The Geology of the Copper Basin Ore Deposits, Lander County, Nevada

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Mining Engineering

by

Michael Charles Tippett

June 1967
The thesis of Michael Charles Tippett is approved:

Anthony J. Payne
Thesis advisor

Anthony J. Payne
Department Chairman

Dean, Graduate School

University of Nevada
Reno

June 1967
## CONTENTS

Abstract

Introduction ................................................. 1
Scope of Paper .................................................. 11
History of Copper Basin ..................................... 11
Acknowledgments ............................................... v

Geology ........................................................................
General Geology .................................................... 1
Geology of Copper Basin ........................................... 2
Sedimentary Rocks .................................................. 2
Extrusive Rocks ..................................................... 7
Intrusive Rocks ..................................................... 7
Quaternary Deposits ............................................... 9
Alteration ............................................................ 9
Structure ............................................................ 13

Description of the Ore Deposits .................................... 16
Contention Ore Deposit ........................................... 16
Sweet Marie Ore Deposit ........................................... 17
Copper Queen .......................................................... 20
Other Areas of Interest ............................................. 22
Badger ............................................................... 22
Mesa Copper .......................................................... 22
Henrietta ............................................................. 23
Copper King .......................................................... 23
Happy Area ........................................................... 23

Formation of the Ore Deposits ...................................... 24
Oxidation and Enrichment ......................................... 26

References Cited
List of Illustrations
(Plates in Pocket)

Plate 1. Geologic Map of Copper Basin
Plate 2. Geologic Sections at Copper Basin

Figure 1. Index Map
Figure 2. Location Map of Copper Basin
Figure 3. Sequence of Geologic Events at Copper Basin
Figure 4. Stratigraphic Section at Copper Basin
Figure 5. Photograph of Copper Basin, November, 1963
Figure 6. Photograph Showing Structure in Sweet Marie Pit, October, 1966
Figure 7. Fault and Fracture Systems at Copper Basin, Lander County, Nevada
Figure 8. Metal Zoning Pattern at Copper Basin, Lander County, Nevada

Table 1. Production of gold, silver, copper, and turquoise, Copper Basin, 1916-53...page iii.
ABSTRACT

The ore deposits at Copper Basin consist principally of supergene enriched copper minerals contained in arenites of the Cambrian Harmony Formation. Hypogene metallization is thought to be coincident with Eocene quartz monzonites which intrude the host rocks, causing widespread metamorphism.

Hypogene ore was introduced via NNE and NNW fissures, filled fissures and replaced metasomatized calcareous shales in the upper part of the Harmony Formation. Subsequent oxidation of hypogene chalcopyrite-pyrrhotite-pyrite tactite zones has formed at least three commercial supergene copper deposits. Important secondary ore controls are fracture intersections with favorable beds, creating permeable conduits for migrating copper-bearing solutions. Considerable alteration of the sediments and intrusive rocks attended the supergene enrichment process.
Introduction

Copper Basin is on the northeast slopes of the Battle Mountain Range, in the northeastern part of the Battle Mountain mining district, a copper producer since the late 1800's. The area is eight airline miles southwest of Battle Mountain, Nevada, and is accessible via State Highway 8A south of Battle Mountain and a connecting black-top county road to the mine gate.

The property lies at an average elevation of 5,500 feet with relief ranging to 900 feet. The topography is rounded and maturely developed. Vegetation consists principally of desert sage, although trees occur in the area near springs. Average rainfall is 10 inches, occurring largely in the spring and as winter snow. Winters are cold, temperatures frequently dropping below zero. Summers are moderate, with the warmest days during August.

Much work has been done in the area. The earliest descriptions in 1877 by Hague (1877, p. 317) and Emmons (1877, p. 666) were followed by Bastin's work in 1920 (Bastin, 1920); and most recently by Ralph J. Roberts and D. C. Arnold (1964, 1965). Roberts' and Arnold's work is the most exhaustive and complete coverage of the Range to date and will furnish the reader with a substantial background to complement this thesis.
LOCATION MAP OF COPPER BASIN, LANDER COUNTY, NEVADA

1 inch = 4 miles

Figure 2
Scope of Paper

Mapping at Copper Basin began in May of 1963, when the author was a field geologist employed by the Duval Corporation. Duties included mapping, sampling, logging core, and preparing maps. This paper is based on data obtained from May of 1963 until the exploration phase terminated in June of 1964.

History of Copper Basin

Copper Basin was first worked around 1869. In 1897 the Glasgow and Western Exploration Co., Ltd. consolidated various properties in the area and began production of copper ore. Shipments went to the smelter at Golconda, Nevada. In 1914, the Battle Mountain Exploration Co. acquired the property and explored for copper by churn drilling. The Copper Canyon Mining Co. obtained the property in 1917 and undertook a progressive exploration program. From 1924 to 1941, excessive fluctuations in the price of copper created little enthusiasm to explore and/or systematically develop the copper deposits at Copper Basin. Lessors shipped small tonnages of high grade ore until 1941, when the International Smelting and Refining Company leased the Copper Canyon Mining Co. holdings. International undertook drilling and some underground development to evaluate mineralization associated with prominent veins and faults. In 1945, the International lease terminated, and the property reverted back to the Copper Canyon Mining Co. Lessors made sporadic ore shipments until 1959, when the American
Smelting and Refining Co. purchased the assets of the Copper Canyon Mining Co. Messrs. Landwehr, Hewitt, Newman, Bowditch, and others of American Smelting undertook a limited exploration program which included geologic mapping, geophysical prospecting and diamond drilling.

Table 1

Production of gold, silver, copper, and turquoise, Copper Basin 1916-53

<table>
<thead>
<tr>
<th>Year</th>
<th>Ore (tons)</th>
<th>Gold (ounces)</th>
<th>Silver (ounces)</th>
<th>Copper (pounds)</th>
<th>Turquoise Royalty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1916</td>
<td>5,000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1927</td>
<td>935</td>
<td>4.93</td>
<td>240</td>
<td>620,000</td>
<td></td>
</tr>
<tr>
<td>1928</td>
<td>7,764</td>
<td>313.68</td>
<td>1,811</td>
<td>2,015,750</td>
<td></td>
</tr>
<tr>
<td>1929</td>
<td>12,627</td>
<td>383.84</td>
<td>4,241</td>
<td>2,935,370</td>
<td></td>
</tr>
<tr>
<td>1930</td>
<td>4,371</td>
<td>50.26</td>
<td>1,768</td>
<td>925,220</td>
<td></td>
</tr>
<tr>
<td>1931</td>
<td>294</td>
<td>4.47</td>
<td>181</td>
<td>81,710</td>
<td></td>
</tr>
<tr>
<td>1932</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1933</td>
<td>81</td>
<td>1.09</td>
<td>29</td>
<td>19,035</td>
<td></td>
</tr>
<tr>
<td>1934</td>
<td>591</td>
<td>369.32</td>
<td>1,893</td>
<td>15,954</td>
<td></td>
</tr>
<tr>
<td>1935</td>
<td>760</td>
<td>456.19</td>
<td>2,389</td>
<td>17,462</td>
<td></td>
</tr>
<tr>
<td>1936</td>
<td>2,929</td>
<td>1,897.12</td>
<td>11,890</td>
<td>195,726</td>
<td></td>
</tr>
<tr>
<td>1937</td>
<td>5,876</td>
<td>2,082.88</td>
<td>9,505</td>
<td>681,580</td>
<td></td>
</tr>
<tr>
<td>1938</td>
<td>3,578</td>
<td>1,088.92</td>
<td>6,368</td>
<td>316,072</td>
<td>$ 239.00</td>
</tr>
<tr>
<td>1939</td>
<td>1,038</td>
<td>298.36</td>
<td>2,015</td>
<td>97,715</td>
<td>769.00</td>
</tr>
<tr>
<td>1940</td>
<td>1,138</td>
<td>229.68</td>
<td>1,983</td>
<td>91,680</td>
<td>171.50</td>
</tr>
<tr>
<td>1941</td>
<td>1,598</td>
<td>226.28</td>
<td>2,699</td>
<td>142,000</td>
<td>123.50</td>
</tr>
<tr>
<td>1942</td>
<td>1,320</td>
<td>404.03</td>
<td>2,802</td>
<td>83,442</td>
<td></td>
</tr>
<tr>
<td>1943</td>
<td>1,524</td>
<td>63.57</td>
<td>1,699</td>
<td>201,568</td>
<td>1,542.00</td>
</tr>
<tr>
<td>1944</td>
<td>3,690</td>
<td>23.66</td>
<td>1,708</td>
<td>411,535</td>
<td>6,888.00</td>
</tr>
<tr>
<td>1945</td>
<td>5,297</td>
<td>165.80</td>
<td>2,962</td>
<td>468,196</td>
<td>7,200.07</td>
</tr>
<tr>
<td>1946</td>
<td>2,820</td>
<td>23.84</td>
<td>1,277</td>
<td>207,880</td>
<td>5,881.92</td>
</tr>
<tr>
<td>1947</td>
<td>4,910</td>
<td>292.77</td>
<td>3,528</td>
<td>324,727</td>
<td>1,218.97</td>
</tr>
<tr>
<td>1948</td>
<td>2,354</td>
<td>196.60</td>
<td>3,472</td>
<td>180,496</td>
<td>2,202.05</td>
</tr>
<tr>
<td>1949</td>
<td>675</td>
<td>306.12</td>
<td>1,735</td>
<td>13,265</td>
<td>2,499.29</td>
</tr>
<tr>
<td>1950</td>
<td>53</td>
<td>15.31</td>
<td>227</td>
<td>222</td>
<td>1,917.90</td>
</tr>
<tr>
<td>1951</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1952</td>
<td>None</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1953</td>
<td>955</td>
<td>16.09</td>
<td>326</td>
<td>51,323</td>
<td>1,375.38</td>
</tr>
</tbody>
</table>

Total 67,354 8,914.81 66,758 10,851,939 32,332.24

Figures taken from Roberts and Arnold, 1965, p. 64.
Late in 1961, Dr. John Frost, Chief Geologist for the Duval Corporation, recommended the properties. In 1962, Duval took an option on ASARCO's holdings in Copper Basin and Copper Canyon. Geological mapping, geochemical sampling, geophysical prospecting, and drilling were undertaken. In 1965, feasibility studies indicated that the copper deposits of Copper Canyon and Copper Basin were commercial.

In that year, Duval began a program to develop the copper deposits in Copper Canyon and Copper Basin. Development included close spaced drilling, pre-mine stripping, construction of a 3,000 ton/day mill at Copper Canyon, and construction of facilities to recover copper from dump leaching.

Sulfide copper ores will be mined initially from the Contention ore body, and subsequently from other known ore bodies. Production from the Contention will begin in early 1967, while that from other ore bodies has not yet been scheduled.

Stripping and mining of the small Sweet Marie oxide ore body was completed in mid-1966. All of the Sweet Marie ore was placed on dumps to be heap leached. Copper production from heap leaching began in the fall of 1966.

Higher grade ores from the Contention, Copper Queen,
Mesa Copper, and other small deposits will be trucked to Copper Canyon to be treated by the 3,000 ton/day flotation mill which will be completed in early 1967. Lower grade ores will be segregated in dumps to be leached.

From the time of the first prospectors to the present, Copper Basin has been explored by over 15,000 feet of underground workings and about 400 churn, rotary, and diamond drill holes, aggregating perhaps 100,000 feet of exploration drilling.

Acknowledgments

Many thanks are extended to Robert W. Sayers, Geologist, and Robert C. James, Project Manager, for guidance and help in the developing of data at Copper Basin. Special thanks go to Dr. John E. Frost, Chief Geologist for Duval, for the time spent in discussion and mapping of difficult features at the property. Ralph J. Roberts was most gracious in introducing the writer to the area and further discussing matters of common interest. The author is particularly indebted to Dr. A. L. Payne of the Mackay School of Mines, University of Nevada, for his critical reading and discussion of the paper.

Special thanks are given the Duval Corporation for permitting the use of company data in the preparation of this report.
General Geology

Copper Basin is in an area of Cambrian, Pennsylvanian, and Permian arenites and limestones intruded by early Tertiary quartz monzonite and granodiorite and locally capped by Late Tertiary volcanics.

Deposition of the sediments began in Late Pre-Cambrian or early Cambrian in the Cordilleran Geosyncline and continued until late Paleozoic time. During late Devonian, sedimentation in the west-central part of the geosyncline was interrupted by the Antler Orogeny. The orogeny caused widespread thrusting of eugeosynclinal rocks eastward over miogeosynclinal sediments along the Roberts Thrust zone. The Cambrian Harmony Formation was involved in the eastward thrusting. As a result of the orogeny, orogenic clastics were deposited over the allochthonous Harmony Formation. These orogenic sediments are known as "overlap assemblages" and at Copper Basin include the Pennsylvanian Battle Formation and the Pennsylvanian-Permian Antler Peak Limestone.

Deposition in the western and eastern part of the geosyncline continued during the Antler Orogeny. At the end of the Permian, another orogenic cycle known as the Sonoma Orogeny was initiated in the western part of the geosyncline. The orogeny caused another major cycle of eastward thrusting along the Golconda thrust. The thrust displaced
Sequence of geologic events at Copper Basin, Lander Co., Nevada

<table>
<thead>
<tr>
<th>Era</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent</td>
<td>Exposure of Miocene surface and continued erosion. Continued oxidation of Copper Basin ore deposits.</td>
</tr>
<tr>
<td>Pleistocene</td>
<td>Erosion of quartz latite and pyroclastics.</td>
</tr>
<tr>
<td>Pliocene</td>
<td>Volcanic activity with extrusion of quartz latite and pyroclastics over enriched Copper Basin ores. Relative quiescence and erosion of Battle Formation and Harmony Formation. Oxidation and enrichment of Copper Basin ore deposits.</td>
</tr>
<tr>
<td>Miocene</td>
<td>Intrusion of granodiorite and quartz monzonite, and related rocks. Thermal metamorphism of adjacent rocks. Metallization of wall rocks.</td>
</tr>
<tr>
<td>Oligocene</td>
<td></td>
</tr>
<tr>
<td>Eocene</td>
<td>Period of emergence, relative quiescence, and erosion of western allochthonous assemblage.</td>
</tr>
<tr>
<td>Paleocene</td>
<td>Period of Sonoma orogeny with evolution of the Golconda thrust. Probable overthrusting of western sediments over autochthonous overlap units. Deposition of orogenic clastics (Battle Formation) and Antler Peak Limestone (Roberts’ overlap units).</td>
</tr>
<tr>
<td>Jurassic</td>
<td></td>
</tr>
<tr>
<td>Triassic</td>
<td></td>
</tr>
<tr>
<td>Permian</td>
<td>Depression of Harmony Formation.</td>
</tr>
<tr>
<td>Pennsylvanian</td>
<td>Deposition of Harmony Formation. (Roberts’ transitional assemblage)</td>
</tr>
<tr>
<td>Mississipian</td>
<td></td>
</tr>
<tr>
<td>Devonian</td>
<td></td>
</tr>
<tr>
<td>Silurian</td>
<td></td>
</tr>
<tr>
<td>Ordovician</td>
<td></td>
</tr>
<tr>
<td>Cambrian</td>
<td></td>
</tr>
</tbody>
</table>

Sequence and geologic timetable according to Roberts, 1964.

Figure 3
eugeosynclinal Havallah sequence sediments over the "overlap assemblages" deposited during the Antler Orogeny and over the allochthonous sediments thrust by the Roberts Thrust.

The Copper Basin area was emergent for much of the interval from the Jurassic to the Present. During early Tertiary, widespread intrusive activity emplaced quartz monzonite and granodiorite into the sedimentary sequence at Copper Basin. The intrusion caused widespread metamorphism and metallization which is thought to be related to the intrusives (Roberts and Arnold, 1965, p. 35).

Mid-Tertiary volcanism and recent Basin-Range faulting have further complicated the regional setting. Morphologically, the Battle Mountain Range is circular in outline rather than elongate, as is the habit of Basin-Range mountains. The Range has a north trending frontal fault on the west flank, but does not appear to have a comparable one on the east flank.

Geology of Copper Basin

Sedimentary Rocks

Copper Basin is predominantly underlain by the Cambrian Harmony Formation (Roberts, 1964, p. 25). The Formation consists of sandstone, shale, siltstone, and limestone. Lithologic facies vary over such short distances and thicknesses
STRATIGRAPHIC SECTION AT COPPER BASIN, LANDER COUNTY, NEVADA

Figure 4
that Roberts (1964, p. 23) has theorized that the Formation is a turbidite. Portions of the Formation have been thermally metamorphosed; the sandstones to quartzite, shales and siltstones to hornfels, and limestone to tactite. The separate lithologic types and their metamorphosed equivalents are described as they now appear at Copper Basin. The geologic map of Copper Basin (in pocket) does not differentiate the Harmony units because attempts to separate varying lithologies into mappable members proved unsuccessful.

The total thickness of the Harmony is not known because the base is not exposed in the Battle Mountain Range. Folding and repetition by faulting has caused sections to thicken and others to thin. Rapid facies changes within the Formation make correlation of outcrops difficult. Roberts (1964, p. 23) estimates the thickness at about 3,000 feet.

The arkosic sandstone of the Harmony Formation is composed predominantly of quartz and feldspar grains, with minor clay minerals. It is light gray, weathers to a light tan color, and rarely crops out.

The most conspicuous lithology of the Harmony Formation in Copper Basin is a relatively clean metaquartzite which weathers light brown. The unit is a metamorphosed sandstone. Unoxidized pyrite is commonly seen on fresh surfaces.

The shale facies is distinctly fissile, typically
silty, and commonly micaceous. It is generally light gray to brown when fresh, but weathers to a light cream or tan color. The unit forms rare outcrops. Thermal metamorphism, hypogene mineralization, and supergene alteration of the shale characteristically obliterate the fissility.

The dominant lithologic type of the Harmony Formation in Copper Basin is siltstone. It is gray to brown when fresh and weathers to a very light gray to cream color. Where thermally metamorphosed, exposures exhibit a brownish hue, which is thought to be caused by finely disseminated biotite.

Hornfels occurs in the Harmony Formation in the northern part of Copper Basin near a large stock. It is light tan when fresh and weathers brown, due to the high biotite and iron sulfide content of the rock. Outcrops are numerous. The unit is probably a thermally metamorphosed shale and/or siltstone.

Calcareous sediments varying from calcareous shale to rare massive limestone are generally restricted to the upper portions of the Harmony Formation. These sediments, particularly the thin-bedded calcareous shales, have been recrystallized to tactite in the vicinity of the Chase, Carissa, and the Copper King mines. Although the calcareous rocks form a relatively small part of the Harmony Formation, the tactite has probably played a very significant role in the
The presence of substantial amounts of sulfides causes the Harmony Formation in Copper Basin to weather to a dull brown with patches of red. The Formation is generally easily eroded and forms low, broad hills.

At Copper Basin, the Harmony is overlain unconformably by the Pennsylvanian (Roberts, 1964, p. 31) Battle Formation which consists of basal coarse clastic chert and quartzite pebbles and cobbles in a siliceous matrix and a calcareous shale. All Battle outcrops within the Basin proper have been thermally metamorphosed. Voids in the rock suggest that some of the clastic debris and cementing material may have been calcareous and readily leached. The unit is tan to brown when fresh and weathers to a rusty brown and forms bold ridges.

The thickness of the Battle Formation at Copper Basin is less than at Copper Canyon, 6 airline miles to the southwest. In contrast to Copper Canyon, the base of the Battle Formation at Copper Basin is generally not calcareous, as evidenced in good outcrops near the Sweet Marie Mine.

The Battle Formation at Copper Basin is usually not more than 30 - 50 feet thick. The most complete exposed section is preserved at the Copper King Mine, where a basal
conglomerate is overlain by calcareous shale which is probably correlative with the middle member in Copper Canyon. At Copper Basin no upper conglomerate member exists, and the Antler Peak Limestone lies directly on the calcareous shale. The lack of the upper member present at the type section of Battle Formation on the east slope of Antler Peak 5 miles southwest may be due to erosion of the upper member prior to deposition of the Antler Peak Limestone, or may reflect proximity to the northern limits of deposition.

As will be discussed in more detail below, the limited stratigraphic thickness of the siliceous Battle Formation at Copper Basin played a dominant role in the accelerated erosion occurring in the Basin as compared to the steep and young topography present at Copper Canyon. This relationship also exerted a significant influence on the oxidation and enrichment of the two areas.

Unconformably overlying the Battle Formation is the Antler Peak Limestone of Pennsylvanian and Permian age (Roberts, 1964, p. 34). The unit consists of massive limestone and calcareous shale. The formation is gray to tan when fresh and weathers to a creamy white. It does not occur within the main mineralized area, is not known to contain commercial mineralization, and therefore has not been subjected to detailed study. Although isolated tactite zones occur within the Antler Peak Limestone, they have not
proved to be economically significant to date.

**Extrusive Rocks**

Overlying the Antler Peak Limestone, Battle Formation, and Harmony Formation, and forming a bold ridge, is a large isolated occurrence of quartz latite deposited during late Oligocene or early Miocene (Roberts and Arnold, 1965, p. 15). The ridge forms a prominent profile of an elephant's head, as observed from north or south, and is, naturally, called Elephant Head. The extrusive was not mapped by the writer and occurs just beyond the northeast border of the map. The latite is about 100 - 150 feet thick, but has undergone faulting and tilting since deposition. Although the latite is post-ore in occurrence, it had an important indirect effect on the ore deposits of Copper Basin, as will be discussed later.

**Intrusive Rocks**

Intrusive rocks in the area consist of quartz monzonite porphyry, granodiorite, quartz diorite, and diabase.

The quartz monzonite is porphyritic, with large phenocrysts of potash feldspar in a fine-grained ground mass of potash feldspar, plagioclase, biotite, and quartz. Biotite occurs as finely disseminated grains, and as well-developed crystals 1-2 mm in width. Doubly terminated beta-quartz euhedral phenocrysts are common. The rock is generally well fractured with quartz veinlets filling the fractures.
The rock is gray-green and weathers readily to a brownish gray. Zircon lead-alpha ratios indicate an Eocene age (Roberts, 1964, p. 62).

Most of the quartz monzonite porphyry within Copper Basin occurs as irregular dikes and sills related to stocks to the west and northwest. Dikes and sills are characteristically 50 - 80 feet thick. The dikes dip gently and usually cross bedding planes. Quartz monzonite intrudes all of the Pre-Tertiary sedimentary units in Copper Basin.

Granodiorite crops out near Copper Basin and constitutes a large part of the intrusive rock of the area. No granodiorite was recognized within Copper Basin and is mentioned only to acknowledge its presence in the area.

Quartz diorite which crops out near the nose of Badger Hill and west of the Copper Basin Camp is more siliceous than the quartz monzonite porphyry, has a higher biotite content, and a very fine-grained groundmass. The unit is gray-green and weathers readily to a light gray. The rock may be an alteration facies of the quartz monzonite rather than a separate rock type. In field mapping it is a mappable unit and is treated as such here.

Diabase occurs outside the main mineralized area and is not thought to play an important part in the economic geology of the area. The unit consists of very fine-grained
dense rock that weathers to a dark gray. A large irregular body of diabase crops out near the Henrietta oxide pit east of the Sweet Marie Mine, and above the Copper King Mine.

Various other minor intermediate and mafic rock types have been observed, but do not materially modify geologic interpretations.

Quaternary Deposits

An older fluvial deposit was mapped at Copper Basin. This older unit has since been dissected by recent erosion, probably the result of recent vertical adjustments in the range.

Alteration

Hypogene alteration within the sedimentary formations and the intrusive rocks is a product of thermal metamorphism caused by intrusion and hydrothermal alteration. Thermal metamorphism produced mineral assemblages characteristic of the albite-epidote-hornfels facies, and rarely the hornblende-hornfels facies as indicated by the presence of diopside. Hydrothermal activity produced propylitization, potash metasomatization, pyritization, sericitization and silicification. Unfortunately, evaluation of hypogene alteration and metamorphism of the various lithologies in the Harmony Formation has been obscured by supergene alteration effects generated during oxidation of sulfide-rich rocks. Supergene alteration involves oxidation of pyritized rock,
Figure 5. Photograph of Copper Basin, Nov., 1963
Looking North

Figure 6. Photograph Showing Structure in North wall of Sweet Marie Pit. Oct., 1966
which produces sulphuric acid, which in turn attacks rock
and alters feldspars and mafic minerals to clay products.

The Harmony hornfelses contain much biotite, most of
which was probably formed as the result of thermal metamor-
phism of shales, mudstones, and siltstones. The hornfels
locally contains tremolite and rare diopside. In and near
ore bodies the hornfels contains 1-3% by volume of pyrite.

Thin-bedded calcareous members of the Harmony Formation
were recrystallized to tactite with the formation of chlorite,
biotite, garnet, tremolite and diopside. This tactite may
occur several hundred feet from known intrusives. Apparently
calc-silicate recrystallization proceeded selectively along
permeable and chemically or structurally favorable beds with
little effect upon adjacent rocks. The tactite was irre-
gularly metallized with pyrite, pyrrhotite, and chalcopyrite.
Minor amounts of gold and silver also occur. Rarely, arse-
nopyrite, marcasite, sphalerite, and galena are noted.

Little megascopic evidence of thermal or hydrothermal
alteration of the sandstones and siltstones exists in the
main mineralized area. However, under the microscope argil-
lization and sericitization of the matrix is prominent.
These rocks were particularly susceptible to supergene al-
teration effects because of their high feldspar content and
permeability.
The sandstone, siltstone, quartzite, shale, tactite, and hornfels occurring within the central mineralized area are strongly pyritized. Supergene argillation has modified and often obliterated primary rock texture. The quartzites are relatively unreactive and have only been slightly affected by supergene alteration.

The Battle Formation has been thermally metamorphosed. A particularly prominent alteration facies is observed in the basal conglomerate, where the calcareous and argillaceous matrix has reacted with the siliceous clastic constituents to form tremolite, chlorite, and rarely diopside and a very hard and brittle rock. Minor to strong pyritization occurred in the Formation during the hydrothermal period. Interbedded shale units have been bleached by acid supergene solutions generated by oxidizing sulfides. The iron in the pyrite is thought to have been at least in part derived from ferruginous clastics and matrix rock in the formation. Supergene effects are displayed less prominently in the coarse-grained conglomerates.

Because of the relatively pure nature of the limestones in the Antler Peak sequence, no widespread alteration is present in the Antler Peak Limestone. The purer limestone (?) is altered to marble near intrusive contacts and the impure calcareous shales are locally altered to tactites.
The quartz monzonite contains phenocrysts of orthoclase, quartz, biotite, and plagioclase and a groundmass of fine-grained plagioclase and orthoclase, biotite and secondary orthoclase, sericite, and pyrite. Much of the biotite has been altered to chlorite. Some biotite is possibly of a secondary nature as indicated by its scraggy appearance, fine grain, and local vein-like occurrence. Coincident with the period of hypogene metallization, quartz monzonite was enriched in potash, which combined with alumina, iron, silica, and hydroxyl ion to form sericite, biotite, and potash feldspar. Alumina, iron, and silica were reconstituted during alteration of the primary minerals in the monzonite. Sulphur was also added and combined with excess iron to form pyrite. The average pyrite content of the quartz monzonite is less than 2%. Silicification is moderately developed, but is locally intense, especially in well fractured zones.

The sulphuric acid produced by the oxidation of pyrite has caused much of the sericite and the feldspars to alter to clay, and some of the biotites to become bleached. The result is an extremely light colored rock of low density whose original texture is almost obliterated.

In general, the rocks at Copper Basin are strongly altered, for they have undergone thermal metamorphism, hydrothermal alteration, and strong supergene alteration.
Structure

The predominant fault and fracture trends in Copper Basin are NNE and NNW. Important E-W faults also occur. Figure 7 illustrates the fault and fracture patterns at Copper Basin.

The NNE and NNW sets of faults are steep dipping, and generally have 1 inch or more of gouge along their surfaces. Appreciable offsets are suspected, but the variable lenticular lithologies of the Harmony Formation make it difficult to measure displacement of units on either side. Low angle NNE and NNW faults are present and can be important in localizing supergene copper ore bodies.

The steep NNE and NNW faults on the east side of Copper Basin, similar to faults near the Empire Mine, probably were the conduits for hypogene mineralizing solutions in this portion of the district. Some of the intensely mineralized areas in the east part of Copper Basin may be replacement zones which have subsequently been sheared.

The E-W set of faults generally dip gently to the north and in some cases have been occupied by intrusive dikes. The Contention fault contains considerable gouge and has had an important effect on the localization of the Contention ore deposit by restricting the downward movement of migrating copper solutions. The Sweet Marie and Widow
DIAGRAMMATIC FAULT PATTERN

FAULT AND FRACTURE SYSTEMS AT COPPER BASIN
LANDER COUNTY, NEVADA

FIGURE 7
faults have acted in a similar role.

No direct evidence for thrusting was seen in the Basin proper. A minor system of imbricate thrusts was mapped west of the Copper Basin Camp near the map border.

Close-spaced fracturing is well developed throughout the area of significant copper mineralization and has played a dominant role in the localization of the ores. Two prominent, steep dipping fracture systems are discontinuously developed: N30W and N60W. Other trends occur, but are poorly developed. The combination of well developed high angle faults, low angle faults, and discontinuous, diversely oriented fracturing of the various rock types has combined to form a favorable environment for secondary enrichment of copper minerals.

The sediments in Copper Basin strike N10-30E and generally dip to the east at 40-60°. Restricted areas of anticlinal and synclinal folding were mapped, but do not appear to significantly influence the localization of supergene ore. Drag folding of the sediments along faults is noted locally. The surficial structural grain of the Basin is NNE, whereas the basement structure is thought to be NNW. An area of structural complexity exists at the Carissa Mine where strikes and dips in the tactite are divergent and indicate sharp folding and faulting. It is
possible that the tactite at the Carissa Mine is thrust into place. There is no evidence for this, however, and the idea is proposed on the basis of the superficial nature of the unit and the anomalous nature of the structures.

Sediments in contact with the quartz monzonite dikes have not been greatly disturbed. It is felt that the intrusives were introduced via the mechanism of permissive emplacement, but little direct evidence has been observed to support the concept of magmatic stoping.

An interesting feature of the Copper Basin area is the occurrence of "pebble dike" structures containing rounded fragments of black shale, quartzite, and intrusive material, in a dark gray to black gougey matrix. The dikes were apparently intruded in a semi-mobile stage along established fault planes and range from several inches to several feet in width. A three foot "pebble dike" crops out 300 feet southwest of the Contention Mine. In general, the soft nature of the structures usually precluded any outcrops.

No relationship of hypogene mineralization to "pebble dikes" has been established, and no significant metallization is found in the "pebble dikes". The most likely source for the black shale within the dikes is the Valmy Formation, several thousand feet stratigraphically below the Harmony Formation.
Description of the Ore Deposits

Incomplete exploration of Copper Basin has resulted in the discovery of at least three minable ore deposits thus far.

Contention Ore Deposit

The Contention ore body, located near the center of the mapped area, has been formed by supergene enrichment. Chalcocite has replaced pyrite, pyrrhotite, and minor amounts of chalcopyrite.

The enriched chalcocite blanket averages about 80 feet thick and the overlying oxidized rock about 200 feet thick. Sediments below the Contention ore deposit contain 5-10% pyrite with very minor amounts of chalcopyrite. No other significant metal values occur.

The deposit is wholly contained within sandstones, siltstones, quartzites, and minor tactite of the Harmony Formation. Quartz monzonite intrusives are areally restricted in the mineralized area and do not contain commercial concentrations of copper.

Fracturing has controlled the downward movement of supergene copper-bearing solutions and localized copper mineralization. Favorable beds, such as sandstone, intersected by strong fracture patterns, are loci for the highest
concentration of ore. Steep faults usually contain higher concentrations of copper. Chalcopyrite and pyrrhotite occur sporadically in tactite in the east portion of the Contention ore deposit near the Chase Mine.

The low angle Contention fault marks the southern limit of the commercial chalcocite blanket, and probably acted as a barrier to copper-bearing solutions migrating downward in the hanging wall.

The margins of the Contention deposit are determined by mineralogy of the host rocks, faults, and relative permeability. The northern margin of the deposit is the contact of the arenaceous sediments and hornfels. The hornfels is relatively impermeable and did not act as a favorable host for supergene enrichment. The western margin is a NNW fault. The eastern margin may be a fault, but poor exposures limit interpretation.

The upper surface of the chalcocite blanket roughly conforms with modern topography, raising questions as to time and space relationships during enrichment. This subject will be discussed later in the report.

Sweet Marie Ore Deposit

The Sweet Marie ore body is about 1,400 feet southeast of the Contention ore body. A submarginal chalcocite
blanket exists between the two deposits. The deposit occurs in highly altered Harmony quartzites and siltstones, intruded by steeply dipping quartz monzonite porphyry dikes. The ore is primarily copper oxides controlled by bedding which contains some residual chalcocite. The Sweet Marie deposit, as was the case with the Contention ore body, carries no other metals of economic significance.

Faulting in the deposit is dominantly northeast with numerous gently dipping faults and cross-fractures. The Sweet Marie fault is the major structural feature of the deposit. The fault strikes NNE and dips at 25° to the west and is the major locus for copper oxides. Whether this fault served as a conduit for hypogene mineralization is not clear, but is thought unlikely, as no primary metallization is found in the structure below the zone of oxidation. Oxidized copper minerals occur sparingly at the surface. Approximately 200 feet of leached cap rock existed over the deposit.

The Sweet Marie deposit differs from the Contention ore body in several important respects. The ore controls for the Sweet Marie deposit are similar to the Contention; namely, bedding and fracture control within the Harmony quartzites and sandstones and a gently dipping major fault. However, the Sweet Marie deposit is almost totally composed of oxidized copper minerals. Chrysocolla, melaconite-
tenorite, malachite, azurite, cuprite, and brochantite are the predominant ore minerals. Residual chalcocite occurs, but is minor except near the bottom of the ore body. A small irregular lens of tactite contains chalcopyrite and pyrrhotite.

The Sweet Marie and Contention enriched deposits probably formed contemporaneously, but at the Sweet Marie a lower over-all pyrite content and a very high clay content both from sedimentary deposition and the altering effects of supergene acid solutions, restricted the mobilization of copper causing in-situ oxidation of the Sweet Marie chalcocite zone. Primary argillization and secondary alteration during oxidation destroyed the original texture of the quartz monzonite porphyry, siltstone, and sandstone and created a high concentration of neutralizing clay which chemically and physically trapped the copper minerals.

The Sweet Marie ore body is also limited by assay walls. At depth, the oxide minerals give way to sulphides; however, the chalcocite zone is poorly developed and unreplaced pyrite is found immediately beneath.

A submarginal chalcocite blanket extends south from the Sweet Marie Mine to the Widow Mine. The Widow mineralization and ore controls are similar to those of the Sweet Marie and the deposit will probably be mined in the future.
Depth of oxidation in the Sweet Marie area is much greater than in the Contention area. It is a habit of the district that areas intruded by porphyry tend to be oxidized to greater depths. The greater susceptibility to alteration by supergene acidic solutions and the apparently higher permeability of the intrusives from that of the surrounding sediments are probably contributing factors. Intrusive rocks also tend to coincide with major drainage locations. The combination of the two factors causes deep oxidation levels which have little relation to topography.

Copper Queen Deposit

The Copper Queen deposit is on the north side of Vail Creek and about 2,000 feet northwest of the Contention ore body. The deposit occurs in Harmony quartzites and siltstones intruded by a nearly horizontal sill-like porphyry dike. The deposit is an enriched chalcocite blanket with important oxide copper mineralization.

Mineralization is influenced by fracturing and high-grade oxide copper minerals were mined from major fault zones which traverse the deposit.

The Copper Queen area has been more deeply eroded than the Contention or Sweet Marie areas and the chalcocite zone is out of equilibrium with the topography, for oxidized copper minerals are seen cropping out at the elevation of
the secondary enriched zone on the 5,850 foot contour. The deposit is a nearly horizontal blanket chalcocite replacement of pyrite. High grade parts of the deposit are controlled by the permeability and neutralizing effect of a highly argillized quartz monzonite porphyry sill. Relatively impermeable quartzite areas are lower grade because chalcocite is restricted to fractures.

A sub-marginal zone of supergene copper mineralization probably existed between the Contention and Copper Queen deposits. Here the rock is hornfels and not a good host for enrichment. Supergene copper mineralization has probably been leached by near-surface waters in the vicinity of Vail Creek.

Leaching of older enriched blankets is amply demonstrated in the drilling on the nose of Badger Hill, north of the Basin Camp. Little secondary copper mineralization remains near the main drainage. Sericitized and argillized feldspar phenocrysts in the quartz monzonite and quartz diorite immobilized the copper, resulting in a small occurrence of oxidized copper mineralization contained largely in the feldspar phenocrysts. The remnant secondary sulfides under Badger Hill occupy a nearly horizontal plane, disregarding physiography. This lack of conformity with the topography must be due in part to relatively recent adjustments in the major drainage pattern in the area and
accelerated erosion with respect to the mobility of the enriched zone.

**Other Areas of Interest**

Other, partially explored, copper showings in Copper Basin may have future potential.

**Badger**

A nearly horizontal blanket of mixed copper oxides, chalcocite and significant molybdenite occurs under the Badger Hill. Because of an extremely high stripping ratio, the deposit is not presently being actively explored. There is little doubt that the deposit will be mined in the future.

**Mesa Copper**

Exploration that was conducted subsequent to the author's personal tenure at the property delineated a zone of massive sulfide replacement in calcareous units of the Battle Formation and Harmony Formation. The area is known as the Mesa Copper and is located east of the mapped area. These replacement zones are undoubtedly continuations of the replacement horizons which have since been eroded from the main Copper Basin area and contributed the copper for the supergene chalcocite blankets. This area will undoubtedly be mined in the future.
Henrietta

The oxidized Henrietta deposit is a small concentration of copper that migrated from mineralized faults nearby.

Copper King

The Copper King Mine contains very high grade copper oxide minerals with important gold values in a tactite-limestone environment. The deposit appears to be concentrated within a fault zone.

Happy Area

The Happy area is located between the Badger Hill and the Widow Mine and forms a commercial concentration of chalcocite ore which extends from the Chase Mine area and is probably controlled by the strike-extension of the Chase Fault. No plans for mining the deposit in the near future have been formulated.

Numerous other small showings occur throughout the Copper Basin area, demonstrating widespread copper mineralization.
Formation of the Ore Deposits

Hypogene mineralization at Copper Basin was probably contemporaneous with the Eocene intrusive activity. Feeders for the metallization were NNE and NNW faults and fissures.

As evidenced by deposits east of Copper Basin, such as the Mesa Copper, primary metallization most likely consisted of bedding replacement bodies in the calcareous portion of the upper Harmony Formation, and, to a lesser extent, the basal clastic member of the Battle Formation.

The mineralization consisted of pyrite-pyrrhotite-chalcopyrite replacement in tactite, together with disseminated pyrite and minor chalcopyrite in the non-calcareous units. Small areas of tactite are also found in calcareous beds lower in the Harmony Formation, and they commonly contain chalcopyrite-pyrrhotite metallization, such as that north of the Chase Mine. Chalcopyrite mineralization is not abundant in non-calcareous Harmony units, averaging less than 0.1% copper.

Metal zoning controlled at least in part by heat is well demonstrated at Copper Basin. As shown by Figure 8, the zonal pattern is imperfect, but clearly defined about the stocks directly west of the Basin proper.
METAL ZONING PATTERN AT COPPER BASIN
LANDER COUNTY, NEVADA

1" = 1 mile

FIGURE 8
The zonal pattern is imperfect in that a higher heat gradient extends eastward from the main stocks. This might be an indication of an easterly subsurface trend to the intrusives.

Within the stocks there is a molybdenum-copper zone. On the northeast and east margins of the stock there is developed a pyrite-pyrrhotite-chalcopyrite zone, a chalcopyrite-gold zone, and finally a minor zinc-lead-copper-gold zone furthest from the intrusive outcrop.

To the south and west of the stocks, a silver-lead-zinc zone occurs relatively near the stock with an antimony zone furthest from the stock. Pyrite is ubiquitous through all the zones.

Vertical zoning appears to occur, but to date not enough deep drilling has taken place to supply definitive data.

Copper Basin has a separate zonal pattern from that expressed at Copper Canyon. Although two centers of metal zoning are present, they are probably related in time in that they appear to be genetically related to contemporary intrusives.
Oxidation and Enrichment

Oxidation of the hypogene pyrite-pyrrhotite-chalcopyrite replacement deposits discussed in the previous section is thought to have been completed during the Miocene. Copper, liberated from chalcopyrite, migrated downward to form a supergene chalcocite deposit by replacement of disseminated pyrite in the Harmony Formation. The processes and reactions during oxidation and enrichment at Copper Basin are thought to be similar to those postulated for other bulk low grade deposits in the west.

A study of leached outcrops at Copper Basin indicates that chalcocite enrichment was not derived directly from the hypogene deposits, but rather was a product of a previous supergene cycle of mineralization. The original supergene deposit probably formed prior to a period of Miocene volcanism which covered Copper Basin with a sequence of quartz latite welded tuffs. The volcanic cover effectively protected this older supergene deposit by preventing erosion of the Miocene surface, and perhaps also by raising the water table above the supergene mineralization.

Progressive erosion during Late Tertiary stripped the volcanic cover from Copper Basin, except for isolated remnants such as Elephant Head Hill (immediately to the northeast of the mapped area) again exposing the Miocene surface.
Erosion has now progressed far enough that the upper portion of the chalcocite deposit is beginning to be affected, as will be discussed more fully below.

An examination of the surface at Copper Basin indicates the predominant limonite to be goethite with subordinate, but important jarosite and hematite. The limonites commonly occur as coatings on fractures and as discrete cavities in rocks. Limonite "paint", indicative of transported limonite, is not uncommon. The occurrence of limonite derived from chalcocite and the rare limonite of chalcopyrite derivation is the basis for assuming that the present supergene deposit is derived from an older enriched chalcocite deposit.

The limonite thought to be most directly produced from chalcocite at Copper Basin occurs as distinct disseminated cavities with very thin septa formed in the shape of a cube and usually filled with a powdery, fluffy, dark iron oxide. The cubic shape is attributed to the replacement of pyrite by chalcocite. The color of the cavity is dark purple to black with brown septa. The over-all appearance can best be described as velvety. This particular and generally unique

---

**Note 1/** Limonite: A generic term for brown hydrous iron oxide, not specifically identified. Commonly consists mainly of goethite.

**Note 2/** Transported Limonite: Lacks definitive form, indicating migration from source. Occurs as halos and crusts, sometimes iridescent.
limonite is referred to by Locke as "relief limonite" (Locke, 1926, p. 120) and is observed in the outcrops over many supergene enriched chalcocite deposits.

At Copper Basin relief limonite is rarely seen on the surface. Perhaps the natural processes of weathering tend to destroy the friable mineral. As is common in many southwest copper districts, the best preserved diagnostic cavities are found on fresh surfaces in the more siliceous rocks.

Other types and textures of limonites have not been successfully correlated with chalcocite. Pyritic limonites are commonly found in many of the leached outcrops, regardless of the chalcocite content in the underlying supergene zone. Apparently relief limonite cavities and textures are filled and covered by a crust or coating of limonite derived from pyrite which has migrated from its immediate source. For these reasons, it is obvious that a cursory examination of the surface at Copper Basin would lead one to underestimate the subsurface copper content. It is felt that this problem is inevitable in environments where copper minerals oxidize in the presence of high iron sulfides. The iron to copper ratio at Copper Basin is about 5:1.

The mechanics involved in the deposition of a supergene chalcocite deposit have been discussed by numerous
authors (Anderson, 1955; Locke, 1926; Emmons, 1917). There is a general consensus that several conditions must prevail for the successful enrichment of chalcocite in a supergene zone. These conditions follow:

1. Oxidation of copper minerals in the presence of limited amounts of iron sulfides.

2. Presence of oxygen and sufficient water to mobilize the copper ions in the upper portions of the deposit.

3. Permeable, non-reactive host rock so that copper remains in the downward moving aqueous solutions, rather than entering into intermediate "secondary" minerals.

4. Relatively stable water table in general equilibrium with a terrain of moderate relief.

5. Primary sulfides in the supergene zone to act as precipitants for the copper in solution.

A number of variables might be considered for each of the criteria listed above, any of which might influence the oxidation - enrichment process.

The listed conditions are thought to have been present at Copper Basin during the enrichment process. Because of certain features present at Copper Basin, the writer believes that chalcocite enrichment could have occurred above the water table in an interface below the zone of active oxidation.

Copper Basin sediments contain a relatively high primary clay content, particularly the sandstones and shales. It is the writer's opinion that the primary clay, and
secondarily-derived clay formed during oxidation, might have neutralized vadose copper-bearing solutions causing copper to precipitate prior to reaching the water table. Neutralization of the vadose solutions and a possible lack of oxygen in the lower portions of the deposit may have inhibited oxidation and could have created a reducing environment, allowing copper in solution to form chalcocite and to replace unoxidized pyrite.

The present water table appears to be about 25 - 75 feet below the bottom of the present chalcocite zone. This estimate is based on scattered data gained from rotary drilling and infrequent observations by diamond drilling crews.

At the present time, it is felt that the upper surface of the enriched zone at Copper Basin is being leached. Vadose solutions are leaching chalcocite coatings from pyrite, leaving fresh-looking pyrite in a horizon below the zone of most vigorous oxidation, but above the supergene zone. Spencer (1917, p. 81) describes a similar situation at Ely, Nevada. Apparently, there is insufficient meteoric water to thoroughly oxidize the more stable pyrite.
REFERENCES CITED


Bastin, E. S., 1920, Geologic atlas of Copper Basin property for the Copper Canyon Mining Co., Lander County, Nevada: unpublished report.

Emmons, S. F., 1877, United States Geological Exploration of the 40th Parallel, Clarence King, geologist in charge, Part II, Descriptive Geology.


Hague, A., 1877, United States Geological Exploration of the 40th Parallel, Clarence King, geologist in charge, Part III, Mining Industry.

Locke, Augustus, 1926, Leached outcrops as guides to copper ore: Williams and Wilkins Co., Baltimore.

