Oxidized Copper Mineralization along the Continental Fault near Butte, Montana

Theodore H. Eyde

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OXIDIZED COPPER MINERALIZATION ALONG
THE CONTINENTAL FAULT
NEAR
BUTTE, MONTANA

by
Theodore H. Eyde

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, 1955
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A veinlet of cuprite filling a fracture in aplite.
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ACKNOWLEDGEMENTS

I would here like to express my appreciation for the assistance of the following people in the preparation of this report.

Without the invaluable aid of Mr. March, head of the Geology department Montana School of Mines, this paper would have been far more difficult to write. His vast experience with oxide copper deposits was of great value in deciphering many of the confusing features of the deposits.

Mr. Norman Rogers, operator of the Bullwhacker Mine spent considerable time in pointing out information exposed during the course of mining operations.

A great amount of information on the history of the deposits and elevations were received from Mr. Ed Shea of the Geological Department of the Anaconda Copper Mining Company.

Mr. Rolland R. Reid has helped greatly through suggestions and helpful criticism of this report.

Mr. John Richards contributed much time assisting in the mapping of the deposits.
OXIDIZED COPPER MINERALIZATION ALONG
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BUTTE, MONTANA

by Theodore H. Eyde

ABSTRACT

Located in the fault zone of the Continental fault near the western edge of the Boulder batholith of southwestern Montana the oxidized copper deposits are developed by three open pit mines, one of which is presently in operation. Copper has been deposited by descending cold solutions which have leached copper from the surrounding quartz monzonite and deposited within the crushed fault zone. Local high grade "bunches" of ore occur along narrow limonite veins, remnants of primary sulfide veins which have been enriched by the descending cold solutions.

An oxide ore body, valuable chiefly for its copper-silica content occurs in the fault zone. Chrysocolla, cuprite, supergene chalcocite, and tenorite are the most abundant minerals with lesser amounts of malachite and azurite. Gangue minerals are chiefly plagioclase, orthoclase, ferro-magnesian minerals, limonite, and pyrite.

The Bullwhacker open pit mine shows a conspicuous lack of hydrothermal alteration, while the Butte Duluth (Altona) and Sarsfield exhibit a greater degree of hydrothermal alteration which consists principally of kaolinization. Average grade of ore diminishes rapidly with increasing depth. A zone of aplite between the Sarsfield Mine and the Bullwhacker is barren of copper mineralization. Further study is necessary to determine the conditions which localize the high grade "bunches" of ore and the conditions which influence the formation of chrysocolla.
INTRODUCTION

Purpose of Report

This report is written to partially fulfill the requirements for the Bachelor of Science Degree in Geological Engineering at Montana School of Mines. Mr. Walter S. March, head of the geology department, and Mr. Rolland R. Reid, instructor in the geology department were the faculty advisers for this project.

The ultimate objective of this study was to determine the source of the oxidized copper ores, the conditions which caused the deposition of the ore, the conditions which localized small deposits of cuprite, chalcocite, native copper, and tenorite within the larger low grade ore body, and the limits of the ore body.

Investigation of the deposits included mapping the veins, faults, and topographical features of the deposits supplemented by the laboratory investigation of the ores and rocks collected at the deposit and in the vicinity adjacent the deposit. As the scope of this paper is somewhat limited it was impossible to thoroughly study either the alteration products or the conditions which caused the deposition of copper in the fault zone. Inclement weather also limited the field mapping.
Location and History

The oxidized copper deposits are located about two miles east of the city center of Butte, Montana along the foothills at the base of the East Ridge and trend in a north-south direction. The deposits are readily accessible throughout the year by a good improved road which terminates in U.S. 91 at the base of Woodville Pass. Mining of the most northerly deposit terminated when highway 91 was intersected by the open pit. The deposits are also accessible from the Columbia Gardens Road which cuts between the Bullwhacker and Altona or (Butte Duluth) claims.

Before the turn of the century the "flat" and the East Ridge had been considered barren ground.

Figure 1. Index map of Montana showing the location of the Butte mining district.
After the Pittsmont discovery in 1902 and with high copper prices prevailing, the East Ridge area was the scene of renewed mining activity. In 1906 the Bullwhacker Company, Patrick W. Clark president, organized to treat the low grade oxide and silicate ores which occurred near the surface on the west face of the East Ridge. First shipments were made directly to the smelter; but soon the possibilities of leaching the ore were realized and a 5 ton pilot plant was built in 1912 with results so successful that a 50 ton plant was constructed. Open pit mining began in March 1914 after the completion of an entirely new 250 ton plant. After 52,000 lb of fine copper was shipped to Germany with a consequent loss of money, the plant closed down in August 1914. The process cost more than the copper was worth.  

In late 1912, Captain A.B. Wolvin, president of the Butte and Superior Company, organized the Butte and Duluth Company on the Altona property and installed a leaching plant which had a capacity of 150 tons per day. By 1914 the plant was producing 64,000 lb electrolytic copper and 30,000 lb cement copper a month. In February 1915 the company produced 120,000 lb electrolytic copper and 30,000 lb cement copper; shortly after this month of peak production the company had financial troubles and went into receivership. This company

also found the cost of production was just above the price of copper.2

No important work was done on the properties until 1947, when a lessee mined out the remaining ore in the Butte Duluth Pit. In 1948, Roger Brothers Gold Mining Company leased the Bullwhacker Pit and adjoining claims from the North Butte Mining Company and began shipping about nine railroad cars a week to the Anaconda Reduction Works for use as a flux in the reverberatory furnaces. The same arrangement was continued after the North Butte Company was bought out by the Anaconda Copper Mining Company. A royalty of 10 percent of the net smelter returns is paid to the Anaconda Copper Mining Company. Presently the mine is producing from four to nine railroad cars of ore weekly.

In 1950 another operation began just below the Sarsfield shaft; Joe Farrell and Sons using open pit mining methods, similar to those employed at the Bullwhacker Pit, began shipping ore to the Anaconda Reduction Works under the same arrangement as Roger Brothers. This operation was abandoned in 1954 when the ore was exhausted.

**Physiography**

The most prominent physiographic feature in the area

2. Ibid., p. 16.
is the fault scarp of the Continental fault, which is the western face of the East Ridge. Corry states that lack of glacial debris and morainal material point toward the conclusion that the final movements along the fault proper must have taken place during late Quaternary, certainly since the pre-Wisconsin glaciation. Most glaciers in this vicinity were, however, above an elevation of 8,000 ft. Possibly the criteria advanced by Corry to date the fault are not valid, because the area surrounding Butte most probably never was glaciated, and also since the nearest glaciation took place in the Highland Mountains approximately 19 mi south of Butte.

The valley floor or "flat" is covered with from 200 to 600 ft of alluvial material derived from the surrounding mountains. The foot hills of the East Ridge were formed by the rotational movement of the Continental fault in which the surface has been tilted gently toward the south with the corresponding appearance of a wedge. This rather rugged mountainous region has been dissected by stream erosion, which has carved several deep canyons extending into the main portion of the East Ridge and Rampart Mountain. The greatest amount of relief in the area is approximately 2,800 ft between the valley floor and the summit of the East Ridge.

Previous Work

To the writer's best knowledge no detailed investigation has been made of the oxidized copper mineralization along the Continental fault prior to this paper. Walter Harvey Weed, Reno Sales, William Emmons, and others have mentioned and advanced ideas concerning the genesis of the ores. None of them, however, have ever written a detailed article concerning the deposits. Opportunities to investigate the deposits and follow the mining operations have been rather limited, since the properties were inactive from 1915-1947, a period of about 32 years. Any articles mentioning these deposits were written prior to 1915.
PLATE II
GEOLOGIC MAP OF THE BOULDER BATHOLITH

SCALE: 1 IN = 8 MI

QUATERNARY
- RIVER GRAVEL & ALLUVIUM
- DACITE & RHYOLITE

TERTIARY
- RHYOLITE
- QTZ MONZONITE & DIORITE

MESOZOIC
- ANDESITE

PALEOZOIC
- SEDIMENTARY ROCKS

PRE-CAMBRIAN
- METAMORPHIC ROCKS
AREAL GEOLOGY

Boulder Batholith

The oxidized copper deposits occur near the west edge of the Boulder Batholith to which the deposits are genetically related. Extending from Helena, Montana on the north, to the Highland Mountains on the south, the long axis of the batholith is approximately 70 mi long trending about N 30° E with an average width of from 25 to 48 mi. Although rocks composing the batholith are essentially few and similar in chemical and mineral composition, they may be very dissimilar in appearance. Quartz monzonite and diorite are the principal rock types found in the batholith.

Rocks of the District

Sedimentary Rocks. Sedimentary rocks do not occur in the Butte mining district. Unconsolidated stream gravels and alluvial material are widespread throughout the eastern part of the district and are the most recent rock aggregate of the area. The East Ridge copper deposits are covered with from 15 ft, on the east, to 40 ft, on the west, of alluvial material.

Igneous Rocks. Rocks of igneous origin which occur

in the eastern portion of the district in order of decreasing age are as follows (1) porphyritic quartz monzonite, (2) aplite, (3) rhyolite.

1. Quartz monzonite. Quartz monzonite, the major rock type of the Boulder batholith is also the most abundant rock type of the East Ridge portion of the Butte district. According to Weed, the rocks of the East Ridge area resemble more closely those of the Bluebird silver area than those of the Butte hill. Typical Butte quartz monzonite shades into aplite with corresponding basic modification of the magma. In the more basic rock, pyrite is absent or nearly so, but chalcopyrite is very abundant. Best material is from the deep workings of the Altona, Montgomery, and Bullwhacker Mines. All the underground workings of these mines are inaccessible and dump material has been badly altered, consequently the writer was unable to study any of this rock.

Megascopically, the quartz monzonite is a medium-grained, porphyritic rock of pale gray color, speckled with

grains of biotite. Occasionally the quartz monzonite contains large phenocrysts of orthoclase with diameters of from \( \frac{1}{2} \) in. to 2 in.

2. Aplite. Aplite occurs in steeply dipping dikes from 1 in. to several ft in thickness having a general east-west strike. Large irregular masses of aplite also occur through out the area. Although Weed states the contact between the aplite and quartz monzonite is rather gradational, exposures of contacts of these two rock types in the Bullwhacker Mine showed them to be nearly "knife sharp". Aplite has no relation to the ore bodies in the area and is generally considered to be inert in the Butte district. Although not genetically related to the ore, aplite had the effect of being "tight" and not readily amenable to the deposition of ore minerals.

3. Rhyolite. Tabular post-batholithic dikes of rhyolite occur north of the Main Range Mine but are not present in the actual thesis area.
Structural Geology

The major structural feature in the area is the Continental fault which can be traced for about 15 mi along the lower slopes of the ridge. Corry 6 in his study of the Continental fault concludes that it is a normal gravity fault with a series of faults composing a broad fault zone at the base of the ridge. The east block has apparently moved up in relation to the west block.

Striking about north-south the Continental fault dips from 67° - 75° west. Corry 7 states that the vertical displacement is about 1350 ft vertically. Judging from the amount of relief between the valley and the summit of the East Ridge, as well as considering the quantity of material removed from the ridge by erosion and also the depth of alluvium on the valley floor it appears as if the vertical displacement may have been more than twice this figure.

Mining operations have exposed one strand of the Continental fault in the Bullwhacker Pit where it consists of from 2 to 3 ft of gray colored, dry fault gouge. Seemingly this strand is the eastern limit of the main Bullwhacker ore body.

7. Ibid., pp. 34-35.
In the Main Range Mine, the Continental fault consists of two strands, the first about 25 ft in thickness and the second about 15 ft in thickness, of dark gray, "rubbery", fault gouge. The fault acted as a dam, creating a perched water table on the east side of the fault which caused considerable difficulty during the mining operations; the flow amounting to several thousand gal of water per min. No primary mineralization exists in the Continental fault and it displaces all the earlier veins and faults.

A series of narrow limonite veins from 4 in. to 1 ft wide, with an east-west strike, and steep (80°) south dip occur in all the open pit mines. Small stringers of limonite from ½ in. to 3 in. in width are disseminated throughout the entire area.

8. Personal communication with Ed Shea of the Anaconda Copper Mining Company Geological Department.
The criterion used to distinguish between the leached, oxidized primary sulfide veins and the narrow aplite dikes is the conspicuous absence of limonite in the aplite, even in areas of intense oxidation. Two sets of strong faults are also exposed, the first with a strike of N 20°E and a dip of 75°E, and the second with a strike of N 20° to 30°W and a dip of 60°W. Some primary mineralization has occurred in these faults, since the fault clay contains small quantities of limonite. None of these structures can be traced through the strand of the Continental fault.

Copper Mineralization

As shown by the north-south trend of the ore bodies, the copper deposits occur within the fault zone of the Continental fault. Primary copper veins in this area are very narrow and of practically no economic value both because of the narrow width and low tenor of the ore. Veins of the East Ridge resemble more closely the veins of the Butte silver zone than those of the copper zone. Had not the copper deposits undergone sulfide enrichment and oxidation enrichment the deposits would be of no economic importance.

Previous attempts at leaching the oxidized ore have ended in failure because of the low solubility of cuprite and
tenorite in sulphuric acid and the presence of large amounts of fault gouge (clay) mixed with the chrysocolla, markedly lowering the solubility of the chrysocolla.

More readily leached carbonate minerals azurite and malachite are formed only close to the outcrop where the carbon dioxide can react with cuprite, tenorite, native copper, and chalcocite. No carbonates are found within the deposit because of the acidic, high silica, environment formed by the decomposition of the quartz monzonite.

Polished sections of the ore in quartz monzonite show many angular fragments of quartz which have been crushed during the movement of the Continental fault, and have been recemented by chrysocolla. Aplitic has cracked and fissured upon weathering and the copper minerals have deposited within these cracks without replacing the aplite, evidently forming actual cavity fillings. Hornblende, and biotite have not been altered, remaining
as abundant in the fresh monzonite as in the strongly mineralized monzonite. Altered, mineralized monzonite contains numerous grains of limonite, remnants of the chalcopyrite which has been leached out. Plagioclase alters to kaolin that is a light green color from the chrysocolla which formed contemporaneously during the alteration of the plagioclase.

Figure 8. Kernels of cuprite in chrysocolla and quartz monzonite.

Small high grade "bunches" and stringers of cuprite and supergene chalcocite with smaller amounts of tenorite, native copper, and chrysocolla occur where the small east-west veins and stringers crosscut the lower grade ore body. These ore
GEOLOGIC MAP OF THE BULLWHACKER MINE, BUTTE, MONTANA

- Scale 1" = 200'
- Quarts Monzonite
- Covered Veins
- Aplites
- Faults
- True North

Plate 11
Plates IV A, B, C

Vertical Cross Section A - A
Looking North
Scale 1" = 200'

Quartz Monzonite
Aplite

Vertical Cross Section B - B
Looking North

Vertical Cross Section C - C
Looking North
bodies are not uniform along the strike and dip but occur sporadically in "bunches" with no apparent reason for their deposition.

Mineralogy of the Ore Minerals

Oxidized ore minerals which occur in East Ridge Oxidized Copper Deposits listed in order of decreasing abundance are: (1) chrysocolla, (2) cuprite, (3) chalcocite, (4) tenorite, (5) native copper, (6) malachite, and (7) azurite.

Chrysocolla occurs within quartz monzonite intermixed with the clay formed from the decomposition of plagioclase. Concentric rings of chrysocolla often form around grains of cuprite, usually with a thin black transition zone. Thin crusts of chrysocolla are often deposited as a filling in cracks in the aplite, but never as a replacement.

Chrysocolla is the mineral of greatest economic importance because of (1) its greater abundance and (2) its chemical composition, which makes it a suitable silica flux for the copper reverberatory furnaces.
Cuprite occurs as "kernels" or grains in the aplite and quartz monzonite. A transition ring or envelope of tenorite surrounds the cuprite with an outer envelope of chrysocolla. Usually cuprite, when viewed in polished section, is an intimate mixture of supergene chalcocite and cuprite with occasional blebs of native copper.

Figure 10. A transition ring or envelope of tenorite surrounding a kernel of cuprite.

Chalcocite occurs usually only as a secondary sulfide as deeper workings encountered principally chalcopyrite and tetrahedrite as the primary copper minerals. Weed\(^9\) saw several specimens from these claims in which the

tetrahedrite and quartz crystals were coated with sooty chalcocite. In polished section chalcocite forms around grains of pyrite replacing them. Wherever pyrite is abundant the secondary chalcocite does not form native copper, instead it forms a small amount of cuprite. Usually, however, supergene chalcocite occurring near the outcrop alters directly to malachite without any intermediate steps.

Malachite forming directly from chalcocite:

\[
\text{Cu}_2\text{S} + \text{CO}_2 + 3\text{H}_2\text{O} + 80 \rightarrow \text{CuCO}_3 \cdot \text{Cu(OH)}_2 + 2\text{H}_2\text{SO}_4
\]

In the presence of little or no pyrite, chalcocite forms native copper or cuprite.

Native copper forming from chalcocite:

\[
\text{Cu}_2\text{S} + 3\text{Fe}_2(\text{SO}_4)_3 + 4\text{H}_2\text{O} \rightarrow 2\text{Cu} + 6\text{FeSO}_4 + 4\text{H}_2\text{SO}_4
\]

OR

\[
\text{Cu}_2\text{S} + 4\text{Fe}_3(\text{SO}_4)_3 + 4\text{H}_2\text{O} \rightarrow \text{Cu} + \text{CuSO}_4 + 8\text{FeSO}_4 + 4\text{H}_2\text{SO}_4
\]

Cuprite forming from chalcocite:

\[
\text{Cu}_2\text{S} + 2\text{O}_2 + \text{H}_2\text{O} \rightarrow \text{Cu}_2\text{O} + \text{H}_2\text{SO}_4
\]

OR

\[
2\text{Cu}_2\text{S} + \text{O} \rightarrow 2\text{CuS} + \text{Cu}_2\text{O}
\]

Tenorite usually occurs as a black vitreous min-

11. Ibid., p. 72.
12. Ibid., p. 72.
eral enveloping the cuprite, with chrysocolla an outer envelope around the tenorite. In the south end of the Bull-whacker Pit and all through the Sarsfield Pit tenorite occurs as "copper pitch" which is probably a mineral composed of varying percentages of copper and manganese oxides. Tenorite on the outcrop frequently alters to both malachite and azurite. Best exposures of this type could be seen on the hill side west of the Sarsfield Shaft, however, these exposures have since been removed by mining operations at the Sarsfield Pit.

Native copper occurs as irregular "blebs" in cuprite and supergene chalcocite. Generally cuprite forms from chalcocite with subsequent formation of small amounts of native copper.

Native copper forming from cuprite:13

(1).  
\[ 2Cu_2S + 5O \rightarrow Cu_2O + 2Cu + 2SO_2 \]

or in the presence of small quantities of pyrite:

\[ Cu_2O + 2FeS_2 + H_2SO_4 \rightarrow 2Cu + Fe_2(SO_4)_3 + H_2O \]

Under oxidizing conditions native copper can oxidize to cuprite.

(2).  
\[ 2Cu + O \rightarrow Cu_2O \]

The greatest quantity of native copper in oxidized copper deposits is the result of reaction (1), however,

13. Ibid., p. 72.
in any single deposit both reactions occur and a certain quantity, though very small, is the result of reaction (2).

Malachite and azurite occur only on or close to the outcrop. Chalcocite, cuprite, tenorite, and native copper all are replaced by malachite. Azurite is far less abundant than malachite. According to Schwartz azurite frequently replaces malachite according to the following reaction.\(^\text{14}\)

\[
3[\text{CuCO}_3 \cdot \text{Cu(OH)}_2] + \text{CO}_2 \rightarrow 2[2\text{CuCO}_3 \cdot \text{Cu(OH)}_2] + \text{H}_2\text{O}
\]

Both minerals generally occur in the area as botryoidal and mammillary aggregates filling cracks and fissures in the quartz monzonite and aplite. Frequently these minerals are formed on and around masses of limonite.

**Gangue Minerals**

Principal gangue minerals are quartz, limonite, pyrite, orthoclase, plagioclase, clay minerals, and ferromagnesian minerals.

Quartz occurs as a major component of both aplite and quartz monzonite. In polished sections it appears as crushed fragments associated with the ore minerals. The east-west oxidized primary sulfide veins and stringers contain considerable quantities of quartz associated with limonite and pyrite. Although considered a gangue mineral, high percentage of quartz is very desirable for reverberatory fur-
nace flux. In fact Norman Rogers, operator of the Bull-whacker Mine, states that he is penalized heavily for low free silica content.

Limonite occurs throughout the area in the east-west veins, stringers, and altered quartz monzonite, as well as intimately associated with the malachite and azurite on the outcrop. Pyrite is associated with the chalcocite and in the limonite it occurs as remnants. Both pyrite and limonite are composed of iron compounds which must be fluxed off by increased additions of silica. Mine operators are therefore penalized heavily for excessively high percentages of iron in the ore.

Orthoclase, plagioclase, clay minerals, and the ferro-magnesian minerals are gangue minerals because of their high percentages of aluminum silicates, which are considered as combined silica by the smelter operators. Aluminum silicate has a high melting point and must be slagged off, requiring the addition of more flux. These minerals are the most abundant and consequently the most undesirable gangue minerals. It is nearly impossible to sort the ore because of the close association between the ore and the gangue minerals.

Alteration

The Sarsfield and Butte Duluth (Altona) Mines show some rather limited hydrothermal alteration and also a large aplite body on the eastern boundary of the ore, while
in the Bullwhacker Pit the lack of hydrothermal alteration is conspicuous. Alteration in the Bullwhacker Mine, and for the most part in the other mines in the area, consists principally of cold descending solution clay alteration.

Cold water alteration at the Bullwhacker Mine strongly suggests that the deposits of copper were formed or deposited by solutions which leached the copper from the quartz monzonite on the hill above the deposits and carried the copper ions in solution down into the fault zone where conditions were favorable for deposition.

The Sarsfield and Butte Duluth (Altona) Mines are located east of the Bullwhacker Mine; seemingly on the east side of the strand of the Continental fault which traverses the Bullwhacker Mine. Since the fault is covered by alluvium between exposures and is not readily traced through the covered areas, the fault exposed in all three open pits, is perhaps the same strand of the Continental fault. A small ore body in the north east corner of the Bullwhacker Mine also shows the same type of hydrothermal alteration and the same aplite as in the other pits. Mr. Ed Shea, of the Anaconda Copper Mining Company Geology Department is of the opinion that this alteration has no influence on either the size or grade of the ore bodies and is consequently almost meaningless. He states further that these alteration rings occur sporadically throughout the district.
Paragenesis

The order of deposition of ore minerals is:

Primary Sulfides

Supergene Chalcocite high pyrite  Supergene Chalcocite low pyrite

\[ \text{CO}_2 \text{ (Atmosphere)} \]

- Native Copper  Cuprite

- Tenorite

Malachite

- Chrysocolla

Azurite

\[ \text{CO}_2 \text{ (Atmosphere)} \]

Figure 11.

Paragenetic Diagram of the High Grade Ore

Earliest primary sulfides were chalcopyrite, tetrahedrite, and pyrite, which were deposited in the east-west veins and stringers prior to movement along the Continental fault. Two definite types of supergene chalcocite were formed (1) containing a large percentage of pyrite and (2) containing a relatively small percentage of pyrite. Chalcocite containing the small percentage of pyrite was reduced by the limonite to
Native copper (Cu) and cuprite (Cp) replacing supergene chalcolite (Cc) and primary chalcolite (Cc'). Some cuprite (Cp) is replacing native copper (Cu).

Native copper (Cu) and cuprite (Cp) replacing supergene chalcolite (Cc).

A veinlet of chrysocolla cross-cutting cuprite (Cp).

Supergene chalcocite (Cc) forming around grains of pyrite (Py).
native copper and cuprite, while chalcocite containing the high percentage of chalcocite did not form oxide minerals. Some small amounts of native copper were later oxidized to cuprite, however a larger portion of cuprite was reduced to native copper. In the acidic environment of the fault zone the cuprite was replaced by tenorite which in turn was replaced by chrysocolla. Upon exposure to the atmosphere the supergene, pyrite-rich chalcocite, cuprite, and tenorite, all were altered to malachite, which with additional carbon dioxide partially altered to azurite.

CONCLUSIONS

Origin of the Copper

The copper has been derived from two sources (1) alteration of the chalcopyrite-bearing quartz monzonite, which contains from .4% to 1.0% copper and (2) supergene and oxidation enrichment of east-west primary sulfide veins and stringers. The large low grade ore body is located in a permeable fault zone where conditions were suitable for the deposition of copper. Ground water transported the solutions from the leached quartz monzonite down the slope into the fault zone. It may be hypothesized that during the leaching of the quartz monzonite some silica was released during the alteration of plagioclase to kaolin. Seemingly the silica may have combined with the copper ions in the ground water
and formed copper silicate, chrysocolla, within the clay or kaolin.

**Extent of the Orebody**

With increasing depth the grade of ore will drop rapidly for two reasons (1) circulation of copper bearing solutions is limited to the upper portion of the fault where circulation exists and (2) high grade concentration of cuprite and chalcocite will become smaller and less frequent with increasing depth because of diminishing oxidation and supergene enrichment. Formation of cuprite is also suppressed by large quantities of chrysocolla. Primary sulfide veins do not contain sufficient copper and are not wide enough to be of any economic value. Between the 100 ft and 200 ft levels of the Bullwhacker Mine the copper content of the ore declined tremendously and on the 400 ft level the vein was barren. 15

No evidence was discovered which would explain the irregular bodies or "bunches" of cuprite and chalcocite which occur irregularly along the east-west veins. Kernels of cuprite surrounded by envelopes of tenorite and chrysocolla are scattered indiscriminately in the chrysocolla-bearing, altered quartz monzonite. Possibly a grain of pyrite existed in the unaltered rock and supergene chalcocite replaced the

pyrite, however no field evidence could be found which supported this hypothesis.

Considerable tonnages of low grade ore should exist south of the present operation in the Bullwhacker Mine and this possibility should warrant further development. Possibilities for ore existing beyond the northern limit of the Bullwhacker Mine are poor, since the rock is aplite on both sides of the strand of the Continental fault and surface exposures of bedrock show little copper mineralization.

The ore body being mined in the Sarsfield Pit "pinched out" toward the south because the rock on both sides of the strand of the Continental fault was aplite which left only a very narrow crushed fault zone. Vertical displacement of the strand of the Continental fault is very conspicuous in the Bullwhacker and Sarsfield Mines; especially so in the Sarsfield where a large mass of aplite is exposed on the east side of the fault indicating an almost vertical movement along the fault. However, it is impossible to measure the magnitude of the vertical displacement.
Problems Which Require Further Study

During the preparation of this report, several interesting problems were encountered upon which little work was done, since they were considered to be beyond the scope of this report.

1. Additional work is required to determine the conditions which localize high grade "bunches" of ore in the east-west veins.

2. Small kernels of cuprite which occur without relation to the east-west veins or any fissures are equally baffling since no pyrite was noted in the polished sections of these kernels.

3. Research should be conducted to determine whether enough free silica is liberated during the alteration of plagioclase to combine with the copper ions in the ground water to form chrysocolla. The writer has noted that water passing through old gobs leaches silica from the decomposing rock and deposits it in gelatinous masses under and on the lips of the chutes.

Although it is not known whether this leaching action occurs in the fault, both field and laboratory evidence strongly support the hypothesis.
BIBLIOGRAPHY


