Paragenesis of the Primary Ores of the Norwich Mine

Edward E. Scheitlin

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OF THE NORWICH MINE

by
EDWARD E. SCHEITLIN

A Thesis
Submitted to the Department of Geology
in Partial Fulfillment of the Requirements
for the Degree of Bachelor of Science
in Geological Engineering

MONTANA SCHOOL OF MINES
BUTTE, MONTANA
May 18, 1955
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ACKNOWLEDGEMENTS

I wish to thank the members of the faculty of the geology department at the Montana School of Mines, for advice and guidance in preparing this report. Professor March was especially helpful in suggesting the problem and methods of procedure and Mr. Reid was of much help in the laboratory work.

My sincere appreciation is tendered to Mr. Nelson and Mr. Irving for their kind permission to visit the Norwich mine, and for the invaluable information that was given freely. I also wish to thank the lesers and employees of the mine who were most considerate and gave much valuable information.
ABSTRACT

The Norwich vein is thought to belong to the Anaconda vein system. It contains fairly large deposits of manganese. The study of 19 thin sections and 15 polished sections was made to determine the paragenesis of the vein minerals, which is: quartz-pyrite, rhodochrosite, quartz, minor rhodochrosite, quartz-pyrite-sphalerite, quartz, galena, freibergite, and later quartz. Some supergene rhodochrosite was found, and most of the silver minerals were found to be of supergene origin.

Ground water was found to contain appreciable manganese in the bicarbonate form, from which rhodochrosite could easily be precipitated. Precipitation is thought to be caused by the reducing conditions present below the oxidized zone.
INTRODUCTION

The presence of manganese in the Butte mining district has been known since the silver-boom days, when it was thought of only as a gangue material, or at best, a low-grade silver ore used for fluxing. Until fairly recently, little attention has been paid to the origin and paragenesis of the manganese minerals.

The manganese of the district did not become economically important until the increased price of manganese made mining of the manganese veins profitable. During the Second World War, large tonnages of rhodochrosite and manganese oxides were gouged out of the near surface deposits with no recourse to geology. With the close of the war, prices declined, and only the Anaconda Copper Mining Company continued to mine the manganese veins.

Recently, manganese has become a mineral of strategic importance to our country, and to increase the production, the government has initiated a subsidized program not only to increase our now small domestic production, but also to produce an incentive toward future exploration for, and development of, new manganese deposits.

Very little is known of the paragenesis of the hypogene manganese ores. The possibility of supergene enrichment of manganese has been mentioned by many geologists, but as yet this has been neither proved or disproved. This report is

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intended to determine the paragenesis of the hypogene manganese ores, and to determine if supergene enrichment is present in the ore bodies studied.
THE NORWICH MINE

The Norwich mine was chosen for specific study because it provides an easy access to a continuous and uninterrupted section of vein from the surface to the 250 foot level, in which the gradation from the oxide ore to the carbonate ore can be seen. Active mining in the area immediately below the oxidized zone provided an excellent opportunity to study the possibility of manganese enrichment.

Location

The Norwich mine is located on the extreme western edge of the Butte (Summit Valley) mining district, about two miles west of the Montana School of Mines. The property consists of a group of three claims, the Norwich, the Plutus, and the Little Sarah. Access to the mine is gained through the 400 foot Plutus shaft (vertical) and through the 185 foot Norwich inclined shaft. The mine is currently in operation on two veins, the Norwich vein, and the Plutus vein.

Other properties in this area that are currently producing manganese ore are the Mapleton (working the westward extension of the Norwich vein), and the Hibernia (working the Nettie vein). In the past, manganese was mined on the Great Republic, the western tip of the Norwich vein.

History and Production

The Norwich mine produced approximately 1,800 tons of
Fig. I. General view of the Norwich mine. B.A.L. shaft on left, Plutus shaft in center, and Norwich shaft to the right.

oxide ore, and 800 tons of carbonate ore that averaged over 23% manganese, during the period 1943-1945. Two inclined shafts, 80 feet and 135 feet deep, provided access to the Norwich mine workings, which consisted of 800 feet of drifting and cross-cuts. The main ore body was stoped for 200 feet along the strike and 135 feet down the dip. The ore body ranged in width from 3 to 8 feet.

All work on the Plutus was done prior to 1921. Access to the workings was through a 400 foot vertical shaft. The
operating levels were on the 125 foot and 225 foot and the 400 foot levels. On the 400 foot level, a cross-cut was driven to the Norwich vein and over 480 feet of drifting was done on the vein. Maps of these old mine workings indicate only the presence of manganese carbonate in the vein. No grade or widths of the manganese was mentioned, since the mine was a silver producer at that time. The Plutus shaft was reopened in 1952 to provide access to the Norwich ore body.

In 1949, an extensive diamond drilling program was carried out by the government. Because of the intense fracturing encountered, the core recovery was very low, and the overall results were discouraging. Nelson and Irving acquired the property in 1949, and the current mining program began in 1952.
PREVIOUS WORK

The literature on the Butte district is extremely prolific. The classic reports by Sales⁹ and Weed¹⁶ along with the many other early writers, have made Butte perhaps the most completely studied area in the world. Early papers on the Butte district made some mention of the presence of the manganese oxides and rhodochrosite, but no specific studies were devoted to rhodochrosite and its paragenesis.

Among the earliest works is that of Pardee⁶ dealing mainly with the occurrence and economic significance of rhodochrosite and manganese oxides. Wayland¹⁵ recently made a complete study of the physical properties of the Butte rhodochrosite. More recent work consists mainly of three undergraduate thesis by students at the Montana School of Mines. These three papers were mainly concerned with the rhodochrosite - rhodonite relationships of the northern district.

Wendell¹⁷ found that "rhodochrosite as an ore mineral or as a gangue occurs as one of the last minerals to be deposited in the Butte veins". However, most early writers considered quartz and rhodochrosite to be of the same age. Wayland¹⁵ stated that rhodochrosite was one of the latest of the primary minerals found in the peripheral zone, and that fracturing and brecciation proceeded and accompanied its deposition and sulphides were in general earlier than the
rhodochrosite and occurred in part as breccia fragments cemented by rhodochrosite.

Farbo\(^3\) and Parent\(^7\) excluded hypogene rhodochrosite from the northern part of the district, holding that the rhodochrosite appearing there was formed by supergene processes from the breakdown of rhodonite.

Farbo\(^3\) further stated that the intermixing of rhodonite and rhodochrosite in the west-central district was due to the intermingling of relatively hot acid solutions containing the rhodonite, and cool basic solutions containing rhodochrosite. This seems highly improbable to the author.
GEOLOGY

General Geology of the Butte District

The Butte ore deposits are in quartz monzonite, a part of the late Cretaceous Boulder batholith. The ore deposits are concentrated, almost all the rich deposits being in an area two miles square on Anaconda Hill. The minerals occur in wide veins which continue to great depths. The vein structures and fault systems are very complex and require constant geologic work to render mining effective and economical.

The geology of the region has been determined to be the result of a series of geologic events which is given below:

1. Intrusion of the Boulder batholith.
2. Intrusion of quartz porphyry dikes.
3. Intrusion of aplite and pegmatite dikes.
5. Formation of the Blue or Northwest veins.
7. Development of Mountain View breccia faults.

The Anaconda and Blue veins contain the rich producing ore bodies of the district, and the other veins and faults only complicate the mining of these deposits.

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The zonal arrangement of Butte has been cited as the perfect example of this phenomena of mineralization. The mineral areas at Butte have been divided into three zones, each approximately one-half mile wide at the surfaces. These zones are:

1. Main central copper zone, containing chalcocite, bornite enargite, etc.
2. Intermediate zone, containing copper minerals with sphalerite, rhodonite, and rhodochrosite appearing near the outer edge of the zone.
3. Outer peripheral zone, extending indefinitely out and containing galena, sphalerite, silver, rhodonite and rhodochrosite.

The order of deposition, or paragenesis of the Butte minerals as determined by Lindgren is as follows: quartz (more or less continuous throughout deposition), pyrite, sphalerite, tennantite, enargite, chalcopyrite and some silver minerals, and chalcocite.

Any mineral may be seen replacing any one of, or all of the minerals preceeding it on this list. Most authors explain the different 'stages' of mineralization. The author does not agree with this concept, but has come to the conclusion that the difference in mineral deposits is due only to a difference in the temperature of deposition. In other words, as the deposits were formed, the temperature of the rising hydrothermal solutions increased, the hotter solutions attacked the minerals deposited by the earlier cooler solutions (by the various methods of replacement) and carried
them farther up, or out, to the cooler zones of deposition, i.e., the rhodochrosite of the peripheral zone were deposited at the same time as the high temperature copper minerals of the central zone.

Geology of the Norwich mine

The Norwich mine contains two principal vein structures, the Plutus vein and the Norwich vein. The general attitude of the veins suggest that they are related to the Anaconda veins. Generally, the strike is slightly north of east, and the dip is to the south.

The Plutus vein has had little development work done above the 250 foot level. Extensive drifting on this structure on the 250 foot level disclosed the vein to be intensely strike faulted, with some cross faulting and flat-lying faults. Some very rich rhodochrosite ore has been found in lenses along this vein, however, no stoping has been done to date. Alteration of the country rock is intense, especially where it is in contact with the vein, and, except for quartz, all minerals have been altered and some completely removed. The alteration was probably intensified by the faulting.

A granular siliceous granitic rock consisting mostly of feldspar and quartz is abundant in the mine. This rock has long been classified by the geologists as aplite, although it is sometimes rather coarse. This aplite is found enclosing the Plutus vein and forming the hanging wall of the Norwich
PLATE I. GENERALIZED LONITUDINAL SECTION OF THE NORWICH FOOTWALL VEIN
vein. The aplite contains many sheeting planes that are roughly parallel to the veins. The footwall of the Norwich vein appears to be the normal Butte quartz monzonite.

The Norwich veins appears to be a multiple structure containing a hanging wall and a foot wall vein. The hanging wall vein on the 250 foot level is relatively flat, dipping about 35° to the south.

Drifting on this structure on the 250 foot level, and a cross-cut on the 170 foot level indicated it to be a fairly large fault zone containing some rhodochrosite breccia which was not commercial. However, old maps of the 80 foot level indicated the ore to be fairly wide and of a commercial grade. From indications on the 300 foot level, and diamond drill holes, this structure may be a down-faulted section of the Norwich vein, produced by a normal strike fault on the Norwich vein.

The footwall section of the Norwich vein has been the largest ore producer of the property. The average strike of the vein is slightly north of east, and the average dip, from the surface down to the 250 foot level is 47°. The vein has been intensely strike-faulted and is cut by many high angle faults and cross faults (Fig.II). The cross faults have a relatively small displacement of from 3 to 5 feet to the right. The strike faulting has caused pull-aparts in some sections of the vein, and doubling up in other parts,
greatly complicating the mining of the vein. The wall rock has been intensely crushed and altered, causing very heavy ground. In many places two or three inches of dark blue fault gouge forms along the hanging wall of the vein.

Mining in this area has shown the average depth of oxidation to be about 50 feet, although some manganese oxide is found as deep as the 250 foot level. Some rhodochrosite has been found within 30 feet of the surface.

Neither the Plutus nor the Norwich veins form prominent outcrops on the surface, although the outcrops may be traced roughly by means of old trenches. The Norwich ore body appears to be part of the vein that extends into the Mapleton and the Great Republic to the west, and extends eastward to the rhyolite flows.

Rhyolite is found covering much of the Norwich claim. Two distinct varieties of rhyolite occur on this claim; intrusive rhyolite, which forms large dikes, and extrusive or surface rhyolite, which forms flows and surface breccias. Distinction is made between the two main types of rhyolite on the surface maps prepared by Nelson and Irving. No mineralization has been found in the rhyolite on this property.
### TABLE I

Norwich Mine Water Analysis

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<th>Surface pump discharge</th>
<th>ppm</th>
<th>Cl</th>
<th>ppm</th>
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<tr>
<td>SiO₂</td>
<td>290</td>
<td>150</td>
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</tr>
<tr>
<td>Al₂O₃</td>
<td>35</td>
<td>HCO₃</td>
<td>65</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>375</td>
<td>Na</td>
<td>285</td>
</tr>
<tr>
<td>Mg</td>
<td>48</td>
<td>K</td>
<td>8</td>
</tr>
<tr>
<td>Mn</td>
<td>51</td>
<td>Zn</td>
<td>nil</td>
</tr>
<tr>
<td>SO₃</td>
<td>72</td>
<td>Cu</td>
<td>nil</td>
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Norwich vein seepage, 250 foot level.

<table>
<thead>
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<th>ppm</th>
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<tbody>
<tr>
<td>Ca</td>
</tr>
<tr>
<td>346</td>
</tr>
<tr>
<td>Mg</td>
</tr>
<tr>
<td>112</td>
</tr>
<tr>
<td>Mn</td>
</tr>
<tr>
<td>20</td>
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<table>
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<th>ppm</th>
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<tbody>
<tr>
<td>HCO₃</td>
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<tr>
<td>68</td>
</tr>
<tr>
<td>Zn</td>
</tr>
<tr>
<td>Cu</td>
</tr>
</tbody>
</table>
PROCEDURE

Field Work

Prior to sampling, the author made several trips underground for the specific purpose of becoming thoroughly familiar with the ore bodies. Geological and assay maps were studied to aid in the correlation of underground observations. Over sixty samples were taken representing a longitudinal section of the 170 foot level of the Norwich vein. Other samples were taken in the Norwich shaft and in the Plutus vein. 19 thin sections were made to study the manganese minerals, and 15 polished sections were made for study of the sulphide minerals. Some specimens were assayed for manganese.

To determine the relative solubility of the vein minerals, two samples of mine water were taken and analyzed to determine the mineral content. One sample was taken from seepages in the Norwich vein. The analysis (Table I) indicates that manganese is one of the most soluble of the vein minerals, and that it is in the bicarbonate form which will precipitate as rhodochrosite under favorable conditions.

Mr. Allsman, who is currently studying the oxide ores, was able to dissolve a small amount of rhodochrosite in distilled water that was adjusted to the pH of the mine water by addition of a small amount of acid. When the solution was
evaporated slowly, some rhodochrosite, along with manganese oxide was found in the residue.
TABLE II

Assay of impure manganese 'paint'

<table>
<thead>
<tr>
<th>Element</th>
<th>Assay (%)</th>
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<tbody>
<tr>
<td>Mn</td>
<td>39.70</td>
</tr>
<tr>
<td>CaO</td>
<td>0.85</td>
</tr>
<tr>
<td>MgO</td>
<td>0.92</td>
</tr>
<tr>
<td>Fe</td>
<td>1.10</td>
</tr>
<tr>
<td>Insol.</td>
<td>2.30</td>
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Assay average ore shipped

<table>
<thead>
<tr>
<th>Element</th>
<th>Assay (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mn</td>
<td>19.10</td>
</tr>
<tr>
<td>CaO</td>
<td>0.78</td>
</tr>
<tr>
<td>MgO</td>
<td>0.82</td>
</tr>
<tr>
<td>FeO</td>
<td>6.10</td>
</tr>
<tr>
<td>Ag</td>
<td>6.20 oz.</td>
</tr>
</tbody>
</table>

Assays by courtesy of Dick Roach
LABORATORY PROCEDURE

A Leitz - Wetzlar petrographic microscope with nicols for polarized light was used in the work on the thin sections. Solar illumination was used throughout the petrographic work. Identification of minerals was made with references to Rogers and Kerr.

A Leitz - Wetzlar reflecting microscope with nicols for polarized light was used to determine the opaque minerals. Minerals were identified according to the methods described by Short.\textsuperscript{12} Identification of certain minerals was confirmed by microchemical tests as described in the article. By use of 32 mm., 14 mm., and 8 mm., objectives and 8 X, 10 X, and 25 X oculars, magnifications varying from 32 to 500 diameters were obtained.

Photomicrographs were taken with a Bauch & Lomb camera. The adjustable bellows of the camera approximately doubled the indicated magnification of the microscope. Kodak Super XX Panchromatic film was used for all photographic work.
OBSERVATIONS

The minerals found present in the vein, listed according to abundance are: quartz, rhodochrosite, pyrite, sphalerite, calcite, galena, freibergite, chalcopyrite, argentite, pyrargyrite, native silver, and some stromeryite. Some minor sericite was also noted filling late fractures in the ore.

Every specimen of rhodochrosite ore from the Norwich mine shows signs of intense deformation and brecciation. In many of the specimens the deformation of rhodochrosite crystals could be seen with the naked eye. None of the specimens examined under the petrographic microscope lacked undulatory extinction; the minimum distortion noted was in euhtedral crystals of rhodochrosite that had been in open vugs at the time of deformation. Some of the quartz also showed wavy extinction.

One specimen indicated a relatively long period of deposition of pure rhodochrosite, which had been intensely brecciated and recemented with later rhodochrosite. This was further brecciated and the whole mass was recemented with quartz.

Many small vugs were present, not only in the brecciated ore, but also in the massive rhodochrosite. Locally, these vugs are lined with euhtedral rhombic crystals of rhodochrosite on some of which there is deposited a layer of tiny crystals
of quartz and a few small pyrite and sphalerite crystals. Most of the vugs are completely filled with quartz.

Many of the sheeting planes and cross fractures in the country rock contain a very thin deposit of a very fine grained, pure, unconsolidated rhodochrosite. This rhodochrosite has been termed manganese 'paint' by the mine geologists. Although this 'paint' is often found a great distance from the vein, it is also frequently found in some of the poorly cemented rhodochrosite breccias giving rise to some of the higher grade ore pockets. This manganese is considered to be of supergene origin by the author.

Assays of the rhodochrosite breccias containing a large amount of the supergene rhodochrosite showed the manganese 'paint' to have a much lower CaO - MgO content than the average ore mined. This could either indicate the replacement of calcium and magnesium carbonates of the original ore, or merely the colloidal deposition of the less soluble manganese, under reducing conditions.
MINERAL RELATIONSHIPS

Rhodochrosite-quartz

Rhodochrosite antedates some quartz, is contemporaneous in part, and younger than some of the quartz. Rhodochrosite occurs interstitially to euhedral quartz crystals, and thus is here later than the quartz. Conclusive proof of rhodochrosite being earlier than some quartz was shown by replacement of rhodochrosite by quartz. Replacement remnants of rhodochrosite crystals are in optical continuity, and cleavage traces may be followed from remnant to remnant.

The later quartz was the most common impurity in the rhodochrosite and was commonly seen replacing the rhodochrosite. Quartz veinlets were commonly seen crossing both the rhodochrosite and the previously mentioned quartz.

Small veinlets of rhodochrosite were seen cutting one of the later veinlets of quartz in one specimen. A fine, powdery rhodochrosite was found in the fractures of some of the ores fractured by cross faulting. This rhodochrosite is believed to be later than all other mineralization, and is thought to be supergene in origin.

Pyrite-quartz

Some pyrite was seen associated with the oldest quartz. However, most of the pyrite was associated with the later large scale silicification. Some minute pyrite crystals were
noted coating some of the latest quartz.

**Pyrite-sphalerite-chalcopyrite-galena**

Pyrite and sphalerite were seen closely related in the later silicification of the manganese. Sometimes pyrite could clearly be seen replacing the sphalerite, while other specimens showed the sphalerite to be replacing the pyrite.

Chalcopyrite was seen replacing pyrite along fractures in the pyrite grains, and was seen replacing the edges of pyrite. Chalcopyrite was also seen as an exsolution texture in sphalerite as well as a possible decomposition product of freibergite.

Galena was always noted to be replacing pyrite and sphalerite, and closely associated with chalcopyrite. The relationship between galena and chalcopyrite is not definitely known, but chalcopyrite is thought to be later.

**Freibergite - later silver minerals**

Freibergite was noted in some of the later dense white quartz, and in one instance was noted replacing sphalerite. Freibergite is thought to be the only primary silver mineral found. Argentiferous galena was quite common in the high silver specimens. Under high magnification, small inclusions of argentite were noted in the galena. In some of the galena, the triangular pits along the cleavage planes were indistinct and hard to see. In these specimens, all the diagnostic
Properties of native silver were present, and microchemical tests showed the presence of both silver and lead.

Pyrargyrite was noted in one specimen replacing galena, and in another was noted associated with freibergite and chalcopyrite. Stromeyerite was seen closely associated with chalcopyrite in one specimen and is thought to be formed by the decomposition of the primary freibergite.

Stephanite was long thought to be the silver mineral in this mine, however, none of the specimens studied by the author showed stephanite.
CONCLUSIONS

The paragenesis of the Norwich vein was found to be similar to that proposed by the earlier authors. The detailed paragenesis as found is: quartz-pyrite, rhodochrosite, quartz, minor rhodochrosite, quartz-pyrite-sphalerite, quartz, galena, freibergite, and later quartz. Argentite, pyrargyrite, stromeyerite, and native silver are thought to be supergene minerals.

Ground water was found to contain appreciable manganese in solution as manganese bicarbonate, a form from which rhodochrosite can be precipitated. The intense brecciation of the vein would aid in the solution and deposition of the secondary rhodochrosite. The method by which rhodochrosite was redeposited can only be postulated, however, the mere removal of the oxygen by reducing conditions found in the unoxidized section of the vein would be sufficient to precipitate much of the manganese. The high magnesium and calcium content of the mine water may point the possibility of the rhodochrosite either replacing partially decomposed minerals in the country rock, or replacing some of the primary carbonate found in the veins.

Some supergene enrichment of the rhodochrosite was definitely present in the Norwich vein. Although this enrichment was probably small, and limited to brecciated zones immediately below the oxide zone, it may be responsible for some of the higher grade ore shoots. Supergene enrichment may also have been responsible for raising the grade of subcommercial rhodochrosite ore to a commercial grade.
PLATE II

Photomicrographs of Polished Sections

Figure 1

Stromeyerite (stm) and chalcopyrite (cp) associated with freibergite (fr). 440 X

Figure 2

Veinlet of argentite (arg) crossing quartz (q) and fractured pyrite (py). 200 X

Figure 3

Pyargyrite (pyr) in galena. Galena (ga) replacing pyrite (py) in rhodochrosite (rc). 250 X

Figure 4

Sulphide veinlet in rhodochrosite (rc). Native silver (ag) in galens (ga) with sphalerite (sp). 80 X

Etched with HNO₃ and repolished.
PLATE III

Photomicrographs of Polished Sections

Figure 1

Freibergite and quartz - rhodochrosite breccia in rhodochrosite (rc). 80 X

Figure 2

Argentite (arg) in rhodochrosite (rc) and galena (ga). 80 X

Figure 3

Argentite (arg) and rhodochrosite (rc) veinlet crossing galena (ga). Argentite appears to be replacing rhodochrosite. 200 X

Figure 4

Veinlet of galena (ga) crossing brecciated pyrite (py). Chalcopyrite (cp) replacing pyrite (py). 200 X
PLATE IV

photomicrographs of Thin Sections

Figure 1

Quartz (q) in rhodochrosite. Plain polarized light. 80 X

Figure 2

Same field as Fig. 1 under cross nicols show extreme undulatory extinction. 80 X

Figure 3

Same specimen as Fig. 1. Lack of undulatory extinction in banded euhedral rhodochrosite crystals indicate quartz filled vug was open at time of greatest deformation. Cross nicols, 240 X

Figure 4

Rhodochrosite (rc) filled fracture in quartz crystal. Cross nicols, 240 X
PLATE V

Photomicrographs of Thin Sections

Figure 1

Phantom of rhodochrosite (rc) in quartz crystal. Cross nicols, 80 X

Figure 2

Quartz (q) replacing sphalerite (sp) and pyrite (py). Plain polarized light, 120 X

Figure 3

Rhodochrosite remnants in quartz pebble. Quartz and rhodochrosite breccias re-cemented with quartz. Cross nicols, 80 X

Figure 4

Rhodochrosite (rc) and quartz (q) apparently replacing sphalerite (sp). Cross nicols, 352 X
PLATE VI

Photomicrographs of Thin Sections

Figure 1

What had appeared to be banding of quartz and rhodochrosite in hand specimens is here shown to be quartz replacing rhodochrosite along fractures. Plain polarized light, 25.2 X

Figure 2

Rhodochrosite (rc) remnants in quartz. Quartz appears to be replacing sphalerite (sp). Plain polarized light, 352 X

Figure 3

Pyrite filling reentrant angles in euhedral rhodochrosite crystals. Quartz apparently replacing the pyrite. Remnants of sphalerite in pyrite. Cross nicols, 80 X
BIBLIOGRAPHY


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PLATE VII. GENERALIZED CROSS-SECTIONS OF THE NORWICH VEIN

SCALE 1" = 40'