68th Raise. This is a relatively high grade ore, assaying 20 ounces of silver and 40 per cent. lead. It is a typical steel galena consisting of galena, gangue, pyrite, tetrahedrite, pyrrhotite sphalerite, chalcopyrite, and freibergite. All of these minerals, except some of the galena and the chalcopyrite, appear to be primary because they all show the affects of breaking. The rounded particles of sphalerite, the borders of many tetrahedrite particles and the gangue appear to be replaced by galena, which indicates galena of a later age than that present before the breaking and crushing of the vein. Pyrite occurs in small individual crystals throughout the ore. Pyrrhotite is also quite abundant and is extremely broken up. Chalcopyrite is the latest mineral to be deposited in this ore and is seen cutting all of the other minerals present.

The high silver content of this ore can be consigned to the freibergite which is present in small particles having the same appearance as the tetrahedrite. Tetrahedrite is quite abundant and possibly some of the silver may be included in it. No boulangerite was observed in the sample.

4. Sample from the 18th Floor above No. 3 Tunnel. This specimen is a fine grained steel galena, which shows the effects of crushing very distinctly. Minor fracture planes are present and are somewhat slickensided from slight movement. The ore also shows the effect of percolating solutions which have removed the galena, sphalerite, and softer gangue minerals, leaving the pyrite with a honeycomb structure. Besides the gangue minerals, pyrite, pyrrhotite and galena are the most abundant, with sphalerite, tetrahedrite, chalcopyrite and freibergite in smaller amounts. Hand specimens do not show any marked structure, but the polished sections reveal a definite flow structure, in which the broken particles of the primary minerals are suspended in the flowage zones of the galena.

This ore is also quite high grade, assaying 17 ounces of silver and 19.1 per cent. lead. The silver can again be assigned to the freibergite and possibly partly to the tetrahedrite.

The ore is so extremely crushed that little can be said definitely about the order of deposition of the minerals.

There are, however, indications of two ages of galena, and the chalcopyrite again shows clearly that it is secondary and is the last mineral to be deposited.

5. Sample from the 18th Floor above No. 3 Tunnel, close to the foot of the fault. This ore is a steel galena with an unusual amount of pyrrhotite. Between the quartz and chloritic gangue, and the galena ore is a considerable amount of siderite. The ore itself shows a roughly banded structure of alternating bands of galena, pyrrhotite and chalcopyrite. In polished sections, this banded flow structure is much more pronounced. See Plate V . Tetrahedrite, pyrrhotite, pyrite and the gangue minerals all show an arrangement of their broken particles in somewhat parallel rows in the flowage zones of the galena. Often the tetrahedrite particles are completely surrounded by broken particles of pyrrhotite in the flowage zones and this is conclusive proof that the tetrahedrite is a primary mineral. Galena also shows a second stage of deposition in that it replaces the siderite, sphalerite and is probably the cause of the rounded shape of the tetrahedrite particles. Tetrahedrite is very abundant, especially where the pyrrhotite occurs. In these portions, the broken particles of tetrahedrite and pyrrhotite are cemented together by a groundmass

of galena. Chalcopyrite again appears to be the latest mineral deposited and can be seen cutting the other minerals present. It is in this sample that the replacement of galena and siderite by chalcopyrite is very distinct, and also the alteration of tetrahedrite to chalcopyrite as described under the minerals.

Freibergite is present and occurs associated with the tetrahedrite. Other than this, no more silver minerals were found in the sample. No assay values were given for this sample but it is probably of the same grade as the sample from the 18th Floor, just described.

6. Sample from back of broken stope on the 16th Floor, above No. 3 Tunnel. This specimen proved to be of considerable interest because of the abundance of silver bearing boulangerite. The boulangerite is confined entirely to the flowage or schistosity planes of the rather coarse galena and is, therefore, of secondary origin. If cut perpendicular to the flowage, the boulangerite appears as elongated oval areas arranged roughly end to end, but if cut parallel to the flowage, the areas of boulangerite exposed are much larger. This indicates that the boulangerite occurs in roughly lens-shaped areas in the flowage planes. Slight subsequent movement may have aided in the formation of these

lenses. The galena of this sample is much coarser than that of the other ore specimens but it shows a very definite flow or schistose structure. Pyrite, sphalerite, chalcopyrite and tetrahedrite are nearly absent in the coarse galena but near the contact of the galena and gangue, they appear more abundantly. Near the contact the galena also becomes much finer grained.

The silver in this specimen can be assigned entirely to the boulangerite because it is silver bearing, and occurs in considerable quantities.

At the 16th Floor, the vein is very pronounced, averaging about three feet in width. Toward the east it fingers out into poor seams while toward the west it reaches a width of 15 to 20 feet, and is especially big below the O'Neil fault which cuts it off.

7. Sample from the 600 Foot Level. On the 600 foot level, the vein splits and generally the ore is not of very good grade. The sample examined is another typical steel galena, formed by intense crushing. It breaks freely along surfaces which have been formed by minor slipping and along these, descending solutions have deposited a thin layer of clayey material, and have caused some of the tetrahedrite to be altered to covellite which gives the surfaces

a bluish tint. Flow structure shows up well in the polished sections but it is obscured in the hand specimens because of the intense crushing which took place. Galena is the chief mineral and in it are suspended the broken particles of the other minerals. Tetrahedrite is abundant and has been extremely broken and partly replaced by galena and chalcopyrite. Chalcopyrite again appears as a secondary mineral of later deposition than the others. Sphalerite occurs more abundantly and in larger masses than in the ore farther up in the vein. It shows characteristic breaking due to movement and also rounding of particles due to replacement by galena. Pyrite and pyrrhotite are also abundant, and are broken into small particles. The pyrite also occurs in small cubic crystals.

Neither boulangerite or freibergite were noticed in this ore.

CONCLUSIONS

Occurrence of Silver.- The only silver minerals found in the examination of the Hecla East Vein ores were freibergite, and boulangerite, which microchemical tests showed to contain silver. Because boulangerite is confined nearly entirely to the coarse galena which does not show high silver values, and because freibergite occurs only sparingly, it may be safe to assume that some of the silver is also contained in the abundant tetrahedrite but not in high enough percentages to give the tetrahedrite the freibergite composition. Tetrahedrite and freibergite were not observed in the rich, partly oxidized ore and boulangerite occurred only in extremely small specks, therefore, the silver must now be so finely divided and thoroughly mixed in the oxidized ore, that it can not be observed in polished sections.

Paragenesis.- Because of the extremely broken character of the ore it was difficult to determine accurately the order of deposition of the different minerals, however, the following conclusions arrived at through the examination of the polished sections seem to be logical.

It appears that the original ore body consisted chiefly of galena, sphalerite, pyrite, pyrrhotite, tetrahedrite freibergite, quartz and siderite. When movement took place along the O'Neil fault and possibly along other minor slips, the ore body was greatly crushed, during which time the galena acted as a putty-like mass for the suspension of broken fragments of the harder minerals. This breaking resulted in the formation of the typical steel galena. At the same time, numerous cracks were formed in the quartz and siderite, and a chloritic rock and gouge were developed along the larger planes of movement.

The arrangement of the mineral fragments shows clearly that the galena acted as a putty-like mass and also shows conclusively the primary character of some of the minerals. The broken pyrite crystals, the particles of tetrahedrite, freibergite, sphalerite and pyrrhotite all show a stringing out and a definite arrangement parallel to the flowage of the galena. The primary character of the tetrahedrite is more clearly brought out by the fact that some of the particles are completely surrounded by broken pyrrhotite particles. (See Plate VI).

After the breaking and crushing of the ore body, mineral bearing solutions could circulate through it freely. This resulted in a deposition of the silver bearing boulangerite along with very small pyrite crystals, in the flowage or schistosity planes of the coarser galena. Included in the lenses of boulangerite are numerous small individual pyrite crystals that may be of about the same age as the boulangerite.

Two ages of galena are also evident. First, the galena of the original ore body which acted as a putty-like mass for the suspension of the broken particles of the other minerals; second, a later stage, probably soon after the breaking occurred, which can be seen replacing the siderite and sphalerite, and which is possibly responsible for the rounding of some tetrahedrite particles. This second age of galena has also filled some of the cracks in the gangue which were caused during the faulting. It is assumed that these stringers or veinlets of galena are later than the original galena because they do not show transverse cracks or displacements which would surely show if they had been present before movement took place in the vein.

Chalcopyrite was deposited later than the faulting of the vein and was the last of the sulphide minerals to be precipitated. It is seen cutting and replacing the galena, tetrahedrite, sphalerite and siderite, and filling many small cracks, especially in the gangue.

Slight movement took place subsequent to the deposition of the chalcopyrite and developed small cracks which have since been filled with calcium or lead carbonates. These small stringers of carbonate can be seen cutting across chalcopyrite stringers, sphalerite particles and across the general direction of flowage of the galena.

Oxidization then took place, chiefly along the fault plane, resulting in the alteration of (1) galena to cerussite, (2) pyrite and pyrrhotite to limonite, (3) tetrahedrite and chalcopyrite to covellite; and (4) the oxidization of freibergite and boulangerite leaving the silver finely divided in the oxidized ore.

STAR VEIN.

General Description.- The Star Vein lies immediately to the north of the Morning Vein, about two miles northwest of Mullon, Idaho.

It is a poorly defined, metasomatic vein in the Revett quartzite and varies considerably both in direction and width. In many places it is a poorly defined, low grade quartz vein, and in other places considerable quantities of lead-zinc ore have been stoped out. The main stopes are in the Evening Star fraction. Toward the west, on the Morning Star claim, and toward the east, on the Evening Star claim, the vein narrows and becomes very poor grade.

About 500 feet from the east end of the workings, the vein was interrupted by a small dike. The mine map shows, instead of a continuity of the vein on both sides of the dike, an offset of about 200 feet. This offset can hardly be due to a fault because the Morning Vein, which is well defined, shows no offset at this point, and besides, the directions of the veins on both sides of the dike are not the same. It is, therefore, probable that the offset of the vein at the dike is due to replacement along different fissures.

The Star Tunnel, which has its portal at an elevation of 4,596 feet, is the main entrance to the Star workings.

The Morning Vein, which is well defined with a steep dip toward the north, is evidently independent of the Star Vein which is poorly defined and has a steep dip toward the south. A dip of 75 degrees south-southeast was indicated on the mine map, for the Star Vein at Star No. 1 Tunnel, elevation 5,334 feet. The dip was also brought out on the same map where an extension of the No. 5 Tunnel of the Morning Mine encountered the Star Vein on the Evening fraction. The portion of the vein which was encountered by this tunnel is at an elevation of 4,185 feet, to the south and parallel to the Star Vein workings which are at an elevation of 4,620 feet. The horizontal distance between these two levels averages about 40 feet, which with the vertical distance of 445 feet between the levels, indicates a dip of about 85 degrees to the south.

Minerals.- Sphalerite was the most abundant ore mineral present in the specimens examined. It is massive, very fine-grained and relatively dark in color. Its dark color may, however, be due to its fine grain, rather than to a high iron content.

Galena is the next important ore mineral. It is also massive but occurs nearly entirely as steel galena. The workings.

The Morning Vein, which is well defined with a steep dip toward the north, is evidently independent of the Star Vein which is poorly defined and has a steep dip toward the south. A dip of 75 degrees south-southeast was indicated on the mine map, for the Star Vein at Star No. 1 Tunnel, elevation 5,334 feet. The dip was also brought out on the same map where an extension of the No. 5 Tunnel of the Morning Mine encountered the Star Vein on the Evening fraction. The portion of the vein which was encountered by this tunnel is at an elevation of 4,185 feet, to the south and parallel to the Star Vein workings which are at an elevation of 4,620 feet. The horizontal distance between these two levels averages about 40 feet, which with the vertical distance of 445 feet between the levels, indicates a dip of about 85 degrees to the south.

Minerals.- Sphalerite was the most abundant ore mineral present in the specimens examined. It is massive, very fine-grained and relatively dark in color. Its dark color may, however, be due to its fine grain, rather than to a high iron content.

Galena is the next important ore mineral. It is also massive but occurs nearly entirely as steel galena. The steel galena of the Star Vein, however, differs from that of the Hecla East Vein, in that very little gangue or other minerals are mixed with it. Another feature of the galena is a peculiar curly structure which appears to have developed as the result of movement after deposition of the ore.

Pyrite occurs both massive and as small individual crystals, and is usually most abundant near the contact of the gangue and ore minerals. The larger masses of galena and sphalerite are generally quite free from pyrite.

Pyrrhotite occurs only in small isolated amounts, scattered through the ore.

Chalcopyrite was noted only in one specimen of those examined, and there only as very small residual masses.

Boulangerite occurs as small residual specks in the larger galena masses in which other minerals are practically absent.

The gangue consists of massive white quartz, siderite, sericite, chlorite, kaolin, quartzite and monzonite.

With the exception of a few veinlets of sphalerite, the quartz is relatively free from ore minerals. It is generally massive and white in color.

Siderite is the chief gangue mineral which has been affected by replacement of the ore, and now remains only as residual masses.

The quartzite is gray, massive and fine-grained, and shows fracturing which has resulted from minor slips or faults. Some replacement has also taken place, and near the quite sharp contact of the ore and quartzite, pyrite has been deposited in the quartzite.

The monzonite sample available was greatly sheared and contained small amounts of pyrite and sphalerite.

Sericite, chlorite and kaolin are the results of alteration of the original minerals and none occur very abundantly.

Ore Samples Examined.- Only five ore samples, taken from various parts of the vein, were available for examination.

Sample No. 1. This specimen, probably taken from near the contact of the ore and wall rock consisted of white quartzite, sphalerite and pyrite, with small amounts of galena. The sphalerite not only occurs massive but also as small veinlets in the quartzite, associated with pyrite and small amounts of galena. It can be seen that movement has taken place to a small extent, by the presence of sericitic and chloritic material which has developed along small slip surfaces.

Sample No. 2. A relatively pure zinc ore consisting chiefly of sphalerite occurs massive and replaces the siderite which remains only as large residual particles. Steel galena replaces the sphalerite and siderite, generally along cracks which have been developed by crushing. Included in the galena are scattered, very small particles of boulangerite which were evidently deposited at the same time as the galena. The noticeable features of this specimen are, abundance of sphalerite, quite large residual masses of siderite, and veins of steel galena replacing both the sphalerite and siderite.

Sample No. 3. This specimen is similar to the one just described but differs slightly in that the remaining siderite is less abundant and that the amount of galena present is greater. The residual sphalerite particles are smaller and consequently more numerous than in the preceding sample. This is due to greater replacement by the steel galena.

Sample No. 4. This sample contains considerable white quartz included in massive sphalerite. Bordering the quartz is a considerable amount of pyrite, all of which is included in the sphalerite. The galena again appears in veinlets replacing the sphalerite. It shows, on freshly broken surfaces, both the characteristic steel galena luster and the peculiar curly structure. Siderite occurs only in very small amounts.

Sample No. 5. This specimen represents a relatively high grade lead ore, consisting of steel and curly galena with residual masses of sphalerite and siderite. The sphalerite generally includes particles of siderite which have not been entirely replaced. Pyrite and pyrrhotite occur only in extremely small amounts. Boulangerite occurs also in this specimen but its manner of occurrence will be taken up in detail in the discussion of the paragenesis of the ore.

CONCLUSIONS.

Occurrence of Silver.- The ore of the Star vein is all relatively low grade. In the polished sections examined, the only mineral found, other than galena, which might possibly contain silver, was boulangerite. The particles of boulangerite were so extremely small that none of the material could be obtained to verify the presence of silver by microchemical tests, but because the boulangerite of the Hecla East Vein was silver bearing, it was thought that the small amount of silver in the Star Vein could be assigned to the same mineral. The extreme small size of the particles, their scattered positions in the galena, their irregular boundaries, and their absence in some sections, indicate that they were deposited with the galena. Although the boulangerite was not observed in all of the sections it is probable that it occurs quite generally disseminated throughout the ore.

Paragenesis.- The order of deposition of the Star Vein ore minerals is quite simple and is about as noticeable in the hand specimens as it is in the polished sections.

The primary minerals consisted of quartz, siderite and pyrite. Then, at the time of, or subsequent to the intrusion of the monzonite, solutions carrying zinc entered the vein, causing a nearly complete replacement of the siderite by sphalerite. Some pyrite was possibly also deposited at this time as indicated by the small individual crystals included in the sphalerite.

Subsequent to the deposition of the sphalerite, galena was introduced and replaced a large amount of the sphalerite and some of the siderite. The sphalerite remaining in the galena, with the exception of the larger masses, occurs as rounded residual particles left by replacement.

The pyrite remains as residual, unreplaced masses and individual crystals, and is for the most part primary. The tiny crystals in the sphalerite indicate that they were introduced with it.

Although some movement has taken place in the ore body, the results of it are not very marked in the galena-sphalerite ore itself. It appears that the replacement of sphalerite was quite rapid because the steel galena includes only rounded replaced particles of sphalerite and siderite. If the steel galena had been formed mainly by crushing, and not by rapid replacement and precipitation, the particles of included minerals in the galena would show some effects of the crushing, such as irregular boundaries or arrangement of particles along flow lines. The absence of irregular particles, flow structure, and the small amount of foreign mineral particles in the galena would indicate that its steel-like character was due more to rapid precipitation than to crushing. The curly galena is, however, probably due entirely to crushing.

The small amount of boulangerite present was introduced with the galena. This conclusion was arrived at because none of the particles showed any characteristics of replacement.

The age of the chalcopyrite could not be definitely determined because of its rare occurrence. Probably it is of primary origin.

MORNING MINE.

General Description.- The following is a summary of the description of the Morning Mine as given by Ransome[1].

"The Morning Mine has its principal underground workings about two miles north-northeast of Mullan, in a steep ridge separating Mill Creek and Grouse Creek."

Prior to 1906, No. 5 Tunnel was the principal one through which the ore was hauled, and from its portal, the ore was taken to the mill in trains of 6 or 7 cars, each of 25 tons, drawn by shay geared locomotives. In 1906, No. 6 Tunnel was completed so that the ore could be delivered directly from the mine to the mill. This tunnel has its portal opposite the Morning Mill, is 11,000 feet long and intersects the veins of the Morning Mine, 1,000 feet below the No. 5 Tunnel.

The geological structure, in the vicinity of the Morning Mine is somewhat obscured on account of complex folding, faulting, unsatisfactory exposures and lack of distinction of the rocks. No. 5 Tunnel enters the green-gray slates of the Wallace formation on the west side of Mill Gulch, and continues in them nearly to where it intersects the

---

(1) Ransome & Calkins: U.S.Geological Survey, Prof.Paper 62, 1908.

Morning vein. Inclosing this area of Wallace formation of Mill Creek is the St. Regis formation which forms the ridges on the east, north and west sides. Underlying the St.Regis, is the Revett quartzite in which nearly all of the ore occurs. This quartzite has been subjected to stresses and movement as shown by a prominent slaty cleavage, and is, therefore, difficult to distinguish from the Wallace formation. The slaty cleavage is most conspicuous in the southeastern part of the mines.

About 15 feet east of the Morning vein, a dike, about two feet wide, is present between the Wallace and Revett formations. It strikes northwest and southeast, and dips northeast. Faulting has, also, taken place along this dike, and although the faulting has been observed at several levels, it is not of great displacement.

No. 6 Tunnel is confined to the Revett quartzite with the exception of a part of the north end, which is in the St. Regis formation. It cuts the Osborn fault and, also, a second fault, 3,500 feet north of the Osborn fault. It is at the location of the latter that the change from the Revett quartzite to the St. Regis formation, takes place.

Several small dikes have been cut in the Morning Mine, but apparently they have had little influence in the ore body itself.

The two principal veins of the Morning Mine are the Morning Vein and the You Like Vein. The Morning vein is the largest of the two and has been explored a length of about 3,000 feet, 2,000 of which have been productive. This vein varies from 3 to 40 feet and averages 9 feet in width. The You Like vein has been explored for 1,500 feet but only 800 feet were productive.

Both lodes are quite simple, persistant, and relatively undisturbed by faulting or folding.

"Structurally, the Morning and You Like lodes are metasomatic fissure veins, in zones of close sheeting which follow, or cut at small angles, the prevalent slaty cleavage of the quartzite."

The ore has been deposited along many small fissures as sheets, or lenticular masses, or as bunches at the intersection of fissures. There is no marked contact between the ore and the wall rock, but the ore gradually gets poorer by decrease of galena content. The presence of numerous fissures enabled circulation to take place readily, and allowed many **surfaces** of dolomite to be exposed to these circulating waters, thus making it easy for the ore to replace the dolomite.

"So far as developed, the pay shoots seem to have a vertical pitch and appear to be increasing rather than decreasing in length on the lower levels." A schist horse in the Morning vein, divides the ore shoot for a distance of about 800 feet along the No. 4 level, but generally, the ore at corresponding points on opposite sides of the horse, is similar in size and value.

The ore is usually low grade, averaging from 7 to 9 per cent. lead, and 3 to 4 ounces of silver per ton. The oxidized ore of the upper levels was much richer. Galena, the principal ore mineral is associated with sphalerite, pyrite and a little pyrrhotite. The gangue minerals are siderite, barite, and quartz.

Although the oxidized ore of the upper levels was very rich, there does not seem to be much change in the character of the ore below the 200 foot level. The mine is generally wet, but the water evidently percolates down from the surface and the mine is probably still (1904) above the general groundwater level.

Minerals.- Galena is the most important and most abundant of the minerals in the Morning Mine. Its common occurrence is as steel galena, and as curly galena which is crushed galena with peculiar curly-like fracture surfaces.

Sphalerite is the next abundant mineral. It is fine-grained, dark in color, quite fractured in the larger masses, and very often it is full of minute pyrite crystals and chalcopyrite particles.

Pyrite is quite abundant in some specimens and nearly absent in others. It is generally most abundant in the gangue near the contact with the sulphide minerals. In the partly altered ore it occurs as small irregular masses or broken crystals, while in the gangue it is usually in well-formed, small cubic crystals.

Tetrahedrite was observed in a few specimens but only as small residual masses in the galena.

Chalcopyrite, also, occurred quite sparingly and was always associated with the sphalerite in which it was disseminated.

The silver-bearing minerals identified in the ores of the Morning Mine were silver, argentite, boulangerite, and polybasite (?). These will be discussed separately in detail under "Occurrence of Silver".

Cerussite is not very common but occurred as a coating of small crystals over a layer of sandy gouge on one of the specimens of gangue. It may, however, also be present to some extent in the slightly altered, broken ores.

The gangue consisted of lamprophyry, quartzite, quartz, siderite and barite. Alteration products, such as chlorite, limonite, kaolin and gouge are also present to some extent.

Ore Samples Examined.- Samples from Picking-belt. Of these, only four specimens were available, two of which consisted chiefly of an altered chloritic schist penetrated by small veins of sphalerite, introduced along the schistosity planes. These veins vary from small fine stringers to half an inch in width. The sphalerite in the veins is black, massive, and fine-grained. Included in it are numerous small pyrite crystals with definite crystal outlines, which were probably carried in with the sphalerite. Following the deposition of the sphalerite, galena was introduced and is seen replacing the sphalerite. This replacement is generally quite marked along the central parts of the sphalerite veins. Siderite occurs quite abundantly in the veins, and as it shows replacement by the sphalerite and galena it was probably the first mineral to be deposited. Some of the pyrite crystals show replacement, both by galena and sphalerite.

Another sample from the Picking-belt consisted of about half barite and half galena ore. The barite is extremely fine-grained, massive, and white, and includes residual particles of light colored siderite. Siderite was evidently the primary mineral, as shown by the numerous residual particles, left by replacement, scattered throughout the galena and the barite. Sphalerite also occurs massive in the galena but not in very large amounts. It now remains as broken particles and partly replaced residual masses throughout the galena. Apparently it was introduced as one of the primary minerals replacing the siderite. Again, the deposition of sphalerite was followed by the deposition of galena, which can now be seen as the chief mineral replacing the siderite and sphalerite, and penetrating the barite in small veinlets. The deposition of galena was followed by slight movement of the ore body, resulting in a crushing of the galena and a breaking of the siderite and sphalerite masses. The hard specimen, also, shows a quite prominent, irregular streak of coarser galena then the majority of the ground mass, which indicates a probable second age of galena deposition.

Of the minor constituents, which are pyrite, chalcopyrite and tetrahedrite, pyrite is the most abundant and occurs sparingly in the galena and sphalerite but is more concentrated near the contact of the ore and barite. The chalcopyrite is confined to the sphalerite and occurs in small particles. Tetrahedrite occurs very sparingly and is residual in the galena. Sometimes it is associated with the sphalerite.

The fourth sample from the Picking-belt consisted of highly shattered white quartzite with the ore minerals deposited along the fractures. Although the ore is shattered, it shows little effects of alteration.

Steel galena is the chief mineral and in this sample it is very fine-grained. In polished sections, the characteristic triangular cleavage cracks of galena occur in curved lines without any definite direction or arrangement which indicates considerable crushing subsequent to the original deposition. Black sphalerite occurs sparingly and shows both the effects of breaking, and of replacement by galena. Tetrahedrite occurs only in small residual particles left by the replacement of galena. Chalcopyrite and pyrite are practically absent.

The silver minerals present are argentite and polybasite (?). Argentite occurs in very minute, elongated irregular particles in the galena without any definite arrangement and is observed only after the galena has been etched with nitric acid. This leaves the argentite unaffected and the small particles can be seen disseminated through the galena. Polybasite (?) occurs very sparingly and only in minute veinlets, which indicate clearly secondary origin.

Sample from six sets above the 1,250 foot level. This sample represents a typical fine-grained, steel galena and consists chiefly of galena, sphalerite and quartz. Pyrite and calcium and iron carbonates form the minor constituents. Galena, the most abundant mineral, forms the matrix of the other minerals of which sphalerite is the most plentiful. The sphalerite occurs both as rounded and irregular residual masses which indicate both crushing and later replacement by galena. Pyrite is quite abundant and occurs in small masses, nearly all of which show the effects of crushing. Siderite and quartz are the gangue minerals which now remain as residual particles throughout the ore. No silver minerals were observed in this specimen.

Crushed ore. In hand specimens, this ore appears to consist of crushed aggregates of sphalerite, galena and gangue. Some of the material consists largely of steel galena, some largely of sphalerite, and some of galena and sphalerite in about equal amounts. A few of the specimens show quite large fragments of included white quartz. In all of the crushed ore, considerable alteration has taken place, resulting in limonite and gouge. Most of the ore shows just irregular fracturing, but when sections are cut from the ore, some well developed flow structure appears.

The mineral identified in the crushed ore were galena, sphalerite, tetrahedrite, boulangerite, pyrite, chalcopyrite, native silver, quartz, siderite and probably some calcium or lead carbonates.

Galena is again the most common mineral and acts as a groundmass for the other minerals present. It occurs only as fine-grained steel galena. Sphalerite does, however, sometimes form the bulk of the ore. The intimate mixture of the galena, sphalerite and the other minerals is primarily due to crushing as shown by the irregular boundaries of the particles, but subsequent replacement by galena has also taken place. The minerals affected by galena replacement were sphalerite, tetrahedrite, pyrite and the gangue minerals. The galena shows the intense manner in which it was crushed by the irregular arrangement of the triangular cleavage cracks.

Sphalerite is the next abundant mineral and occurs in broken and rounded fragments throughout the ore. The borders of these fragments show both irregular boundaries due to crushing and breaking, and smooth boundaries due to replacement by galena.

Tetrahedrite occurs in small residual particles which are now being replaced by chalcopyrite. The tetrahedrite particles present are probably the remnants of larger masses which have been replaced by galena, for some of them are penetrated by small galena stringers.

The presence of boulangerite is quite doubtful although in one specimen reactions were obtained on several small specks which resembled boulangerite.

Native silver was noted in only two of the sections cut. In one section there were only a few very small particles, but in the other there was a quite pronounced vein of native silver which had been deposited in a fracture along with a gangue mineral which was probably cerussite. The occurrence of silver in the fracture indicates secondary origin.

Chalcopyrite occurred very sparingly and was generally associated with the sphalerite or tetrahedrite.

Sample from West face of the 1,850 foot level. This was representative of a brecciated portion of the vein and consisted mainly of large irregular masses of white and bluish-gray quartzite cemented together by steel and curly galena. Small pyrite crystals usually occur quite abundantly in the quartzite near the galena contacts.

In polished section, the minerals identified were galena, sphalerite, pyrite, boulangerite, argentite, quartz and siderite. The galena shows numerous irregular rows of triangular cleavage cracks which indicate clearly intense crushing. It replaces the siderite and sphalerite, both of which remain only in small amounts as scattered rounded particles in the galena. Pyrite, though not very plentiful, occurs as small broken crystals associated with the quartz. Boulangerite and argentite occur disseminated through the galena in small amounts and were probably introduced with the galena. The effect of brecciation is best shown by the arrangement of the galena cleavage cracks and by the quartz which occurs in extremely broken masses.

Sample from West face of 1,850 foot level. This sample appears to be from a portion of the vein which has not been replaced by sulphide minerals to as great an extent as that from which the preceding sample was taken. It consists of white quartz, light colored siderite, galena and barite. Sphalerite and pyrite are present but only in small amounts. In section, the replacement of quartz by siderite, and siderite and quartz by galena are clearly noticeable. The barite in the hand specimen appears to have been deposited before the siderite because it has veinlets of siderite and galena in it. Sphalerite remains only as small residual masses, often in the quartz, though more often in the siderite which it replaces. Pyrite is nearly entirely absent.

Sample from the Star cut at the Morning Vein. This is crushed and broken ore consisting chiefly of black, fine-grained sphalerite, siderite and chloritic gangue. In polished sections, the replacement of the gangue by sphalerite is very evident and the result of breaking can also be clearly seen. The effect of crushing and breaking is, however, more noticeable in the hand specimens in which the sphalerite has a shattered appearance, and where movement and alteration have developed chloritic gangue. Pyrite occurs both as tiny crystals in the sphalerite masses and as large crystals in the gangue. Only small amounts of galena and chalcopyrite occur in this ore and both are disseminated throughout the sphalerite in small amounts. They were probably both introduced after the crushing which followed the sphalerite deposition, but it is also possible that the chalcopyrite was deposited with the sphalerite.

Five samples of gangue material were available, but these will be discussed only briefly.

Sample from the lamprophyre dike on the 1,250 foot level. This is a fine-grained, greenish-gray rock which has been subjected to faulting as shown by the slickensided surfaces. No sulphide minerals are present in it and only a small amount of calcite has been deposited along the fault planes.

Two samples of gangue material were from the 1,050 foot level. One consisted of altered siderite and chloritic material but showed no evidence of mineralization. The other consisted of altered chloritic schist, similar to the material described under the Picking-belt samples, which was penetrated with small veinlets of sphalerite and galena. Besides these veinlets there was also a drusy coating of tiny cerussite crystals covering a thin layer of gouge which had been formed along a slip plane. These small crystals held the fine sandy gouge intact.

A sample of greenish-black, fine-grained quartzite from the west end showed the effects of mineralization in that galena and sphalerite veinlets penetrated it.

A green quartzite from the No. 55 raise of the 400 foot level also showed mineralization, but in these samples the quartzite was cut by quartz stringers, most of which contained some sphalerite and galena.

CONCLUSIONS.

Occurrence of Silver.- Although the ore of the Morning Mine is low in silver, four silver bearing minerals were identified in the polished sections of the ore. These minerals were native silver, polybasite(?), argentite, and boulangerite.

Native silver was observed in only two sections. In one, only a few irregular specks, apparently replacing the galena were visable; in the other, there was a definite veinlet of silver in a small fracture in the galena. The fracture was not entirely filled with silver but also contained some gangue which was probably lead or calcium carbonate. This deposition probably took place at a depth of only a few hundred feet below the surface in the oxidized zone, although the depth may have been greater in this case because the groundwater level is low, over 1,750 feet, in the Morning Mine.

Polybasite (?) was observed only in one section which was from a very broken ore through which solutions could easily have percolated and caused its precipitation. The chemical reactions were quite indefinite but checked better with polybasite than with the other silver minerals.

Both the native silver and polybasite (?) were among the last products to be precipitated and each has replaced the galena to some extent.

When the galena of some sections was etched with nitric acid, minute white specks remained unetched. These are probably disseminated argentite.

Similarly, small white areas were left when some of the sections were etched with ferric chloride. These small areas gave reactions which indicated boulangerite. These reactions were also quite indefinite so that the identity of the argentite and boulangerite may be somewhat doubtful. It is also doubtful whether or not the boulangerite carries silver because not enough of the material could be separated from the galena to test for silver with microchemical methods.

The tetrahedrite may also be silver bearing but these particles were also too small for microchemical tests.

Of these minerals just described, the tetrahedrite appears to be primary and now remains as residual particles; the argentite and boulangerite were deposited with the galena and occur as small particles, without any definite shape or arrangement, disseminated through the galena; and the silver and polybasite are secondary, replacing the galena.

<u>Paragenesis</u>.- Although the ore of the Morning Vein has been considerably crushed, the order of deposition of the minerals is quite evident.

The primary minerals were probably quartz and pyrite. Then followed a replacement of the quartz and quartzite by siderite. Sphalerite and barite were next introduced and these extensively replaced the siderite. At the same time some chalcopyrite and pyrite may have been carried in with the sphalerite as shown by the small included pyrite crystals and chalcopyrite particles. Tetrahedrite may then have been introduced after the deposition of the sphalerite but tetrahedrite occurs so sparingly and crushing has been so intense that the exact age of the different minerals may be obscured. The tetrahedrite does, however, indicate, where it is in contact with sphalerite in the less broken ore that it may be of a later age than the sphalerite. Deposition of galena then followed and it can be seen replacing the sphalerite, siderite, barite and quartzite. Boulangerite and argentite were introduced with this age of galena and are both disseminated through it.

Following this deposition, was a period of faulting and breaking of the vein, the effects of which can be seen by the broken character of the particles in the ore, and by the presence of a large amount of steel galena. As in the ore from the Hecla East Vein, the galena, changed to steel galena, acted as a putty-like mass for the suspension of the other broken mineral particles. This feature is also well brought out by the very marked flow structure in the broken ores.

Similar flowage has been observed in the ores from Rammelsberg, German[1], Minnie Moore Mine, Bellevue, Idaho[2], and the Slocan district, British Columbia[3]. The character of the ore from the Slocan district is quite similar to the ores described in this paper.

It also appears that a second age of galena was deposited after the crushing because both the sphalerite and siderite particles show the effects of replacement, and because of the presence of a galena vein of different grain cross cutting the main mass of finer galena in one specimen.

---

(1) W.Lindgren & J.D.Irving: Economic Geology, Vol. 6, 1911, p. 303.

(2) Whitman Cross: Proc. Colo. Sci.Soc., Vol. 2, 1887, p.172.

(3) W.L.Uglow: Economic Geology, Vol. 12, 1917, p. 643.

Further breaking of the ore then took place and made openings through which solutions could enter. These supergene solutions resulted in the deposition of silver, polybasite, and calcium, and lead carbonates.

The order of deposition is, therefore, (1) quartz, pyrite; (2) siderite; (3) barite, sphalerite, pyrite, and chalcopyrite; (4) tetrahedrite (?); (5) galena, boulangerite and argentite; (6) galena; (7) silver, polybasite, calcite and cerussite.

ACKNOWLEDGMENTS.

I have greatly appreciated the courteous help rendered by those connected with the Geological Department of the Massachusetts Institute of Technology. Acknowledgment is especially due to Professor Waldemar Lindgren for granting me the privilege of making an examination of the ores here described, and for his valuable assistance and numerous suggestions.

ILLUSTRATIONS

of

ORE SECTIONS

PLATE I.

Boulangerite (Bl) replacing galena (Gn) along schistosity planes. From Hecla East Vein. Magnification 58.

PLATE II.

Boulangerite (Bl) replacing galena (Gn) along schistosity planes. From Hecla East Vein. Magnification 58.

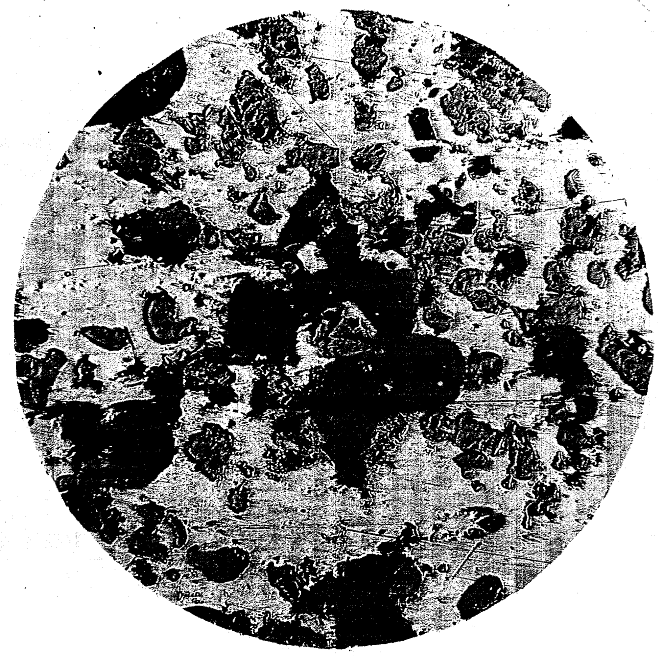

PLATE III.

Steel galena from Morning Mine showing broken particles of sphalerite (light gray) and quartz (black) in galena (white).
Magnification 58.

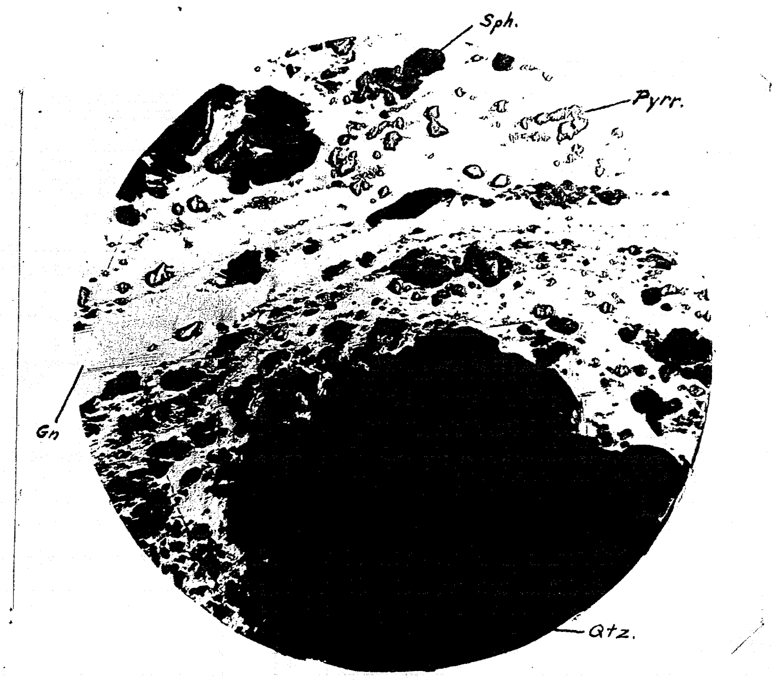

PLATE IV.

Steel galena from Morning Mine showing flowage of broken particles, in galena, around a resistant quartz mass. Quartz (Qtz); galena (Gn); sphalerite (Sph); pyrrhotite (Pyrr). Magnification 58.

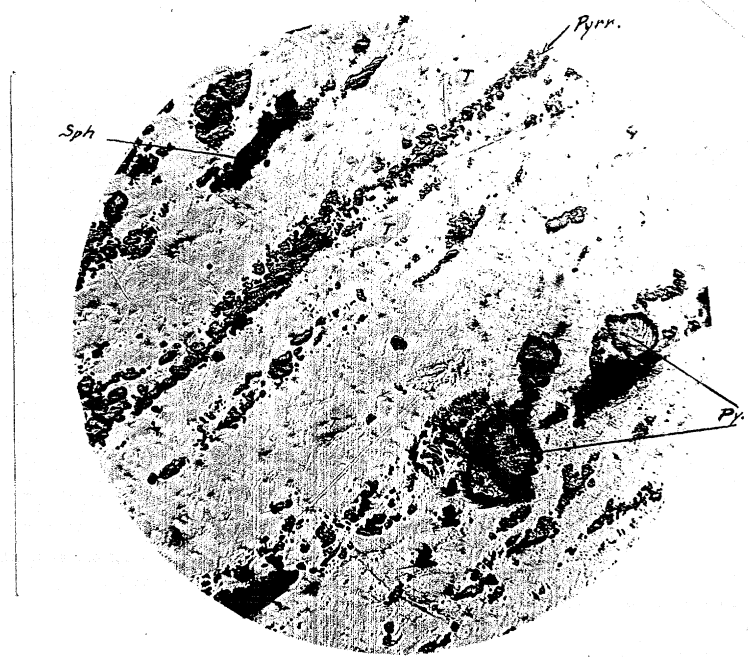

PLATE V.

Steel galena from Hecla East Vein showing schistose structure. Galena (white); sphalerite (Sph); pyrrhotite (Pyrr); tetrahedrite (T); pyrite (Py).
Magnification 58.

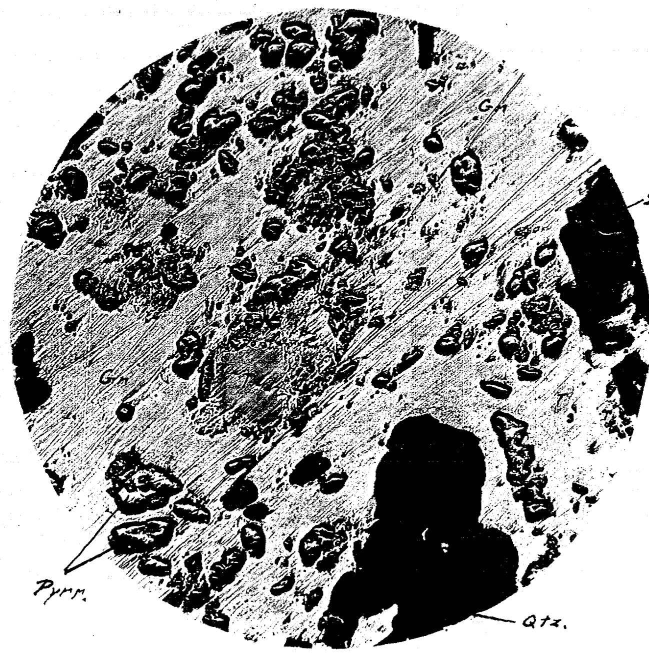

PLATE VI.

Steel galena from Hecla East Vein showing arrangement of pyrrhotite particles around a tetrahedrite mass in the flowage zone. Quartz (Qtz); tetrahedrite (T); sphalerite (Sph); galena (Gn); pyrrhotite (Pyrr).
Magnification 162.

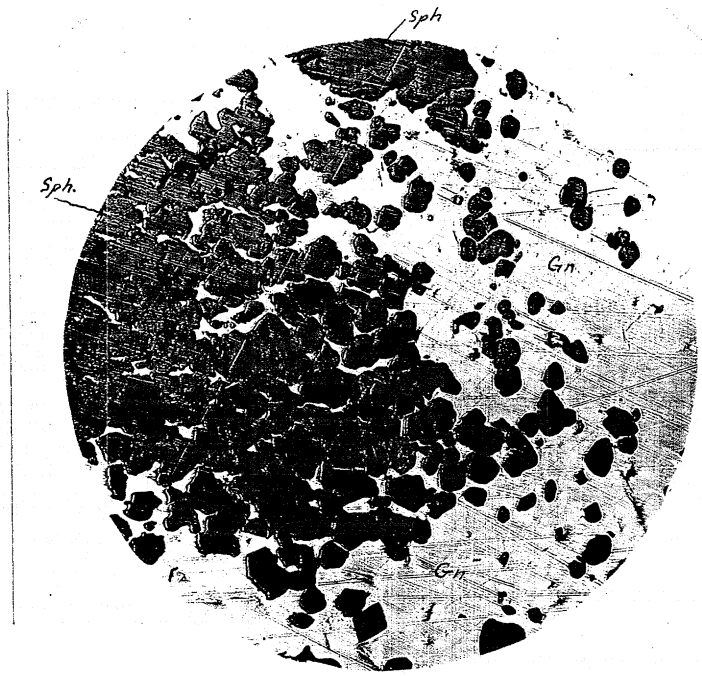

PLATE VII.

Partly broken sphalerite (Sph) being
replaced by galena (Gn). From Star Vein.
Magnification 58.

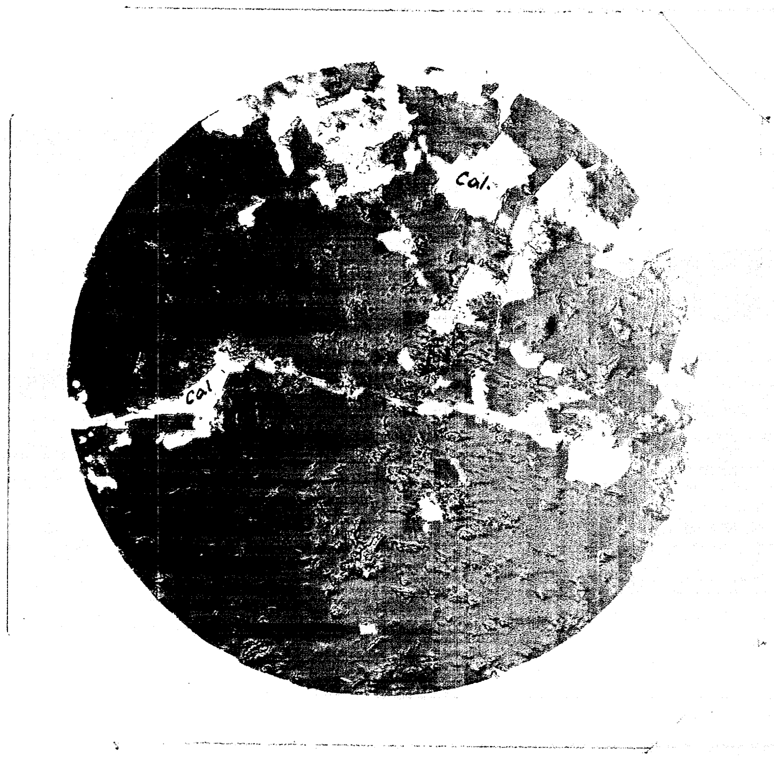

PLATE VIII.

Siderite (Sid) being replaced by chalcopyrite (Cal) and sphalerite (Sph). From Hecla East Vein. Magnification 58.

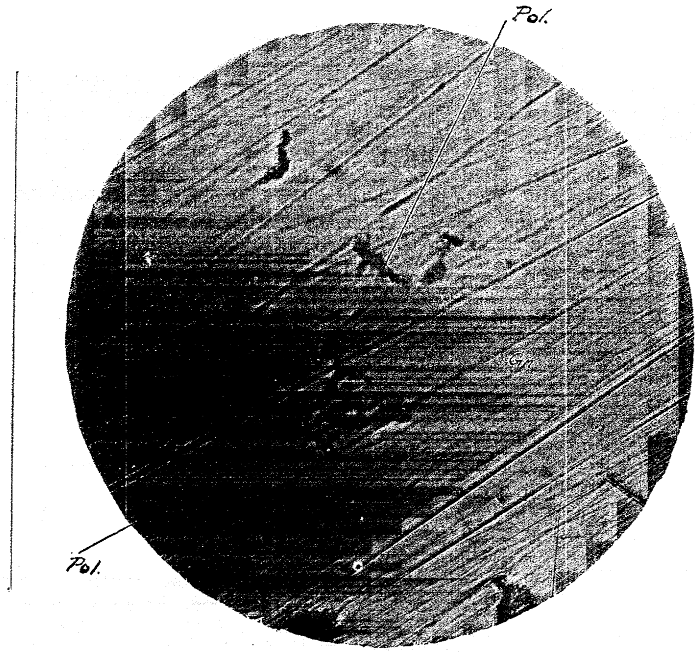

PLATE IX.

Galena (Gn) being replaced by polybasite (?) (Pol).
From Morning Mine. Magnification 162.