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An Investigation of the Ores of the Big Seven Mine, Neihart, Montana

Francis L. Wilson

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ORES OF THE BIG SEVEN MINE,
NEIHART, MONTANA

by

Francis L. Wilson

A thesis
submitted to the Department of Geology in partial fulfillment of
requirements for the Degree of Bachelor of Science in Geological
Engineering.

Montana School of Mines
Butte, Montana
April, 1942
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# Table of Contents

Results ................................................................................................................. 1  
Acknowledgements ............................................................................................. 3  
Introduction .......................................................................................................... 4  
Source of Material ................................................................................................. 6  
Laboratory Apparatus and Technique .................................................................. 7  
General Geology of the Neihart District ............................................................... 11  
Ore Deposits .......................................................................................................... 15  
Wall Rock ............................................................................................................... 15  
Structural Features ............................................................................................... 16  
Megascopeic Description ....................................................................................... 17  
General Character of Supergene Deposition ......................................................... 19  
Mineralogy ............................................................................................................. 23  
Hypogene Ore Minerals ......................................................................................... 23  
Gangue Minerals ................................................................................................... 26  
Paragenesis ............................................................................................................ 27  
Conclusions ........................................................................................................... 30  
Bibliography .......................................................................................................... 32

# List of Illustrations

Plate I .................................................................................................................... 23  
II ............................................................................................................................ 24  
III ........................................................................................................................... 26  
Figure 1 ................................................................................................................ 18  
2 ............................................................................................................................ 27
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RESULTS

During the course of this investigation of the ores of the Big Seven mine, Neihart, Montana, the writer has attempted, through a microscopic study of polished sections, to ascertain the hypogene or supergene character of the ore minerals present in the ore suite. The samples, from which the polished sections were made, were provided by the management of the Lexington Mining Company from the Big Seven mine in Neihart, for whom a copy of this manuscript will be prepared. A discussion on the methods used in preparing polished sections, the reasons for drawing the conclusions herein presented, pictures of diagnostic evidence seen in the polished sections, as well as an account of the general geology of the Neihart district will be found in the body of this paper.

The following is a summary of the author's results:

**Hypogene Ore Minerals**

- Sphalerite
- Galena
- Chalcopyrite
- Polybasite
- Pyrargyrite
- Tetrahedrite

**Oxidized Ore Minerals**

None observed.

-1-
Supergene Ore Minerals
None observed.

Gangue Minerals
Pyrite
Quartz
Ankerite
ACKNOWLEDGEMENTS

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INTRODUCTION

The compiler of statistics on mining companies, or even the close, yet non-technical observer of the mining industry, is probably aware of the large number of mines which start out in a wild burst of activity, and then, within four to five years, close down and nothing more is heard of them, except perhaps the disgruntled complaints of the stockholders.

It is an old story to the mining man. To begin with, these mines or bonanzas, to use an old western term, are very promising; they produce extremely rich ores which require very simple metallurgical treatment; their ore bodies are fairly close to the surface, and seem to be quite extensive; the vein structures appear to continue in depth, and yet the mines close down. Why? This is the natural reaction of our non-technical observer, and again it is the old story; the rich ores have suddenly become so low grade that it is impossible to exploit them any further. And so the extensive surface plants and equipment that were purchased and installed, and the stock that was sold on the great expectations of the rich ore bodies, become worthless.

There are concrete illustrations of the above statements, for example, several of the silver mines near Philipsburg, Montana, which are relatively shallow, have had to close down as their rich ores were exhausted. In the Bannack-Argenta district in southwestern Montana, nearly every mine worked ceased operations at the extremely shallow depths of 200 to 300 feet. Another example is in the Neihart district itself, where the Mountain Chief mine shut down soon after a new mill had been installed since the ore became too low grade to treat.

On the other hand, there are many mines which start out in much
the same manner, and ore productive today at depth, from ores practically as rich as those near the surface. This is exemplified by the copper mines at Butte, Montana. Here production started from workings above the 1000 foot level, and they are now producing from the 4100 foot level.

There must be some explanation for some mines playing out at depth while others remain profitable as their development proceeds downward, and the research work of the past two decades has bared the causes underlying the formation of these bonanzas. These causes and their results have all been put forth under the principles of secondary or supergene enrichment.

Many of short-lived bonanzas owe their character to the fact that their commercial deposits were rich supergene ores, formed in the shallow enriched zone by processes to be explained later. Whereas the primary ores—the original ores deposited by ascending solutions from a magma reservoir—were poor in valuable minerals and needed the secondary processes to enhance the ore grade, so, when the secondary ores were exhausted, the mine necessarily had to close down. It seems hardly necessary to add that some mines start directly on the primary or hypogene ores and thus are able to follow them in depth and still mine them profitably, or, after exhausting their supergene ores, find their primary ores also profitable, although perhaps not to the same degree.

It is extremely pertinent, therefore, that all mining companies, especially those working shallow deposits, should ascertain whether their ore minerals are primary or secondary before investing in expensive equipment. If they are pronounced secondary, then the ore may become exhausted in a short time, and it would be a question as to the commercial possibilities of the undoubtedly lower grade primary ores. Therefore,
the deposit should be mined more or less on a "shoestring" until the primary ore is reached, and tenor determined. But if the ores are primary, or if deeper primary ores are found to be commercial, extensive development and surface plants may be planned with more confidence.

The properties of the Lexington Mining Company at Neihart, from which the ore samples investigated by the writer were taken, have been a large, though intermittent producer of silver since around 1890. The workings now extend to considerable depths, and the ores are lower grade, but with close management, providing the tenor and market price persist, it appears possible to continue operations. So the question as to whether the ores are hypogene or supergene is paramount to the management, for upon a careful analysis of this question must all predictions on future ore reserves be based.

The problem, therefore, is to attempt to ascertain the hypogene or supergene character of the ore minerals by the microscopic study of properly prepared polished sections. To this end, the author has made a detailed polished section study, particular attention being given to exact mineral identification, and paragenesis.

SOURCE OF MATERIAL

Twelve separate working faces in the Big Seven mine were sampled by the Lexington Mining Company to furnish the author with representative material for his study. The specimens varied from solid massive vein filling composed entirely of ore minerals, to others showing a predominance of gangue minerals over the ore minerals. Figure 1 shows a longitudinal cross-section of the Big Seven mine and the locations from which the various samples were taken. A description of the samples is given later in this paper.
As mentioned before, this problem is mainly of laboratory nature, involving the microscopic study of polished ore sections. The microscope used is a reflecting type, and the usual method of preparing a polished specimen is described below.

Pre-Grinding Steps on Sample

The preparation of a polished section from a rough ore sample is accomplished by a series of steps, the number of which, and the time spent on each, being entirely dependant on the nature of the ore and the ease with which it will take a polish. The first is the reduction of the ore sample to a fragment that will give a polished area not bigger than one square inch. In so doing, the specimen is examined and an area is picked out which, in the opinion of the worker, will show pertinent relationships when polished. After this is done, the problem is to extract this area from the whole specimen. For this purpose a large pair of pincers and a hammer were found quite satisfactory, since a "bite" of the rock surrounding the selected area could be grabbed with the pincers, and the "bite" then broken off by pounding one claw of the pincers through the rock while the other was rested on a small iron block. This is repeated until that area has been broken out.

Rock Saw

If the original sample is too big for the pincers, or perhaps, too brittle to risk the impact incurred by use of the pincers, a rock saw may be used advantageously. The rock saw is really a thin copper wheel whose periphery has been impregnated with diamond chips within a thickness of one-quarter inch, mounted on the horizontal shaft of a small, high speed electric motor. Attached to the bench between the operator
and the saw is a clamp so arranged that the specimen may be held securely and steadily against the wheel during the cutting process. The wheel is cooled by a small stream of water directed on it. Since this saw has been in use it has cut down considerably the time spent on preliminary grinding as the surface left by it in cutting through the specimen is already fairly smooth.

After the desired fragment has been broken out of the sample, the preliminary grinding is done on a horizontal grinding wheel, so-called because the plane of the wheel is parallel to the surface of the bench on which it rests. It is merely a flat rim wheel with a rimmed periphery which encloses a piece of plate glass cut so as to just fit inside this rim and cover the iron surface of the wheel. The wheel is located in a square enclosure whose sides are four or five inches higher than the wheel. Its purpose is to reduce the area of splattering by abrasive and cut rock thrown off by the centrifugal action of the revolving wheel. The wheel is turned at a rather slow rate of speed by a motor located under the bench.

Coarse powders, usually 100-mesh carborundum powder, is used in this first grinding step. A thick paste of it and water is put on the wheel, and the wheel is started; the specimen is then pressed against the glass surface and is ground down by the abrasive action of the powder.

Hand Grinding

The horizontal grinding wheel is used until a fairly flat surface is obtained, and then the standard procedure is to change to hand grinding. Finer powders are used here; first 400-mesh, and finally 600-mesh powder. The section should be cleaned periodically and examined under a microscope to see if the surface is attaining a smooth surface. The
grinding with this 600-mesh powder, or finer powders such as tin oxide or chromium oxide, should continue until a microscopically smooth surface is achieved.

Polishing Machine

A final high polish is given to the section, after a microscopically smooth surface has been attained, with the polishing machine. This machine consists of two parts mounted on a common baseboard. One part is a small electric motor, and the other is the frame holding the two vertical and one horizontal wheel. The vertical wheels are coarse grinding wheels of different degrees of coarseness, and may be used for a variety of purposes. The only purpose for which the author used the vertical wheels was to reduce any prominent projection on a surface to be polished, and to bevel the edges of a polished surface. They are attached to both ends of a shaft which is actuated by a belt drive from the motor.

It is the horizontal wheel that is used for the final polish. It is also a flat iron wheel, but has a removable rim so that cloth of various grades may be stretched over the wheel, and held in place by the rim. Polishing powders of various kinds are put on the dry or dampened cloth and the section polished on this wheel. The section should be turned in a 90 degree arc as it is held against the cloth covered wheel. It turns much faster than the larger horizontal wheel previously described, and its power comes from a friction drive against the shaft of the vertical wheels. This wheel is interchangeable with a smaller counterpart of the larger horizontal wheel just referred to; it gives a high polish to some ores when used with finer powders.

Bakelite Press

Often it is desired to make a polished section in a bakelite or leu-
cure medium, in which case the bakelite press is used. Basically it is nothing more than a pressure chamber which can be heated electrically.

The pressure is supplied by a large hydraulic jack such as those with which trucks and other heavy vehicles are supplied, and to which a gauge is attached so that the pressure applied may be known. There is also a small mercury reservoir enclosed near the top of the pressure chamber into which a thermometer may be inserted so that the proper temperature may be maintained.

The polished section is placed face down in the chamber and the proper amount of bakelite or leucite is poured in over it. Then the chamber is closed up, the clamps tightened, and heat and pressure of varying intensity, and for varying times, depending on the mounting medium, are applied. When the mount is finished, it is polished as described in the paragraph on hand polishing.

Polishing Mounted Sections

If it is impossible to polish the mounted specimen by ordinary methods, the mounts may be put in a special Graton-Vanderbilt polishing machine. This machine operates by rubbing the mounted sections against a revolving copper or lead plate in a counter-revolutionary direction and at the same time twisting the mounts back and forth in a 90 degree arc. A paste of oil and extremely fine powders are spread over the plate to do the polishing. Two different sizes of powders are used, and for each size a different plate is put in. The machine is electrically operated.
Neihart lies about 65 miles southeast of Great Falls, Montana, near the center of the Little Belt Mountain Range, in that area where Belt Creek has its head waters. Neihart is easily reached by a spur of the Great Northern Railway from Great Falls; also by the Park to Park Highway, U. S. No. 87 W., which runs from Great Falls through Neihart to White Sulphyr Springs.

The ore deposits were discovered in 1881 during the rush to the gold placers in nearby Yugo Gulch. Mining activity gradually increased until 1886 when the Hudson Mining Company built a mill at its Mountain Chief mine; this mill closed down, however, in 1887 when the rich shallow ores were exhausted. Little was done until 1891 when the railroad was completed to Neihart, and until 1915 only the richest mines were worked because of a contemporary drop in the silver price. In 1916, the silver price improved and camp started in on the best period of its history, more mines and new deposits were opened up, and the district became one of the most important producers in the state. Production started to drop in 1928, and by 1930 all mines but one were idle. Mining started up again in 1933 but on a much smaller scale.

Silver has been the chief metal produced since the discovery of the camp. From 1881 to 1898 the district produced 4,000,000 ounces of silver; 10,000,000 pounds of lead; and $800,000 in gold, having a total value of $5,000,000. Production during the period 1898 to 1904 has been estimated as $2,000,000, and $9,989,553 worth of silver, lead, and gold were produced up to 1935. All this adds up to a grand total of $16,989,000.

*All data for the Geology of the Neihart District has been taken from Paul A. Schafer's publication, "The Geology and Ore Deposits of the Neihart Mining District, Cascade County, Montana," Mont. Bur. Mines and Geol., Memoir No. 13, 1935.
from 1881 to 1935.

Geologically, the host rock for the Neihart deposits are extremely old, since these veins occur in an ancient series of pre-Beltian rocks that underlie the district. They form one of the oldest series in Montana, lying unconformably beneath the Belt series which are themselves pre-Cambrian. The break between the two series indicates a very great lapse of time. These pre-Beltian rocks are divided into two groups: an older group of gneisses and schists, and later gneisses.

The older gneiss is massive, quite brittle, very resistant to weathering and thus formed a favorable host rock for the vein fissures. It is extremely variable in composition and appearance but is seen mainly as a dense, hard, massive, blocky-jointed gneiss with a reddish brown color. Other parts of this group are made up of chlorite and sericite schists, but they are not as conspicuous since they weather easily and are usually covered by detritus and timber. These types were all originally igneous acidic rocks—granite, monzonites, or rhyolites.

The later gneiss is called the Pinto diorite, and is also a metamorphosed intrusive which was probably a diorite or granodiorite. Its degree of metamorphism is not so great as that of the earlier series and it was intruded into the earlier group. This intrusion took place during the time of metamorphism as is shown by the similarity and concordance of the metamorphic structures. Both gneisses belong to the same period of intrusion, indeed, the differentiation is more on a mineralogic basis than on a genetic one. The rock has black and white mottled appearance with large white feldspar phenocrysts in a black ferromagnesian-rich matrix. A border facies of black, compact, lamprophyre, composed mainly of hornblende is common.
a marked unconformity separates the gneissic complex from the overlying Belt series of which the basal member is the Neihart quartzite. This is overlain by a series of shales also of Belt age, which in turn are capped by Paleozoic limestones and shales. The Snow Creek porphyry, one of several, late intrusive dikes which cut the rocks of the district, is also encountered in the Big Seven workings. It varies from 1000 to 25000 feet in width and is fairly regular although smaller branches often diverge from the main body. The porphyry is composed of quartz phenocrysts in a feldspar matrix with very little accessory magnetite and hematite. An alaskite facies of this rock has no phenocrysts. All types contain small amounts of disseminated pyrite.

Weathering usually oxidizes the pyrite to stain the rock a light brown, and also kaolinizes and sericitizes the feldspar.

Other dikes present in the district, but not encountered in the Big Seven mine, are the Carpenter Creek porphyry, porphyry, and some basic dike rocks, all named in chronological order.

The foliation and drag folds in the pre-Beltian rocks indicate that they were tightly folded. This probably took place at depth as shown by the recrystallization of the minerals. Schafer has advanced the theory that the Pinto diorite was injected as a phacolith along the crest of one of these ancient folds, because of the concordance of structures in both rocks, and the way the Pinto diorite splits into two limbs in this district.*

A broad doming of the Little Belt Mountains is the main structural feature of the area. It is not positively known when the ore deposits were formed, but it is thought that the fissures in which they occur

were produced by the same forces which caused the doming in the Little Belt Mountains. The solutions undoubtedly came from the same source as the intrusive which has been metamorphosed into the gneisses; probably they are a late differentiation product which was tapped by the fractures formed by the mountain building forces.
ORE DEPOSITS

The principal economic mineral in the Neihart ores is silver, but it occurs in rather minor amounts which is the reason the operations in this area are contingent upon a high silver price. The vein mineralization shows, however, an overwhelming predominance of sphalerite and galena; especially is this true in depth. Gold and copper are also present in subordinate amounts. In parts of the veins the filling consists of a mixture of carbonates of which ankerite is predominate, but calcite, dolomite, and siderite are also present. The deposits show a decided zonal arrangement in which the richer silver ores are in the upper portions of the veins, and are succeeded in depth by lead-rich and zinc-rich ores in that order. In the lower levels the high grade leads are less common, and are narrower, whereas the proportion of sphalerite becomes increasingly greater. Considerable ankerite is also found in the lower zone vein fillings.

This zonal arrangement is thought due to heat distribution from the magmatic source, which, combined with the earth gradient, will set up zones of equal temperature and pressure, and within which certain types of minerals will be deposited.

WALL ROCK

The veins are not confined to any particular wall rock, but cut indiscriminately across several types which are present in that area. Thus, in pursuing a northeast direction, the veins cut across the Pinto diorite, gneiss, and the snow Creek quartz porphyry. A description of these rocks may be found in that section of the paper dealing with the general geology of the area. The type of wall rock has considerable bearing on the size of the ore bodies, as will be explained later.
The veins are of the fissure type, and strike in a general northeasterly direction although the strike varies considerably. They seem to be formed by movement in which the east side of the vein structures moved northward, and the west side moved southward.

The rock type is very important in the formation of the fissures, and the important deposits are always found in the gneiss. Not only does the width and strength of the fractures, and consequently of the ore deposit vary with the rock type, but also the strike, since the fractures turn in passing from a plastic rock to a brittle type and vice versa. The best host rock for the veins is the older gneiss since it is sufficiently brittle to yield wide, permeable openings with very little gouge. On the other hand, the brittleness of the Pinto diorite has increased to such a point that the veins, when present, are extremely narrow and irregular. The Neihart quartzite and the Snow Creek quartz porphyry are too brittle to sustain a fracture of any size, and the veins become dissipated into a diversity of small fractures causing a dissemination of the ores beyond the point of recovery. Where the veins enter the brittle quartz porphyry and Neihart quartzite, the gold percentage rises. This probably is due to more rapid cooling of the solutions since the brittle rocks are less permeable and so allow a more rapid escape of the heat.

Frequently the veins will split and a segment will depart in a north-south direction. These splits are often considerably mineralized and, where they join the main vein, there is always a widening of the vein structures to produce a correspondingly wider deposit.
MEGASCOPIC DESCRIPTION

Although this paper is concerned primarily with the microscopic features of the specimens as seen in a polished section, a short description of the samples as they appear to the naked eye—a megascopic description—is included for the sake of completeness.

The samples all show a decided crustification or banding typical of mesothermal deposits, in which there is a band of early well crystallized quartz with well developed crystal terminations on the inner side of the layer. This quartz is clearly earlier than the rest of the filling. Other bands and stringers of quartz may be seen in the vein filling itself, which consists mostly of alternate layers of ore minerals and quartz.

The ore mineral assemblage itself is predominantly galena and sphalerite. The galena is dark, massive, and has the characteristic cubic cleavage. The sphalerite varies from the dark, iron-rich variety, to the purer light brown type possessing a resinous luster. Pyrite is scattered throughout the filling, and show a tendency to be concentrated closer to the walls of the veins next to the quartz.

All specimens show vugs and druses which occur in both the quartz and ore filling. They are quite small, and show the development of crystals of quartz, pyrite, etc., along their walls. The vugs are particularly noticeable in the ankerite filling that some portions of the veins show. Ankerite is seen in three samples (numbers 3, 10, and 12) from the deeper portions of the mine (Fig. 1). All three samples show that the amount of ore minerals in the filling becomes definitely less when ankerite is present. The ankerite is soft with a pinkish white to pink color.

In sample 6, small streaks of red pyrargyrite are detected and is
Big Seven Mine
Longitudinal section showing location of specimens.
Scale: 1" = 300'.
the only sample to show the presence of this mineral megascopically.

Many of the samples show the ore to be frieble and crumbly, particularly sample 8 from close to the quartzite-diorite contact, which also contains a higher percentage of pyrite. Sample 11 shows very little mineralization, the ore minerals occurring as tiny stringers through altered granite with disseminated pyrite.
GENERAL CHARACTER OF SUPERCENE DEPOSITION

It is noteworthy that all secondary or supergene deposits are in veins which are exposed, or which extend close to the surface. This is a necessary condition, for weathering plays an all-important role in secondary enrichment. Sulfides, as a group, weather and break down under oxidizing conditions to form more stable minerals under the new environment. The exceedingly common iron sulfide (FeS₂) always does this, forming in the process ferrous sulfate (FeSO₄), ferric sulfate (Fe₂(SO₄)₃) and sulfuric acid (H₂SO₄).

FeS₂ + 70 + H₂O = FeSO₄ + H₂SO₄
2FeS₂ + 150 + H₂O = Fe₂(SO₄)₃ + H₂SO₄

Other sulfides will react with the sulfuric acid and ferric sulfate to form soluble sulfates or they may react directly with the oxygen to form the sulfates which will trickle down to zones of no available oxygen. Taking silver as a case in point, since Neihart is a silver producer:

Ag₂S + 4O = Ag₂SO₄
2Ag + Fe₂(SO₄)₃ = Ag₂SO₄ + 2FeSO₄

Sulfides are reducing, and their neutralizing action on these acidic solutions cause some minerals to precipitate out, or the chemical interaction of the solutions with the metallic sulfides they may encounter will cause a precipitation of the metals as supergene sulfides. For example, silver sulfate and sphalerite react as follows:

Ag₂SO₄ + ZnS = Ag₂S + ZnSO₄

although native silver is usually precipitated by sulfides. This reaction is typical of those which take place between such solutions and the sulfides of copper, lead, and iron, besides that of zinc (sphalerite).
In any event, this zone underneath the oxidizing zone will be enriched by deposition of new minerals.

The geologic history, chemical and mineral composition, environment, and physical conditions such as climate, relief and altitude are important. Two factors important in climate are temperature and rainfall. Temperature is important because low temperature and freezing retards chemical activity and solution, and consequently little or no secondary action occurs. Since solution is necessary, rainfall is important for supergene activity in order to supply the water for underground circulation and solution action. In both cases, it must be remembered that the present climate is not necessarily that of other eras when most of the secondary action may well have taken place. It is also obviously difficult to draw any general conclusions as to former climates because of lack of data. We should not, therefore, be surprised at the occurrence of many rich supergene deposits in arid regions of today. In this connection, the question of underground water circulation is important.

Areas of high altitude are not so conducive to secondary action because of the high relief causing rapid erosion. Moreover, temperatures are usually lower, another detrimental factor. In itself, however, a strong relief is desirable since it maintains an active underground water circulation by which the solutions penetrate downward to enrich the primary ores.

Permeability is important since permeable rocks weather easily, and, if the primary sulfides are impermeable, there will be no secondary deposition at all, since the solutions will not be able to penetrate them. Thus rocks which are brittle fracture easily, and will therefore be more susceptible to secondary enrichment; furthermore,
the fracturing of the hypogene sulfides, thereby producing a large num-
ber of small openings, is more favorable for replacement than a small
number of large openings because of the greater surface exposed to the
supergene sulfate solutions.

Supergene enrichment takes place at a depth where there is an ex-
clusion of air, and thus no available oxygen, which is a condition at-
tained where the spaces in the rocks become filled with water. The up-
per limit of this zone is called the water table. This water table is
not a plane surface, nor is it a permanent thing; rather it follows the
topography of the surface in a subdued fashion, and is found at variable
depths beneath the surface. This depth will oscillate with the seasons,
thus in dry seasons the table moves downward, and in wet seasons it
moves upwards. Moreover, erosion of the surface is constantly forcing
the water table down.

The lower limit of this zone of supergene deposition is hard to
locate; certainly the entire zone is within the zone of fracture, the
uppermost of those zones into which the earth crust is divided. In
depth the rocks tend to tighten, preventing the formation of many frac-
tures and limiting this enriched zone, so that the lower limit of the
supergene zone will rarely go below a depth of 2000 feet.

There may also be a deposition of rich exodized ores, provided
erosion has not stripped it off. The oxidation zone is mainly one of
solution, but there is a tendency for the oxides of iron, aluminum,
manganese, and silicon to precipitate out. Deposition in the oxidation
zone may also take place if certain types of reactive gangue minerals
are present, they will often react with the sulfate solutions to pre-
cipitate oxidized minerals. In such case there will be very little, if
any, supergene sulfide deposition and primary ores will probably extend
upward to the water table.
In arid regions, where the water table is very deep, the solutions may encounter a reducing environment above the water table resulting in the replacement of primary sulfides by supergene sulfides in that area. But as a general rule the succession of zones in a secondarily enriched vein is as follows: an upper zone of gossan from which most values have been removed, there remaining only a porous, crumbly rock usually stained brown by limonite. Preceding downward, this zone will be followed by a leached sulfide ore or an oxidized ore, depending on the gangue; followed by an enriched sulfide ore, when there is no reactive gangue present, and finally, the primary ore. This is more clearly shown in the following idealized sketch.

These zones have no definite boundaries as shown above, rather they grade into one another; the top ones may even be eroded away. Nor does this theory hold for all metallic sulfide veins; those of copper and silver seem to be the most affected, and those of lead and zinc the least. Gold is very rarely affected by supergene processes.
PLATE I

Microphotographs of Polished Sections
(Magnification—48 diameters)

A and B—Galena (g) cutting sphalerite.

C and D—Galena (g) bordering polybasite (p).
MINERALOGY

The number of minerals identified is rather surprisingly small. The silver minerals, upon which emphasis was placed, were never seen in large grains, but instead as small grains scattered through the ore. The bulk of the ore mineral was sphalerite, with galena also present in considerable amounts. Pyrite and quartz were invariably present.

HYPOGENE ORE MINERALS

Sphalerite—This mineral occurs invariably as the matrix in which the rest of the minerals in irregular masses and crystals are embedded. The great predominance of this mineral, its chemical composition, and the complete lack of any evidence of its having replaced another mineral all indicate its undoubted hypogene origin.

Galena—Galena occurs chiefly as an associate of sphalerite, and with apparent contemporaneous relations. There also seems to be a phase of galena later than some of the silver minerals. The usual occurrence with sphalerite is in the form of irregular grains and inclusions which were clearly the result of exsolution of the two minerals. Elsewhere the galena has replaced the sphalerite since it cuts the sphalerite as microveinlets (Plate I, A and B), and the contacts between the two also showed a serrate effect, as if the sphalerite had been "bitten into" by the galena. This would indicate that the galena was introduced both during and after the period of sphalerite deposition.

Where galena is younger than the silver minerals it borders the silver minerals much as if it were supergene, nevertheless, for reasons stated in the descriptions of the silver minerals, it is considered hypogene.
PLATE II

Microphotographs of Polished Sections
(Magnification—48 diameters)

A—Galena (g) rimming polybasite (p).

B—Polybasite (p) and galena (g) surrounding quartz (q) crystal.

C—Chalcopyrite (py) cutting polybasite (p).

D—Exsolution relationships of sphalerite (s), galena (g), polybasite (p), and pyrite (py).
Chalcopyrite—The occurrence of chalcopyrite was very limited indeed, and it is rarely seen in the hand specimens with the naked eye. The microscope revealed its presence, however, as small irregular grains and masses scattered principally through the sphalerite. However, chalcopyrite was seen associated also with most of the other minerals, particularly galena, and also with polybasite. It occurs chiefly in the small irregular masses and as narrow stringers which cut the other minerals, and as little groups of minute specks in sphalerite suggesting an unmixing or exsolution of chalcopyrite from the sphalerite; in any event, it is undoubtedly hypogene. Since, in some specimens chalcopyrite borders silver minerals, namely polybasite and pyrargyrite which are commonly supergene, the writer is forced to the conclusion by this relationship that here these silver minerals are hypogene (Plate II, C).

Polybasite—This appears to be one of the principal silver minerals in the ore. It does not occur in sufficiently large grains to be perceptible to the naked eye, but in the polished section it occurs as microveinlets and stringers, and also as small inclusions in the sphalerite. In the opinion of the author, polybasite is hypogene. This conclusion is reached because polybasite was usually observed being bordered by galena (Plate II, A). There are also isolated, well developed crystals of quartz rimmed by polybasite, and here too this mineral is, in turn, bordered by galena (Plate II, B). Galena is the sulfide of lead and is rarely, if ever, considered a supergene mineral. If galena rims the grains of polybasite, then it should be considered as undoubtedly later than the polybasite. Therefore, if polybasite is earlier than galena, which is thought to be hypogene, then it too must be considered a hypogene mineral. Added proof is given by the fact that chalcopyrite was apparently deposited either contemporaneous with or later than the
polybasite. In some cases the two minerals grade into each other, and elsewhere, microveinlets indicate that chalcopyrite is later (Plate II, C). Chalcopyrite is almost always hypogene.

Polybasite is further proved to be hypogene by the unmistakeable exsolution relationships of that mineral with galena and pyrite (Plate II, D). In other places pyrite is seen cutting the polybasite in narrow stringers, clearly showing that the pyrite is later than the polybasite. This would support the theory previously advanced, that the pyrite deposition was continuous.

Pyrargyrite—This mineral is secondary upon sphalerite, but is also a hypogene mineral. Close examination of the hand specimens reveal the mineral, and under the microscope, in polished section, it is easily identified by its color and strong, deep red internal reflection. Conclusive microchemical tests were made for silver and antimony. Pyrargyrite occurs as small inclusions in the sphalerite with minute stringers branching out into the sphalerite, proving it to be later than sphalerite. In one of the writers specimens pyrargyrite occurs with, and is replaced by another brownish mineral identified as tetrahedrite. This mineral (tetrahedrite) surrounds the small masses of pyrargyrite and cuts them in narrow stringers; elsewhere, it has almost entirely replaced the pyrargyrite leaving but a small rounded residual inclusion in the center. Tetrahedrite is usually a hypogene mineral; since its relationships show a subsequent deposition to pyrargyrite, logical reasoning would lead to the conclusion that pyrargyrite is also hypogene. Added evidence for this conclusion is provided by tiny stringers of chalcopyrite and pyrite which cut both minerals (Plate III, C).
PLATE III

Microphotographs of Polished Sections
(Magnification—48 diameters)

A—Pyrite (py) bordering and cutting pyrargyrite (pr).

B—Polybasite (p) filling fracture cracks in pyrite (py).

C—Ankerite (a) cutting sphalerite (s).
GANGUE MINERALS

Pyrite—The deposition of pyrite seems to have been more or less continuous during the period of mineralization. There was an early generation of pyrite which was probably the first mineral formed since it occurs as a definite band close to the wall rock on which the inner side showed a good development of crystals over and surrounding which a band of quartz was deposited. Pyrite was deposited later also since it occurs with all of the other ore minerals. In most samples, it is in minor amounts; locally, however, it appeared to be the principal mineral present. Cracks and fractures in the large masses of pyrite are often filled with galena, sphalerite, and polybasite (Plate III B).

Quartz—Quartz apparently was deposited both early and late. That it occurred very early is shown by the fact that the quartz band mentioned in the pyrite description also shows an inner side of well developed, hexagonal crystals about which sphalerite was deposited. The crystals show that some of the quartz is considerably older than the rest of the mineralization, since it must have had sufficient time to crystallize before the zinc-lead-silver solutions were introduced. Scattered throughout the rest of the vein-filling are quartz masses of variable size, some showing well-developed crystal faces. Thus there was also a later generation of quartz which was undoubtedly hypogene as shown by its well formed crystals, as secondary quartz is usually recognized by colloidal deposition, often in concentric rings or uniform masses. Chalcedony is a common form of supergene quartz.
PARAGENESIS

The polished sections studied by the author do not show the mineralization of the fractures in this region to be very complex nor were the minerals very numerous. However, it is very difficult, even impossible, to ascertain the time relationships of some of the late silver minerals since very few of them were found in the same polished section. The paragenetic chart (Fig. 2) is accurate only in a relative sense, and then only approximately so. A glance at the chart shows polybasite and pyrargyrite being later than sphalerite which seems well established. The relationships of pyrargyrite and polybasite have been equally well established because small, irregular masses of polybasite were seen in pyrargyrite, apparently an unmixing effect. The color differences of the two minerals were too slight to photograph well, indeed, the only way the two minerals could be definitely differentiated was by exami-

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Fig. 2. Paragenetic Diagram of Ores from Big Seven Mine, Neihart, Montana.
nation under crossed-nicols. Galena is known to be later than polybasite, but its relationship to pyrargyrite or tetrahedrite is indefinite.

In general, the mineralization proceeded somewhat as follows: first an early generation of pyrite and quartz in that order, enough time elapsing between the two to allow the pyrite to crystallize before advent of the quartz. This shown by the idiomorphic outlines of the pyrite against the quartz. An early quartz preceded sphalerite sufficiently to allow the quartz to crystallize. The last stages of the sphalerite mineralization witnessed the beginning of galena deposition which continued for a short time after the deposition of the sphalerite had ceased. As explained and illustrated above, this is concluded from the fact that the galena is seen locally as the result of exsolution from the sphalerite, and as a replacement of sphalerite. Apparently neither mineral replaces pyrite or quartz, although fractures and cracks in the pyrite were filled with both sphalerite and galena.

Polybasite and pyrargyrite were deposited in the next phase or stage of mineralization. That both are later than sphalerite and mutually contemporaneous is indicated by the replacement features cited above. A later generation of galena is younger than polybasite, and indirect evidence (polybasite and pyrargyrite have been found to be contemporaneous) shows it to be younger than pyrargyrite also. The relative ages of polybasite and tetrahedrite are undeterminable since they are not associated, and the relationships of tetrahedrite with minerals known definitely to be older or younger than polybasite are not clear.

The age of ankerite, which is present in the deeper portions of the veins, is not positively known; certainly it is older than the galena as stringers of that mineral cut the ankerite, and younger than the sphalerite for
the opposite reason (Plate III, C). In general, the sulfide mineralization in veins with ankerite is rather scanty.

It must be kept in mind that these stages of mineralization are not separate and distinct. Undoubtedly they grade or merge into one another, the last stage of one sequence being contemporaneous with the first stage of the following phase.
CONCLUSIONS

The microscopic study herein described has led the author to the conclusion that there has been very little if any supergene enrichment of the ores, since no example of supergene replacement could be found in the polished sections examined. Aside from the microscopic study, which is the only precise method of making such a study, other facts make this conclusion appear tenable. The polished sections studied by the author were obtained from samples taken from the deeper portions of the mine at a minimum depth of 1400 feet, since they were the areas of principal production. Although possible, supergene deposition of silver minerals is rarely known to have taken place at depths over 1000 feet. Moreover the compactness and comparative freshness, i.e., little alteration of the country rock except that due to dynamic metamorphism, which makes these rocks all the more compact, would prevent the active, deep underground water circulation necessary for enrichment to such depths.

This view is in concordance with the results obtained by Schafer in his investigation of the Neihart district. None of the silver minerals which he found in the supergene zone, namely native silver, argentite and cerargyrite were identified by the author. Other silver minerals, which Schafer states may be supergene, are classified by him as primary—"ruby silver and polybasite (pearcite?) are abundant in the primary ore."*

Basing his conclusion on the assumption that the top of Big Baldy mountain was probably near the level of Cretaceous erosion surface, Schafer** also states that the deposits were formed less than 5000 feet below the surface. This would place the deposits on the border line be-

** Schafer, Paul C., Op. cit., p. 27.
tween mesothermal and epithermal deposits. This conclusion is born out by the lack of any high temperature minerals, the coarse crustification, and the vugs and druses so abundant in the ore. The zoning of the ores and abundance of sulphantimonides are further evidence in favor of this classification. The temperature of formation was probably in the neighborhood of 175 degrees Centigrade.

In conclusion: the veins of the Big Seven mine, Neihart, Montana, are low temperature mesothermal deposits consisting principally of sphalerite and galena, but which are exploited mainly for silver, the silver-bearing minerals being present in lesser amounts. The ores are hypogene, there being no evidence of supergene enrichment. Deposition occurred at depths less than 5000 feet below the surface, and at temperatures close to 175 degrees Centigrade.
BIBLIOGRAPHY

Emmons, W. H.


Bastin, E. S.


Cooke, H. G.


Ravicy, L. G.


Hurst, N. E.


Swartz, C. N.


Graton, L. C., et. al.


Irving, J. P.

Replacement Ore Bodies and the Criteria for Their Recognition: Econ. Geol., vol. 6, pp. 527-561, 1911.

-32-
Schafer, Paul A.