GEOLOGY AND ORE DEPOSITS OF THE MARBLE PEAK AREA,
SANTA CATALINA MOUNTAINS,
PIMA COUNTY, ARIZONA

by
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STATEMENT BY AUTHOR

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ABSTRACT

Marble Peak consists of a thick sequence of Paleozoic marbles which were intruded during Laramide(?) time by the Leatherwood Quartz Diorite. Lamprophyre dikes cut both the metasediments and the quartz diorite. Displacement along the west-northwest trending Geesman fault brought Precambrian rocks to the north into contact with Leatherwood Quartz Diorite. Low-grade regional metamorphism has affected the rocks in the area.

Metal deposits which are present in the Marble Peak area near the quartz diorite contact belong to the igneous metamorphic deposit class. They were subdivided for this study into three types.

1. Chalcopyrite-pyrite-scheelite mineralization associated with skarn and structural deformation at the contact between the Leatherwood Quartz Diorite and marble. The Daily and Geesman mines typify this deposit type.

2. Bornite-chalcopyrite mineralization in skarn associated with lamprophyric dikes. This type of mineralization occurs at the Leatherwood mines.

3. Sulfide mineralization associated with faults in the Abrigo Formation. The Hartman-Homestake and Stratton mines are of this type.

Igneous metamorphism altered carbonate sediments to skarn in the vicinity of the Leatherwood Quartz Diorite. Silica, alumina, iron, copper, lead, zinc, tungsten, and molybdenum were introduced into the
altered sediments. Deposition of sulfide and gangue minerals appears to have occurred after the formation of skarn without an intervening hiatus.
INTRODUCTION

Purpose and Scope of Study

The purpose of this study is to investigate in detail the alteration effects induced by the Leatherwood Quartz Diorite where it is in contact with the carbonate sediments of Marble Peak. A number of potential igneous metamorphic ore deposits which occur surrounding Marble Peak are studied in detail to determine their silicate and sulfide mineralogy, ore controls, and paragenesis. The deposits of Marble Peak are, in this report, subdivided into three groups on the basis of geologic association and ore controls. The groups are deposits associated with lamprophyre dikes, deposits associated with pre-mineralization faults, and deposits associated with the Leatherwood Quartz Diorite contact aureole. The results of this study are presented with the hope that information gained on the mechanisms of igneous metamorphism and related ore deposition might be useful to the economic geologist. Included in the scope of this investigation is a general geological study of the Marble Peak area.

Methods of Study

Field work consisting of surface mapping of the study area and mapping of the underground mine workings was conducted from May to October of 1967. Surface mapping was done at a scale of one inch equals 500 feet on a base map made from a photographic enlargement of the 15-minute U.S. Geological Survey topographic maps of the Mount Lemmon and Bellota Ranch Quadrangles. Aerial photographs of a similar
scale were also used. Underground mapping was conducted with tape and brunton at a scale of one inch equals twenty feet.

Twenty-three thin sections were studied with the petrographic microscope for identification of rock types and textures. Eleven polished sections were studied with the ore microscope to determine the sulfide and oxide mineralogy, paragenesis, and paragenetic sequence. Nineteen polished thin sections were studied with the petrographic and ore microscopes to determine the relationship between sulfides and silicates. X-ray diffraction techniques were used to supplement microscopic investigation in the determination of minerals and dolomite-calcite ratios of the sediments.

**Definition of Terms**

In this study the term "igneous metamorphism" is used to describe metamorphic effects related to the intrusion of an igneous melt into relatively cold sedimentary rocks, whether the effects be thermal metamorphic or metasomatic in origin. The term is preferred because it is less restrictive in that it implies neither the nature of alteration effects nor necessary proximity to the igneous contact. "Pyrometamorphism" is used to refer to changes in rock due to thermal effects of igneous intrusion. "Pyrometasomatism" is restricted to replacement reactions. The term "skarn" refers to the calcium-magnesium silicate products of igneous metamorphism of carbonate sediments. "Endoskarn" refers to alteration minerals formed on the igneous side of the contact, "exoskarn" to skarn formed on the sedimentary side of the contact.
Location

The area studied is located approximately twenty air-miles northeast of Tucson, Arizona, in the northern part of the Santa Catalina Mountains (Figure 1). The mapped area consists of approximately three square miles which includes section 17 and portions of sections 7, 8, 16, 18, 19, 20, and 21 of T. 11 S., R. 16 E. The area is four miles northeast of Summerhaven and twenty miles south of Oracle, Arizona, via the Oracle Road which connects the two towns.

Topography and Accessibility

Topographic relief in the study area is about 2,000 feet, the highest point being the quartzite-capped Marble Peak with a maximum elevation of 7,670 feet. Slope gradients of 2,500 feet per mile are common. Contact relationships between rock units of differing competency are often obscured by talus cover. Marble, quartzite, and conglomerate units form steep slopes, whereas quartz diorite, granite, and phyllitic units weather to smooth slopes.

On south-facing slopes vegetation is typically sparse, slopes are rugged, and the percentage outcrop for the resistant rock units is large. The north-facing slopes, on the contrary, are covered by thick vegetation, slopes are subdued, and the percentage outcrop for all rock types is small. Most contacts on the north side of Marble Peak are inferred because float distributed down-slope obscures the geology.

The southern portion of the study area is readily accessible via the Oracle Road. A jeep trail connects the mining camp at the eastern margin of the area to Dan's Saddle, and other trails connect to the...
Figure 1. Index Map Showing Location of the Study Area
mines. Most of these trails are usable although trucks or four-wheel-drive vehicles are recommended.

**History, Production, and Previous Work**

The copper-stained skarns surrounding Marble Peak were first recognized by prospectors in the early 1900's. Small-scale development was begun on the Leatherwood, Hartman-Homestake, Stratton, and Daily-Geesman areas at about that time. In 1910 the Phelps Dodge Corporation acquired options on several groups of mining claims. Over 6,000 feet of development were accomplished in the next three years, partly on the Leatherwood property, but mainly in the Geesman area. Work on the Geesman claims included sinking the Geesman inclined shaft 280 feet, drifting on the 100, 200, and 250 foot levels, and driving the P.D. adit. Phelps Dodge Corporation dropped their interests in the Leatherwood property but maintained and patented property in the Geesman area. The developed ore bodies were left unmined because the ore was too low grade at 3-3.5 percent copper to be profitable at that time.

Sometime between 1910 and 1930 the Daily Arizona Consolidated Copper Co. developed the Daily mine by means of an inclined shaft, an adit, and cross cuts. This work showed a sizable body of 2.5 percent copper. Some high-grade ore was shipped prior to 1930.

The first record of production from the Geesman mine was in 1937 when the Catalina Consolidated Copper Co. leased the Geesman and Daily properties. In 1937 they built a 100-ton flotation plant on the Daily ground and mined and treated ores from both properties. In ten months they extracted 18,000 tons of rock averaging 2.7 percent copper.
This grade proved to be unprofitable at the low price of copper, and operations were suspended.

In October 1939, Control Mines Inc. bought the mill and leased the Daily property. In May of 1940, the company acquired the Geesman property on lease from the Phelps Dodge Corporation. In 1943 the property again changed hands, becoming the Control Mines Co. Production continued until 1946 when the government premium plan was discontinued and mining terminated. Total production from the Geesman mine from 1937 to 1946 was 92,400 tons of 3.25 percent copper ore. The Daily mine produced 20,100 tons of 2.5 percent copper ore from 1937 to 1940.

Prior to and during World War II, minor production and development work was performed on the Leatherwood and Hartman-Homestake properties. Some copper-zinc-lead-silver ore was shipped from the Hartman-Homestake mine during World War II after extensive development work failed to show a profitable mine. At the Leatherwood mines area high-grade mixed oxide and sulfide ore has been mined intermittently by four or less people from numerous small workings. Mr. Roy Bishop, prospector and caretaker of the property, is presently working the Leatherwood property with single jack and hand steel. Ore consists of hand-sorted rock containing more than 12 percent mixed oxide and sulfide copper with 5-7 ounces of silver per ton and minor gold values. Past production from the Leatherwood mines area has not been recorded.

Peterson and Creasey (1943), in an attempt to delineate ore reserves of critical war metals, described the copper deposits of the Marble Peak area in a report which includes maps on open file at the
U.S. Bureau of Mines. This work resulted in a drilling program enacted under Defense Minerals Exploration Administration (D.M.E.A.) contract IDM-E-254. Under this contract fourteen holes were drilled in the Daily-Geesman area. Six of the fourteen holes outlined an ore body northwest of the Daily mine. Calculated reserves indicate that approximately 300,000 tons of 1.98 percent copper occur in the Daily mine area.

The area was then inactive until 1951, at which time it was acquired by Arizona Copper Mines, the present owner. In the middle 1950's, American Metals Exploration took an option on the Daily-Geesman area and conducted a detailed geologic study of the area. In this study they mapped accessible mine workings, sampled and assayed mineralized areas, and mapped the contact zone in detail. In addition, six holes were drilled in the attempt to extend the Daily ore body and find reserves in the area between the Daily and Geesman mines. The project was discontinued because drilling failed to increase reserves.

The association of magnetite with copper is apparent and has been used as an ore guide. In 1955 United Geophysical Corporation conducted a magnetic survey over the Daily-Geesman area. In 1960, Allen Rugg, Jr. supervised a general magnetic survey of the Marble Peak area for Arizona Copper Mines.

Published accounts of the geology of Marble Peak and the surrounding area are limited. Bromfield (1952) discussed the general geology of the Santa Catalina Mountains. DuBois (1959) described the metamorphic history, petrography, and structure of the Santa Catalina Mountains. Creasey (1967) described the general geology of the Mammoth Quadrangle.
Unpublished reports include the study by Peterson and Creasey (1943) and a study of the geology of the Tucson Quadrangle by Moore et al (1949). Three unpublished theses by University of Arizona graduate students are concerned with some aspects of the geology of the Marble Peak area. The study area is included within approximately forty square miles studied by Peirce (1958). Peirce mapped the area at a scale of four inches to the mile and described the general geology with emphasis on petrography and structure. Wood (1963) studied the metamorphic effects of the Leatherwood Quartz Diorite on sediments which it intruded and mapped the contact to the south of Marble Peak at the scale of four inches to the mile. One sample location for this study was chosen within the Marble Peak study area. The petrography and structure of the Leatherwood Quartz Diorite was studied by Hanson (1966). Hanson included a map at the same scale as the preceding investigations in which the Leatherwood Quartz Diorite contact was roughly extended around the north side of Marble Peak.
The northern part of the Santa Catalina Mountains is composed of metasedimentary rocks of Precambrian through Paleozoic age and igneous rocks of Precambrian, Laramide(?), and mid-Tertiary age. The older Precambrian is represented by Pinal Schist and Oracle Granite which are unconformably overlain by metasediments of the younger Precambrian Apache Group. The southern part of the range consists of Catalina Gneiss, a gneissic complex of metamorphosed Precambrian rocks, which makes gradational contact with the Apache Group sediments to the north. Paleozoic metasedimentary rocks of Cambrian, Devonian, Mississippian, and Pennsylvanian(?) periods, where preserved from erosion, overlie the Apache Group. Precambrian and Paleozoic rocks were intruded by Laramide(?) Leatherwood Quartz Diorite which, in turn, was intruded by mid-Tertiary Catalina Granite. The mid-Tertiary event marked uplift of the range which has subsequently been eroded to its present form.

The core of the Santa Catalina Mountains consists of a granite-gneiss complex. In the northern part of the range Precambrian Oracle Granite is in fault contact with younger sedimentary and igneous rocks to the south. Potassium-argon (K-Ar) ages for the Oracle Granite average about 1,420 million years (Damon, Livingston, and Erickson, 1962; Damon, Erickson, and Livingston, 1963; and Livingston et al, 1967). One rubidium-strontium (Rb-Sr) age of 1,450 million years adds credibility to the K-Ar ages (Giletti and Damon, 1961). The Oracle Granite
is a coarse-grained porphyritic rock varying from granite to quartz monzonite in composition.

The southern portion of the Santa Catalina Mountains and much of the Rincon Mountains are composed of Catalina Gneiss, a gneissic granite-granite gneiss complex. The apparent age of the Catalina Gneiss by the K-Ar method is about 26 million years. Argon gas was expelled during the mid-Tertiary, accounting for the young apparent age for the gneiss (Damon et al, 1963). According to DuBois (1959), the Catalina Gneiss was derived from older sedimentary and igneous material. This material may have been Oracle Granite, Pinal Schist, or both.

According to DuBois (1959), Pinal Schist crops out as a wide band extending southeast from the vicinity of the Copper Hill mine, located four miles west-southwest of the town of Oracle, in small exposures along the Mogul fault, and in other areas. Banerjee (1957) interprets inclusions in the Oracle Granite to be fragments of Pinal Schist. North of the Mogul fault the contact between Pinal Schist and Oracle Granite is gradational. These data have led Banerjee (1957) to suggest that much schist has become granite by recrystallization and metasomatism.

In the Santa Catalina Mountains the younger Precambrian is represented by the Apache Group which is composed of the Pioneer Formation, Dripping Spring Quartzite, and Mescal Limestone. The Scanlan Conglomerate Member of the Pioneer Formation unconformably overlies the Pinal Schist or Precambrian granite. The Scanlan Conglomerate has a measured thickness from 10-50 feet (Peirce, 1958) and was measured at 3 feet by Stoyanow (1936) in Peppersauce Canyon. The member varies from a coarse sandstone to pebble conglomerate with the matrix
composed of sericite and quartz. The Scanlan Conglomerate grades upward into about 250 feet of arenaceous mudstone and sandstone of the Pioneer Formation (Peirce, 1958).

The Barnes Conglomerate Member of the Dripping Spring Quartzite conformably overlies the Pioneer Formation. The Barnes Conglomerate consists of 25 to 75 feet of cobble-sized quartz and jasper in a matrix of sericite and fine-grained quartz (Peirce, 1958). The Barnes Conglomerate is conformably overlain by approximately 350 feet of sandstone and siltstone of the Dripping Spring Quartzite.

The Dripping Spring Quartzite is conformably overlain by Mescal Limestone. The Mescal Limestone was not observed in Peppersauce Canyon (Stoyanow, 1936), but has been described in the northern part of the Santa Catalina Mountains by Wallace (1955) and Peirce (1958). The Mescal Limestone, as described by Peirce (1958), is a lime-silicate rock composed of calcite, tremolite, quartz, and diopside formed by synkinematic metamorphism of a siliceous dolomitic limestone.

Sills and dikes of diabase intrude Apache Group sediments and younger rocks. Shride (1961) considered that the major diabase intrusions were Precambrian in age. The diabase is often altered by metamorphism and extensively weathered near the surface.

The Cambrian Bolsa Quartzite unconformably overlies the Apache Group. This formation was described by Stoyanow (1936) and Peirce (1958) as Troy Quartzite, but Shride (1961) states that the middle Cambrian unit mapped as Troy Quartzite should be redesignated Bolsa Quartzite. This unit is composed of about 300 feet of medium-grained to coarse-grained quartzite.
Conformably above the Bolsa Quartzite lies the Cambrian Abrigo Formation, originally designated the Santa Catalina Formation, Southern Belle Quartzite, Abrigo Formation, and Peppersauce Sandstone by Stoyanow (1936). The redesignated Abrigo Formation, after Shride (1961), consists of approximately 750 feet of quartzite, shale, and arenaceous dolomitic limestone.

A thick sequence of Paleozoic carbonates overlies the Abrigo Formation. The Paleozoic carbonates are composed of recrystallized dolomitic limestones and dolomites of the Devonian Martin Formation, massive bedded limestone and dolomitic limestone of the Mississippian Escabrosa Limestone, and some limestone and sandstone of the Naco Group.

The Paleozoic carbonates are intruded by Leatherwood Quartz Diorite, a stock-like body with locally concordant contacts, located in the northeast part of the Santa Catalina Mountains. Metamorphism has caused alteration of the original plagioclase to a more sodic variety with the formation of epidote from the released calcium (Peirce, 1958; Hanson, 1966). A K-Ar analysis of a biotite crystal from the Leatherwood Quartz Diorite yielded an apparent age of 29.6±0.9 million years (Damon, personal communication, 1968).

Pegmatite dikes and irregular bodies for which a replacement origin has been proposed by Peirce (1958) transect the Leatherwood Quartz Diorite and other rocks. Damon et al (1963) dated a large musovite from a pegmatite which cuts the Leatherwood Quartz Diorite near Summerhaven by the K-Ar method and obtained an apparent age of 48.2 million years. Damon et al (1963) suggest that this unlikely age is the
result of incomplete degassing resulting from the large dimensions of the pegmatite mica.

Dikes and sills of post-Paleozoic rocks ranging from lamprophyre to rhyolite are common in the Santa Catalina Mountains (DuBois, 1959; Hanson, 1966). The lamprophyre dikes composed of hornblende and plagioclase transect the Leatherwood Quartz Diorite. North of Mount Lemmon, dikes and apophyses from a granite body named the Catalina Granite by Moore et al (1949) also intrude the Leatherwood Quartz Diorite (Peirce, 1958). A metamorphic-metasomatic origin for the Catalina Granite was suggested by DuBois (1959).

According to DuBois (1959), at least two periods of metamorphism affected the rocks of the Santa Catalina Mountains. The earlier period metamorphosed the sediments of the Pinal Schist and may have been contemporaneous with the development of Oracle Granite. The later period was contemporaneous with the formation of Catalina Gneiss. K-Ar age determinations (Damon et al, 1963) of the Catalina Gneiss date this thermal event at about 26 million years ago, corresponding with the mid-Tertiary orogeny which affected the Basin and Range province. The degree of metamorphism was most intense at the Mount Lemmon area as evidenced by the intense deformation and high-temperature mineral facies in that area.

The northern part of the Santa Catalina Mountains is transected by major west-northwest faults and numerous small displacement normal faults of north-south and varying strikes. The west-northwest faults are typified by the Mogul and Geesman faults along which major displacement has occurred. The dominant foliation direction in the northern part
of the Santa Catalina Mountains is west-northwest with dips to the north.
GENERAL GEOLOGY

Marble Peak consists of a thick sequence of Paleozoic rocks completely surrounded by Leatherwood Quartz Diorite (Figures 2 and 3). Peirce (1958) mapped metasediments of the Dripping Spring Quartzite in the southwest extent of the sedimentary block which are not included in the Marble Peak study area. The Leatherwood Quartz Diorite extends beneath Marble Peak, the metasediments of which form the roof of the intrusion. The west-northwest striking Geesman fault brings Precambrian rocks of the north into contact with the Leatherwood Quartz Diorite. Figure 4 is a geologic map of the study area at the scale of one inch equals 500 feet.

Rocks

Precambrian Rocks

Precambrian rocks in the study area occur north of the Geesman fault. Precambrian granite. In the northwest part of the study area, Precambrian granite, which is probably Oracle Granite, is in fault contact with sheared Leatherwood Quartz Diorite. The Precambrian granite megascopically appears to be the same as Oracle Granite, which outcrops to the north, but inasmuch as this distinction was not studied, the rock will be referred to as Precambrian granite in this report to conform with the nomenclature of Peirce (1958). The Precambrian granite is a porphyritic coarse-grained rock composed of 25 to 40 percent quartz,
Figure 2. Aerial Photograph of Marble Peak, in the Foreground, Looking North

Figure 3. Aerial Photograph of Marble Peak, Looking East, with Bolsa Quartzite Cropping out along Oracle Ridge in the Foreground
the remainder consisting of sericite, clay minerals, and remnants of feldspars and mafic minerals (Peirce, 1958). The rock varies from a granite to quartz monzonite in composition with euhedral phenocrysts of feldspar approximately one inch in longest dimension. The porphyritic Precambrian granite becomes increasingly gneissic toward the contact with Scanlan Conglomerate in the study area. The fabric of the gneissosity is parallel to the contact.

**Pioneer Formation.** Metasediments of the Pioneer Formation occur north of the Geesman fault in the northeast part of the area. The Pioneer Formation is composed of approximately 250 feet of arenaceous mudstone and interbedded sandstone (Peirce, 1958). The Pioneer weathers to form gentle slopes and saddles. The Pioneer was intruded by Precambrian(?) diabase along bedding planes.

The Precambrian granite is nonconformably overlain by the Scanlan Conglomerate Member of the Pioneer Formation. The contact is slightly sheared and locally brecciated. Peirce (1958) states that so much decomposed granite was incorporated in the Scanlan that sharp separation of the units is difficult. North of Marble Peak the contact is sharp. The old granite surface was not extensively weathered prior to Scanlan deposition, fragments of granite were not recognized in the Scanlan Conglomerate, and neither apophyses of granite in conglomerate nor protrusions of conglomerate in granite were observed. The Scanlan Conglomerate forms resistant hogback cappings on the granite.

**Dripping Spring Quartzite.** The Barnes Conglomerate Member of the Dripping Spring Quartzite forms resistant ridges north of Marble Peak. The Barnes Conglomerate consists of ellipsoidal pebbles and
cobbles of quartzite in a matrix of sericite and fine-grained quartz. The Middle and Upper Members of the Dripping Spring Quartzite and the Mes­cal Limestone are not present in the mapped area.

Paleozoic Rocks

**Bolsa Quartzite.** The Cambrian Bolsa Quartzite occurs in con­ tact with the Leatherwood Quartz Diorite along the western edge of the Marble Peak sequence of metasediments. The Bolsa is a cliff-forming, medium-grained to coarse-grained, white to brownish-red quartzite con­ taining impurities of muscovite, biotite, magnetite, and locally tourma­ line and sphene (Peirce, 1958).

**Abrigo Formation.** The Abrigo Formation, also of Cambrian age, occurs southwest, west, and north of Marble Peak. Creasey (1967) sub­ divided the Abrigo into three members named the Three C, Southern Belle, and Peppersauce, listed from oldest to youngest. The three mem­ bers are present in the study area but have not been differentiated in Figure 4. The Three C Member consists of 335 feet (Creasey, 1967) of thin-bedded, feldspathic sandstone with shale partings. The Southern Belle Member consists of approximately 30 feet of clean, white, cliff­ forming quartzite. The Peppersauce Member is composed of about 325 feet of laminated, dolomitic sandstone and sandy dolomite. In the study area, the upper portion of this member is an iron-stained quartzite.

**Undifferentiated Paleozoic marble.** The marbles of Marble Peak were not differentiated in this report because metamorphism has obliter­ ated the diagnostic features that were once present. The undifferentiated marble consists of recrystallized and metamorphosed Devonian Martin
Formation, Mississippian Escabrosa Limestone, and part of the Pennsylvanian Horquilla Formation.

Peirce (1958) measured 185 feet of metamorphosed Martin Formation in Alder Canyon, but he was not sure that the measurement began at the base of the formation. Creasey (1967) measured 252 feet of Martin in Nuggett Canyon, located south of Peppersauce Canyon in the northeastern part of the Santa Catalina Mountains. The Martin consists of metamorphosed dolomites and dolomitic limestones with interbedded sandstone. The Martin Formation is in contact with the Leatherwood Quartz Diorite in the area of the Leatherwood mines group.

The Escabrosa Limestone consists of approximately 590 feet of thick-bedded limestones and dolomitic limestones in Alder Canyon (Peirce, 1958). In the study area, Escabrosa Limestone probably occurs in contact with quartz diorite in the area of the Daily and Geesman mines. The upper part of the Escabrosa contains abundant muscovite in the study area. This rock grades into a thin-bedded sequence of limestone and quartzite which is not characteristic of the Escabrosa and probably belongs to the Horquilla Formation.

The Horquilla Formation in Alder Canyon consists of 1,000 feet of thin-bedded limestone grading into siltstone and sandstone near the top of the formation (Peirce, 1958). Creasey (1967) described about 100 feet of interbedded limestone and marl in the Black Hills, 13 miles east-southeast of Oracle, which he attributed to the Naco Group. Near the crest of Marble Peak, on the east flank, metamorphosed thin-bedded limestone, marl, and sandstone occur which probably belong to the Horquilla Formation.
**Undifferentiated Paleozoic quartzite.** Clean, fine-grained quartzite forms the summit of Marble Peak. Peirce (1958) mapped this rock as metamorphosed sandstone of the Pennsylvanian-Permian Andrada Formation. He described the Andrada in Alder Canyon as metamorphosed siltstones, very fine-grained sandstones, and some interbedded limestones lying conformably above about 1,000 feet of Horquilla Formation. The Paleozoic marble sequence of Marble Peak is not thick enough to accommodate the Martin, Escabrosa, and entire Horquilla Formations. The quartzite capping Marble Peak is approximately 100 feet thick (by estimate) and appears to be conformable with the underlying marbles, although the contact is obscured by blocky quartzite talus. Quartzite float forms the rock flow which is conspicuous on the south slope of Marble Peak.

Post-Paleozoic Rocks

Rocks which transect the Paleozoic metasediments are termed post-Paleozoic in this report. These rocks include the Leatherwood Quartz Diorite, lamprophyre, alaskite, massive quartz, and rhyolite(?). Figure 5A is a photomicrograph of Leatherwood Quartz Diorite. Figures 5B, 5C, and 5D are photomicrographs of thin sections of coarse-grained lamprophyre, chilled lamprophyre in contact with skarn, and the contact between chilled lamprophyre and Leatherwood Quartz Diorite, respectively.

**Leatherwood Quartz Diorite.** The Leatherwood Quartz Diorite varies in composition from quartz diorite to granodiorite (DuBois, 1959) of medium-grained hypidiomorphic granular to xenomorphic granular structure (Hanson, 1966). Aligned biotite in the quartz diorite gives an
Figure 5. Photomicrographs of Thin Sections of Leatherwood Quartz Diorite and Lamprophyre

A. Leatherwood Quartz Diorite showing alteration of plagioclase to epidote. Crossed nicols, X17.

B. Coarse-grained lamprophyre, collected from the thick brecciated dike exposed in the Oracle Road cut. Crossed nicols, X17.

C. Chilled lamprophyre in contact with skarn. The lamprophyre intruded along the contact between quartz diorite and skarn east of the Leatherwood mines. The skarn minerals are strung out along flow laminae in the lamprophyre. Large phenocrysts in the lamprophyre are now chlorite. Smaller phenocrysts are hornblende and plagioclase. Plain light, X17.

D. Contact between Leatherwood Quartz Diorite and lamprophyre. A plagioclase crystal from the quartz diorite is partially digested by the lamprophyre. Crossed nicols, X53.
Figure 5. Photomicrographs of Thin Sections of Leatherwood Quartz Diorite and Lamprophyre
east-northeast foliation. Hanson (1966) interprets the foliation as being related to a period of regional metamorphism on the basis of consistency of attitudes and lack of preferred orientation of other minerals. The average modal composition of 26 samples of quartz diorite consists of plagioclase (42%), quartz (22%), biotite (19%), epidote (10%), microcline (5%), hornblende (1%), and trace amounts of apatite, calcite, chlorite, fluorite, opaque minerals, sericite, sphene, and zircon (Hanson, 1966). According to Peirce (1958) and Hanson (1966), epidote formed from calcium released from plagioclase during metamorphism with the formation of a less calcic plagioclase (Figure 5A). Biotite was derived from an earlier mafic mineral and secondary microcline formed by potassic metasomatism of plagioclase (Hanson, 1966). Alteration of plagioclase to sericite and clay is attributed to hydrothermal processes.

Lamprophyre. Hanson (1966) referred to basic dike rocks which transect quartz diorite and Paleozoic metasediments as lamprophyric dike rocks. Lamprophyric dikes are numerous in the study area, particularly in the Leatherwood mines area. The dikes are generally less than five feet thick. One persistent dike which transects quartz diorite east of the saddle between Marble Peak and Lombar Hill is approximately 40 feet thick (Figure 4). Lamprophyric dikes were observed that intrude Leatherwood Quartz Diorite, Pioneer Shale, Abrigo Formation, and all the marble units of Marble Peak. The rock has not been described as cutting Catalina Granite.

A modal analysis of one section of the thick lamprophyric dike gave the following volume percentages: hornblende 45, plagioclase 32, chlorite 8, opaque minerals 5, quartz 4, biotite 2, calcite 2, apatite 1,
and traces of epidote and sphene (Hanson, 1966). Alteration effects include minor sericitization of plagioclase and alteration of hornblende to biotite which, in turn, has altered to chlorite. A thin section of this dike studied for this report showed a similar mineral composition (Figure 5B). Less than one percent of the opaque minerals consists of fine disseminated pyrite.

Thin sections of the more common fine-grained lamprophyre contain phenocrysts of a chloritized (partly penninite) mafic mineral, the crystal outlines of which suggest hornblende. The chloritized phenocrysts are partially corroded by the fine-grained matrix. The matrix of the rock is composed mostly of euhedral prisms of hornblende and euhedral to subhedral plagioclase.

The contacts of the lamprophyric dikes are chilled. Partial melting of the Leatherwood Quartz Diorite has occurred at the contact with lamprophyre (Figure 5D). Lamprophyre has intruded along the contact between Leatherwood Quartz Diorite and skarn east of the Leatherwood mines. Skarn minerals are drawn out in the flow structure of the lamprophyre at the skarn contact (Figure 5C).

The thick persistent lamprophyric dike shown in Figure 4 contains rounded breccia fragments of coarse-grained lamprophyric material in a somewhat finer grained lamprophyric matrix, indicating multiple intrusion. The quartz diorite is somewhat sheared at its contact with the chilled dike rock. Epidote covers joint and fracture planes which cross quartz diorite and lamprophyre with no apparent change in attitude.

According to Hanson (1966), mafic dike rocks crop out on both sides of the Geesman fault, and on this basis he assigns this rock to
the last igneous stage. The persistent lamprophyre dike which cuts the Paleozoic sequence of marbles east of Marble Peak extends up to the Geesman fault but does not occur on the north side of the fault. Displacement along the fault occurred after intrusion of this dike. In the metasediments of the Pioneer Shale, northeast of Marble Peak, there are sills of sheared basic rock, which is probably Precambrian diabase, within which rock of lamprophyric composition occurs. It appears that shearing occurred in the weaker planes of the diabase(?), followed by intrusion of fresh lamprophyric rock. These sills do not cross the Geesman fault so the relationship between intrusion and faulting could not be examined. The lamprophyre in these sills may be the mafic dike rock to which Hanson (1966) referred.

Alaskite. Sills of alaskite have intruded the Paleozoic marbles above the Leatherwood Quartz Diorite contact west of the Leatherwood mines group and above the Daily mine and Road adit. Petrographic examination of two thin sections of this rock show it to be composed of about 60 percent microcline, 35 percent quartz, and minor amounts of tourmaline, biotite, muscovite, epidote, chlorite, sphene, and opaque minerals (Figure 6). The rock is nonequigranular xenomorphic-granular. Locally micrographic granite and myrmekitic textures occur (Figure 6A). A thin section of alaskite collected at the altered limestone contact is composed largely of epidotized plagioclase with minor amounts of sphene and microcline. It was not determined in this study whether the plagioclase-rich phase represents contamination along the contact or whether microcline represents potassic metasomatism of original plagioclase.
Figure 6. Photomicrographs of Thin Sections of Alaskite

A. Alaskite, collected above the Daily mine, showing micrographic granite and myrmekitic textures. The surface is composed of microcline, quartz, and minor amounts of biotite, muscovite, epidote, sphene, and opaque minerals. Crossed nicols, X17.

B. Alaskite, collected above the Leatherwood Quartz Diorite contact west of the Leatherwood mine group, showing nonequigranular xenomorphic-granular texture. The surface is composed of microcline, quartz, and minor amounts of sphene, chlorite, and tourmaline. Crossed nicols, X17.
Figure 6. Photomicrographs of Thin Sections of Alaskite
Massive quartz. Numerous quartz veins of random orientation and branching form are present in the Daily Geesman area and elsewhere. One such vein, which transects the quartz diorite below the rock house at the mining camp, was unsuccessfully prospected for scheelite in the past. The veins carry epidote, biotite, and locally sulfides.

A quartz-muscovite vein of variable thickness, locally exceeding 10 feet in thickness, transects the Escabrosa Limestone(?) immediately below the quartzite capping on the south flank of Marble Peak. Pseudomorphs of limonite after pyrite are present in the quartz. The marble adjacent to the quartz has been coarsely recrystallized. A zone of iron oxide gouge separates the quartz from lamprophyre rock which occurs in the footwall contact of the quartz. It appears that the gouge is sheared lamprophyric material, suggesting that the quartz was emplaced after the lamprophyre, but the same evidence could also be interpreted conversely.

Rhyolite(?). Dikes of rhyolite(?) transect the Precambrian granite west of Dan's Saddle. The rhyolite(?) was not observed to intrude other rocks. The rock is chalky white, very fine-grained with quartz phenocrysts. This rock may be the same rock which Peirce (1958) referred to as quartz latite and which he interprets to be post-Paleozoic in age. He describes quartz latite as a porphyritic rock varying from rhyolite to quartz latite in composition.

Structure

Drag folds in the Scanlan Conglomerate and attitudes of isolated exposures of this rock suggest that the older Precambrian granite
was uplifted sometime after deposition of the Scanlan (Figure 4). It is likely that the gneissic structure of the granite near the contact and shearing at the contact were developed at that time. This evidence supports the mantled gneiss dome concept of Eskola (1949). This concept supports two stages of orogeny which were also suggested by DuBois (1959).

Precambrian sediments north of the Geesman fault strike north-south and dip to the east. Close to the Geesman fault these same rocks strike parallel to the fault and dip to the south. This change of attitude is probably due to drag folding along the fault. Shear foliation in the quartz diorite south of the fault consists of alignment of biotite. The attitude of the sediments adjacent to the Geesman fault is the same as the attitude of shear foliation in the Leatherwood Quartz Diorite.

In the west and southwest part of the study area, the Paleozoic sediments strike north-northwest and dip to the northeast. East and south of Marble Peak attitudes are more irregular and dips are shallower. North of Marble Peak the Paleozoic sediments dip to the south. The sediments form a crude basin shape about Marble Peak.

The major fault in the area is the Geesman fault. The Leatherwood Quartz Diorite, which is sheared near the fault, separates Precambrian rocks north of the Geesman fault from Paleozoic rocks to the south (Figure 4). About 1,500 feet of sediments are missing from the section along the Geesman fault. According to Peirce (1958), displacement occurred along this break after the emplacement of the Catalina Granite. The Geesman fault displaces quartz diorite and lamprophyric dikes in the study area.
Numerous high-angle normal faults transect the metasediments in the study area. Faults of this type occur in the Stratton mine (Figure 7), Hartman-Homestake mine, and Daily mine areas. Some of the faulting occurred prior to or contemporaneous with intrusion of the Leatherwood Quartz Diorite. Igneous metamorphism has altered carbonate beds in the area of the fault plane in the Stratton mine and Hartman-Homestake mine areas. The fault in the Daily mine area has sheared quartz diorite.

Normal faults which displace the contact zone a few feet or less are common in the area. These breaks were recognized underground in the mine areas and may not extend to the surface. The faults displace crystallized skarn.

Metamorphism

The entire sequence of sediments of Marble Peak were metamorphosed. Sandstone units were recrystallized. Shaley and cherty limestone and dolomitic limestone were metamorphosed to muscovitic, tremolitic, or garnetiferous marble. Chert was recrystallized. No decrease in recrystallization of carbonate units was recognized away from the Leatherwood Quartz Diorite suggesting that metamorphism is not solely related to intrusion of quartz diorite. Metamorphism which affected the Leatherwood Quartz Diorite was probably also responsible for the recrystallization of the sediments of Marble Peak.

The metamorphism of Marble Peak is probably related to the formation of Catalina Granite and Catalina Gneiss. Sediments adjacent to the Catalina Granite were subjected to high medium grade, amphibolite facies, metamorphism (Peirce, 1958). Metamorphic grade decreases to the east and is negligible eight miles east of the granite at
Undifferentiated quartzite

Abrigo Formation

Undifferentiated marble
Faults displace the metasediments in the Stratton mine area.
Figure 7. View of Marble Peak Looking Northeast from the Oracle Road.
Faults displace the metasediments in the Stratton mine area.
Peppersauce Canyon. K-Ar determinations indicate this stage of metamorphism occurred during mid-Tertiary time.
IGNEOUS METAMORPHISM

A general description of the igneous metamorphic effects of the Leatherwood Quartz Diorite is reported in this section to introduce the reader to previous work which is related to the present study. The igneous metamorphic effects of the Leatherwood Quartz Diorite on dolomitic marble, marble, meta-arkose, and quartzite were studied by Wood (1963). The dolomitic marble was probably from the Martin Formation. The marble was collected from the Marble Peak area east of the Leatherwood Mines area and was probably from the Escabrosa Limestone.

The unaltered dolomitic marble studied by Wood (1963) is composed of 90 to 98 percent carbonate with minor chlorite, epidote, clay, and quartz. The ratio of dolomite to calcite is 75:25. Magnetite, epidote, chlorite, tremolite, diopside, and dolomite are present near the contact. The calcite-dolomite-tremolite assemblage is stable at the contact except where small pods of calcite-diopside-epidote occur in the immediate vicinity of the contact.

Wood (1963) studied the igneous metamorphism of marble composed of 98 percent calcite with minor quartz, muscovite, chlorite, and dolomite outside the contact aureole at 1.5 feet from the contact. Garnet, pyroxene, and epidote occur within 9.5 feet of the contact. Calcite and tremolite are most abundant at the outer zone of igneous metamorphism. The garnet is near the andradite end-member in composition. Pyroxene consists of diopside75 hedenbergite25. The marble outside the
contact aureole has a sutured, granoblastic texture showing no evidence of fracturing or cataclastic action. Within the outermost tremolite zone, especially where tremolite is abundant, the rock has a distinct cataclastic texture. Calcite grains are flattened and fractured. Wood (1963) states that cataclastic effects have undoubtedly assisted metasomatism.

Igneous metamorphism reached the grade of hornblende-hornfels facies in a zone 20 feet thick next to the Leatherwood Quartz Diorite contact with sediments (Wood, 1963). Farther from the contact the grade of igneous metamorphism drops to the albite-epidote-hornfels facies. Veinlets of sanidine transect both skarn and lamprophyric dikes. Wood (1963) suggests that sanidine may be related to thermal metamorphism related to intrusion of Catalina Granite. Wood (1963) calculated chemical compositions of rocks in the contact aureole. He noted that silica showed a marked increase near the contact, while magnesium showed a minor increase. He did not plot alumina or ferric iron.

Hanson (1966) sampled the Leatherwood Quartz Diorite at distances of 0, 8 inches, 2 feet, 5 feet, and 12 feet from the contact of altered marble. Hornblende, epidote, and microcline are abundant near the contact but decrease inward. Biotite increases from none at the contact to approximately 20 percent at 5 feet from the contact. Quartz is about 5 percent at the contact, increases to 29 percent at 8 inches, decreases to 4 percent at 2 feet, and increases to 26 percent at 12 feet from the contact. Plagioclase increases slightly from the contact.
GEOLOGY OF THE LEATHERWOOD MINES AREA

Workings

The Leatherwood mines group consists of numerous adits and prospect pits located above the Leatherwood Quartz Diorite contact south of Marble Peak (Figure 4). One such tunnel is presently being worked by Mr. Roy Bishop. Figure 8 is four photographs taken on the Leatherwood property when Mr. Bishop was shipping ore. The shipment consisted of about 50 tons of hand-sorted ore composed of approximately 12 percent copper, 6 ounces silver per ton, and 0.05 ounces of gold per ton. The shipment is typical of past mining from the property.

Old mine workings occur above the quartz diorite contact west of the Leatherwood group of mines. An upper adit apparently connects to a lower adit via a shaft. The upper adit and shaft were driven at the intersection of a N 20° W fault with a north-south fault. Upper Abrigo sandstone is intruded by a thin dike of Leatherwood Quartz Diorite at the portal of the upper tunnel. Magnetite-rich rock containing very minor copper was taken from these workings.

An isolated outcrop of skarn surrounded by quartz diorite occurs on the ridge east of the Leatherwood mines. Lamprophyric rock intrudes along the quartz diorite-skarn contact. Megascopically, the skarn is composed of garnet, magnetite, epidote, and amphibole. The outcrop of skarn is penetrated by old workings which followed copper shwoings.

North of the isolated skarn exposure the quartz diorite-skarn contact is intruded by the thin sill of lamprophyre (Figure 5c). Skarn in
Figure 8. Views of the Leatherwood Mines Area

A. Mr. Bishop hand-loading the chute. B. Mr. Roy Bishop, lessee of the Leatherwood property. C. Unloading the chute. D. Mine adit driven along the footwall contact between a lamprophyre dike and mineralized skarn.
this area and to the east consists of epidote, quartz, garnet, magnetite, tremolite, actinolite, and calcite with minor azurite. Tremolite occurs at the outer part of the contact aureole. Skarn is restricted to a zone a few feet thick at the quartz diorite contact.

Two adits were driven to prospect mineralization associated with the thick persistent lamprophyre above the quartz diorite contact east of the Leatherwood mines (Figure 9). The brecciated lamprophyre dike is approximately 30 feet thick here. Magnetite and skarn are well developed in the footwall and hangingwall marbles. Brecciation is pronounced along the lamprophyre footwall contact with skarn. Garnet-epidote skarn is restricted to a zone less than five feet thick next to the lamprophyre contacts. The entire contact aureole is estimated at 20 feet or less in thickness. Igneous metamorphism diminishes along the lamprophyre dike further from the Leatherwood Quartz Diorite contact.

All the accessible adits and prospects of the Leatherwood mines group were entered and described in the present study. In addition, the mine presently being worked by Mr. Bishop, named the Bishop mine in this report, and an old adit exposed in the Bishop mine were mapped with tape and brunton at the scale of one inch equals twenty feet. Portions of the mapped area are shown in Figure 10. Portions of the Bishop mine are so irregular and caved that they have not been shown. The back portion of the adit bends back on itself, changing levels, to form a figure 8.

The surface in the Leatherwood area is locally composed of rock fragments set in a matrix of caliche. The brecciation is probably due to local down-slope slide. The material has not moved far as
Figure 9. Views from an Adit Located on the Brecciated Lamprophyre Dike East of the Leatherwood Mines

A. View of adit, skarn exposed at the portal. B. Brecciated lamprophyre lying on the dump. C. View of the isolated outcrop of skarn which forms the knob along the ridge in the middleground. Mount Bigelow is in the background.
EXPLANATION

- lamprophyre
- garnet-epidote skarn
- magnetite-rich skarn
- tremolitic marble
- brecciation
- shear or fault (mineralized)
- attitude of contact
- copper mineralization

Figure 10. Geologic Map of Part of the Bishop Mine
evidenced by the fact that mixing of different rock types has not occurred. Jumbling was so unimportant, in fact, that ore has been mined from rubble zones.

**Lamprophyre Dikes and Igneous Metamorphism**

Alteration minerals of the dolomitic marble at the Leatherwood mines area include garnet, diopside, epidote, calcite, magnetite, actinolite, serpentine, minor brucite, and minor specularite. The garnet is near the andradite end-member in composition. Brucite, which occurs with calcite as small grains about one millimeter in width, is probably an alteration mineral of periclase. Serpentine occurs with magnetite and in shear planes in skarn. The dolomitic marble in the Leatherwood mines area is probably part of the Martin Formation.

Dolomitic marble of the Martin Formation(?) has been altered to skarn adjacent to lamprophyre dikes which strike northwest and dip southwest. The degree of skarn development is greatest adjacent to lamprophyre dikes near the quartz diorite contact and decreases away from that contact. Three zones within the skarn were recognized. An inner zone of garnet-diopside-epidote-calcite, commonly a few feet thick, grades into a thicker transitional magnetite-rich zone which grades into an outer tremolitic marble zone. The greatest concentration of sulfides occurs between the garnet-diopside-epidote-calcite and magnetite-rich zone. One or more of the zones are locally missing, but the order of occurrence outward from the lamprophyre dikes is the same. The Leatherwood Quartz Diorite-lamprophyre contact was not observed in this area because of cover by mine dumps and float.
The lamprophyre dikes, at the contact with altered marble, are commonly brecciated and physically decomposed. The physical destruction at the contacts probably aided movement of solutions which metamorphosed the marbles. The skarn zones are often two to ten times as thick as the lamprophyre dikes which they border. The thickness of the contact aureoles provides a problem of what the source of the igneous metamorphism may have been. A lamprophyre dike from the Bishop mine is transected by a veinlet of bornite and chalcocite indicating that sulfides were deposited, at least in part, after crystallization of the lamprophyre dikes.

**Mineralization and Paragenesis**

Figure 11 consists of four photomicrographs of thin sections, polished thin sections, and polished sections of sulfides and skarn from the Leatherwood mines area. Sulfides occur as veinlets (Figure 11A) and disseminations (Figure 11B) in skarn. The sulfide mineralogy is bornite, chalcopyrite, chalcocite, and covellite, listed in order of decreasing abundance. Pyrite is conspicuously absent. Sulfides, as veinlets, often occur with coarse secondary calcite. Euhedral crystals of epidote often occur with the secondary calcite and sulfides. In the Bishop mine, discontinuous sulfide veinlets lead from the lamprophyre contact and die out in the skarn. Bornite, as disseminations, replaces garnet and diopside (Figure 11B). Epidote, which formed early with diopside and garnet (Figure 11D) and late with secondary calcite and sulfides, was not observed to be replaced by sulfides.

The first minerals to form in the skarn zone were garnet, diopside, epidote, magnetite(?), actinolite(?), and tremolite(?).
Figure 11. Photomicrographs of Polished Sections, Polished Thin Sections, and Thin Sections from the Leatherwood Mines Area.

A. Bornite (bn) and chalcopyrite (cp) replaced by chalcocite (cc). Branching veinlets carry secondary malachite. Reflected light, X31.

B. Disseminated grains of bornite in a gangue of diopside (d) and garnet(g). Bornite replaces both diopside and garnet. Double exposure; plain light and reflected light, X31.

C. Veinlet of bornite partially replaced by chalcocite (darker gray mineral) which cuts lamprophyre. Double exposure; plain light and reflected light, X31.

D. Banding in garnet (g), epidote (e), diopside, calcite (c), quartz (q) skarn. Diopside is not shown in photograph. Crossed nicols, X17.
Figure 11. Photomicrographs of Polished Sections, Polished Thin Sections, and Thin Sections from the Leatherwood Mines Area
Bornite-chalcopyrite, which formed contemporaneously (Figure 11A), was later and replaced and transected earlier skarn minerals. Late calcite and epidote formed with bornite and chalcopyrite. Chalcocite and covellite, which replace bornite and chalcopyrite (Figure 11A), were late. The latest minerals were secondary malachite and azurite. Sulfides were deposited, at least in part, after emplacement of lamprophyre (Figure 11C).
GEOLOGY OF THE STRATTON MINE AREA

Workings

The Stratton mine workings are located about 50 feet above the Leatherwood Quartz Diorite contact with Abrigo metasediments west of the Leatherwood mines. The main working consists of an inclined shaft approximately 80 feet in length, the lower 30 feet of which are flooded. Other small prospects are located in the area. Two adits, each about 50 feet in length, are located about 800 feet north of Stratton Spring in Stratton Spring canyon. These workings will be referred to as the Upper Stratton prospects. A few tons of hand-sorted copper ore appear to have been shipped from the Stratton property.

Rock Types and Structure

The Stratton mine is located along a bedding plane fault which strikes northwest and dips 27° to the northeast. The fault has displaced beds of the lower part of the Peppersauce Member of the Abrigo Formation. Incompetent beds were sheared yielding soft fault gouge. The inclined shaft follows the bedding fault along which igneous metamorphism has occurred.

The Upper Stratton prospect consists of two adits driven along a fault which strikes N 55° W and dips 73° to the southwest. The southwest hangingwall of the fault is composed of rocks of the Three C Member(?) of the Abrigo Formation. The footwall is sandy dolomitic marble of the Peppersauce Member(?) of the Abrigo Formation.
Igneous Metamorphism and Mineralization

At the Stratton mine, thin veinlets of chalcopyrite-pyrite approximately one-quarter inch thick, fill fractures in the altered sediments, normal to the bedding. Chalcopyrite and pyrite also occur as disseminations in garnet-epidote skarn. The spacing between veinlets decreases with depth. Bornite and molybdenite are associated with quartz at depth. Minor magnetite occurs at the Upper Stratton prospect but was not identified at the Stratton mine.
GEOLOGY OF THE HARTMAN-HOMESTAKE MINE

Workings

The Hartman-Homestake mine, located northwest of Marble Peak, consists of about 2,000 feet of drifts, raises, and winzes. The mine workings were mapped at two scales, one inch equals 20 feet and one inch equals 50 feet, with tape and brunton. Figure 12 is a map of the composite workings at the scale of one inch equals 50 feet. Figure 13 is a photograph of the portal of the westernmost adit, looking along an east-northeast striking fault which will be referred to as the Hartman-Homestake fault in this report. The rocks at the portal of this adit were altered by igneous metamorphism.

Rock Types and Structure

The major structure in the Hartman-Homestake mine area is the Hartman-Homestake fault. The fault varies in strike from N 50° E to N 80° E and dips at high angles to the southeast or northwest. The fault plane consists of a zone approximately five feet thick of gouge, breccia, and slickensides. The fault varies locally in both strike and dip and in some places is a bedding fault. The underground workings generally follow this fault. Cross faults are numerous in the mine area. The cross faults strike northeast, north-northwest, and northwest.

The north wall of the Hartman-Homestake fault consists of metasediments of the Three C Member of the Abrigo Formation. The footwall consists of metamorphosed sandy dolomite, sandstone, and
Figure 12. Geologic Map of the Hartman-Homestake Mine Workings.
Figure 13. Igneous Metamorphism and Mineralization Related to Faulting at the Hartman-Homestake Mine.

The portal is in rocks showing igneous metamorphism and mineralization related to an east-northeast striking fault. The adit follows the fault.
shaley units which are probably part of the Peppersauce Member of the Abrigo Formation. Sheared Leatherwood Quartz Diorite occurs in the westernmost portion of the T-shaped drift. A thin section of this rock shows it to be composed of microcline 50%, biotite 20%, epidote 20%, quartz 8%, and calcite 2%. This rock is cut by late veins, less than one foot thick, of quartz-microcline-fluorite.

**Igneous Metamorphism**

The metasediments adjacent to and within the Hartman-Home-stake fault zone were altered to skarn composed of garnet, diopside, biotite, quartz, epidote, plagioclase, carbonate, and idocrase. Garnet and diopside appear to be restricted to the area of the fault zone. Biotite, calcite, dolomite, epidote, and quartz occur in unaltered metasediments. Idocrase was identified in one sample collected from the area of the fault zone. The biotite exhibits an unusual bright green pleochroism and has a 2V angle of almost zero. The garnet crystals are generally euhedral and zoned. Biotite crystals are frequently bent. A specimen of the unaltered Three C Member is composed of quartz 60%, biotite 20%, epidote 15%, and carbonate 5%. It is difficult to assess the relative importance of pyrometasomatism because of the impurity of the original sediments.

**Mineralization and Paragenesis**

The sulfides at the Hartman-Homestake mine occur as open space fillings in skarn which is restricted to the area of fault zones. Sulfides are most abundant where shearing and brecciation along the east-northeast trending Hartman-Homestake fault were most intense and where cross faults intersect the east-northeast trending shears.
The relationship between faulting and the abundance of sulfides is shown in Figure 12.

Photomicrographs of polished sections and polished thin sections of sulfide and skarn minerals from the Hartman-Homestake mine are shown in Figure 14. The sulfide mineralogy is pyrite, chalcopyrite, galena, sphalerite, and chalcocite, listed in order of decreasing abundance. The sulfide minerals fill voids between skarn minerals. Replacement of skarn minerals may have occurred but was not proved by microscopy. Cataclastic effects exhibited by sulfide minerals include cleavage of galena and fracturing of pyrite (Figures 14A, 14B, and 14D). Exsolution textures exhibited in the sulfide minerals include blebs of galena, sphalerite, and chalcopyrite (?) in pyrite (Figure 14A) and spotty blebs of chalcopyrite in sphalerite. The relative amounts of galena, sphalerite, and chalcopyrite (?) as blebs in pyrite is roughly proportional to the abundance of these minerals in the slide surface shown in Figure 14A.

Fractured pyrite is commonly transected by galena, sphalerite, and chalcopyrite (Figures 14A, 14B, and 14D). The shape of the boundaries between grains of galena, chalcopyrite, and sphalerite suggests that they were deposited in large part contemporaneously. Chalcopyrite, galena, and sphalerite commonly occur with calcite, quartz, and biotite (Figures 14C and 14D). The association of sulfides with quartz, biotite, calcite, or any combination of these minerals is so common that it is difficult to interpret this occurrence in any other way than simultaneous formation. Figure 14C shows galena and chalcopyrite included within zoned garnet crystals along zoning traces. The sulfides appear to have
Figure 14. Photomicrographs of Polished Sections of Mineralized Skarn from the Hartman-Homestake Mine.

A. Galena (gn), sphalerite (sl), and pyrite (py) with interstitial blebs of galena, sphalerite, and chalcopyrite(?). Galena transects a fractured grain of pyrite at upper right. Reflected light, X31.

B. Fractured pyrite (py) cut by sphalerite (sl), and chalcopyrite (cp) in a gangue of quartz (q), epidote (e), and biotite (b). Reflected light, X31.

C. Chalcopyrite (cp) and galena (gn) occur with late quartz (q) and calcite (c). Galena and chalcopyrite are included along zoning traces, within a zoned garnet crystal. Reflected light, X31.

D. Fractured pyrite (py) transected by chalcopyrite (cp) and biotite (b). Reflected light, X31.
Figure 14. Photomicrographs of Polished Sections of Mineralized Skarn from the Hartman-Homestake Mine
formed contemporaneously with growth of the garnet crystals, but the sulfide may have formed as replacement of garnet.

Garnet, diopside, epidote, carbonate, biotite, and quartz formed early. Sulfides cut skarn and fill voids between skarn minerals indicating that the sulfides were deposited after the formation of early silicate minerals. The evidence does not support a time gap between igneous metamorphism and sulfide deposition. Included sulfide in garnet suggests that some sulfide may have been deposited along with the formation of garnet. Biotite, quartz, and secondary calcite formed with sulfide minerals. The first sulfide mineral to form was pyrite, which was still forming when galena, sphalerite, and chalcopyrite (?) were deposited, if blebs of these minerals in pyrite are related to exsolution. The pyrite was fractured prior to deposition of galena-chalcopyrite-sphalerite. A late generation of quartz, biotite, and calcite accompanied deposition of galena, sphalerite, and chalcopyrite.
GEOLGY OF THE DAILY-GEESMAN MINES AREA

Workings

The workings of the Daily-Geesman mines area consist of the Road adit, the Daily mine, the Geesman mine and P.D. (Phelps Dodge) adit, and numerous prospects located along the contact between the Daily and Geesman mines and in the Road adit area. The Road adit, the portal of which is located along the Oracle Road west of the mining camp, is approximately 350 feet in length. The Road adit was mapped at the scale of 20 feet to the inch for this study (Figure 15). A number of short adits and prospect pits are located to the west and above the Road adit.

The Daily mine consists of two adits and an inclined shaft. The main stope, composed of irregular rooms supported by pillars, covers an area of about 150 by 250 feet. The main cross-cut extends westward for a distance of about 450 feet.

At the Geesman mine, the northernmost drift is known as the P.D. adit. The P.D. adit was driven for about 800 feet in a westerly direction. This adit was mapped at the scale of one inch equals 20 feet for this report (Figure 16).

The main adit of the Geesman mine, the No. 1 level, has been driven approximately 900 feet parallel to the P.D. adit and 450 feet in an easterly direction. Three deeper levels exist but are presently flooded. An inclined shaft connects the fourth level 225 feet in a vertical direction to the surface. Extensive stoping has been done along the
Figure 15. Geologic Map of the Road Adit
Figure 16. Geologic Map of the P.D. (Phelps Dodge) Adit
contact down to the fourth level. The ore shoot is about 200 feet wide, 300 feet long down its plunge, and 15 to 20 feet thick. The shoot plunges 35° to 50° to the southwest. The geometry of the workings indicates that the ore shoot narrows with depth. The mine workings at the Daily and Geesman mines were mapped by Peterson and Creasey (1943).

**Rock Types and Structure**

Clean, coarse-grained white marble is intruded by the Leatherwood Quartz Diorite in the area of the Daily mine, Geesman mine, and Road adit. X-ray diffraction of the marble shows that it is composed of calcite with trace amounts of quartz. The marble is probably metamorphosed Escabrosa Limestone. Igneous metamorphism has altered the limestone to skarn minerals adjacent to the Leatherwood Quartz Diorite. The skarn zone varies in thickness from more than 20 feet in the mine areas to almost lacking between the Daily mine and Road adit. The geology of the contact zone at the Daily mine and Geesman mine is shown in cross section (Figure 17, in pocket).

Lamprophyre, alaskite, and vein quartz are present in the area. The lamprophyre occurs as thin, persistent, northwest striking, southwest dipping dikes which vary in dip and locally are sills. Lamprophyre dikes are exposed in the contact aureole of the Daily and Geesman mines where they are associated with high-grade copper and magnetite. Cataclastic effects are not present at the contact of these dikes.

Alaskite has intruded the limestone as sills above the Leatherwood Quartz Diorite contact in the Daily mine and Road adit areas. Igneous metamorphism and limited mineralization are commonly
associated with these sills. The timing of alaskite with respect to Leatherwood Quartz Diorite intrusion is unknown.

Quartz veins are numerous in the area of the quartz diorite contact. The quartz veins cut the quartz diorite and skarn but are generally limited in occurrence to the contact zone. The quartz veins carry epidote, biotite, or both. Infrequently the veins carry sulfides. The veins are usually thin, less than a foot in thickness, and are branching and irregular in form.

Rolls in the contact zone form broad anticlinal and synclinal structures in the area of the mines. The undulations are clearly visible at the skarn-marble contact at the Geesman mine (Figure 18). The axis of the rolls at the Geesman mine is orthogonal to the general strike of the contact between quartz diorite and skarn.

Small displacement normal faults are common in the Daily-Geesman area. One such fault, named the Daily fault in this report, is exposed in the Daily mine and Road adit. The plane of the Daily fault is extensively sheared. Other faults displace the contact zone a few feet. The faults displace quartz diorite and skarn.

Igneous Metamorphism

The contact between quartz diorite and exoskarn is gradational in the Daily-Geesman area. The field criterion used for distinguishing skarn from altered quartz diorite was the lack of visible feldspar. Biotite, epidote, and quartz are abundant in both skarn and quartz diorite. The contact between skarn and marble is sharp. The thickness of the skarn is proportional to the amount of structural deformation at the
Figure 18. The Skarn-marble Contact along the North Limb of an Anticlinal Roll at the Geesman Inclined Shaft

s = skarn; m = marble.
contact. Past mining operations involved the extraction of mineralized skarn from the deformed contact zone (Figure 19).

The Leatherwood Quartz Diorite was altered to endoskarn near the contact. The alteration effects are difficult to assess because of the inconsistent mineralogy of the quartz diorite. The epidote content of the quartz diorite increases significantly near the marble contact, especially adjacent to quartz veins. Microcline appears to show an erratic increase near the contact with a concomitant decrease of plagioclase. Sericite and chlorite are also more abundant in this rock. The variation in quartz content is difficult to assess because of the abundance of quartz as veins.

The exoskarn is composed of epidote, garnet, quartz, biotite, actinolite, tremolite, and calcite. Garnet is near the andradite end-member in composition. Epidote and garnet are the most abundant minerals of the skarn. Tremolite is uncommon. Crumbly magnetite occurs in limited amounts at the skarn-marble contact and is associated with lamprophyre dikes. Some of the calcite fluoresces red, probably indicating a high manganese content.

Veinlets and vugs of quartz are common in the exoskarn. Epidote, biotite, and sulfides are frequently associated with the quartz. Veinlets of calcite-epidote-biotite are less common. Large euhedral crystals of epidote, often exceeding one inch in longest dimension, occur with quartz, with calcite, and in clusters.
Figure 19. Views Underground in the Daily Mine

A. The Daily fault zone in sheared quartz diorite, looking upward about 30 feet. B, C, and D. Undulations in the contact zone. The roof of the stopes consists of coarse-grained marble, the pillars are mineralized skarn.
Mineralization and Paragenesis

Sulfides occur in garnet-epidote-quartz-biotite-calcite skarn. The sulfides are most abundant near the marble-skarn contact. Copper as sulfides is quite constant in grade, about two percent copper, over thousands of square feet in the mine areas. Sulfide minerals fill open spaces in fractured skarn and replace skarn minerals. Chalcopyrite, pyrite, bornite, chalcocite, and covellite, listed in a decreasing order of abundance, constitute the sulfide minerals.

Figure 20 consists of four photomicrographs of polished sections and polished thin sections of mineralized skarn from the Geesman mine. Sulfides commonly replace garnet (Figures 20B and 20D) and fill voids in fractured skarn (Figures 20A and 20C). Pyrite is commonly fractured. Chalcopyrite, quartz, calcite, and epidote fill fractures in pyrite (Figures 20A and 20B). This is the same assemblage which is recognized as veinlets in the skarn zone. Chalcopyrite and bornite appear to have formed contemporaneously (Figure 20D). Chalcopyrite is replaced by chalcocite (Figure 20A) and covellite (Figure 20C).

Scheelite occurs in the Daily and Geesman mines but is absent at the Road adit. Scheelite occurs as disseminated grains with quartz veins in both altered quartz diorite and exoskarn in porous marble, in porous garnet skarn with chalcopyrite, and at the skarn-marble contact. The grade and occurrence of scheelite are spotty and inconsistent. The scheelite, which fluoresces yellow, probably contains some powellite molecule.

Sulfides were deposited subsequent to the formation of early garnet-epidote-quartz-biotite-calcite skarn. The skarn minerals were
Figure 20. Photomicrographs of Polished Sections and Polished Thin Sections of Mineralized Skarn from the Geesman Mine.

A. Chalcopyrite (cp) partially replaced by chalcocite and covellite (?) occurs as fracture fillings in pyrite (py). Calcite (c) transects pyrite. Reflected light, X31.

B. Chalcopyrite (cp), quartz (q), calcite (c), and epidote (e) fill fractures in pyrite (py). Euhedral garnet (g) appears to be replaced by pyrite. Reflected light X31.

C. Chalcopyrite (cp) which is partially replaced by covellite (cv) fills voids in fractured garnet skarn. Reflected light, X31.

D. Pyrite (py), chalcopyrite (cp), and bornite (bn) occur as fracture fillings and replacement of garnet skarn. Reflected light, X31.
Figure 20. Photomicrographs of Polished Sections and Polished Thin Sections of Mineralized Skarn from the Geesman Mine
fractured prior to the deposition of sulfides. Pyrite was the first sulfide mineral to form and was fractured prior to deposition of chalcopyrite and bornite. Calcite, quartz, and epidote were deposited after fracturing of the pyrite. Scheelite formed with late quartz-sulfides. Late chalcocite and covellite replace chalcopyrite.
VERTICAL MAGNETICS

In 1955, United Geophysical Corporation conducted a magnetic survey of the Daily-Geesman area. Allen Rugg, Jr., in 1960, supervised a general magnetic survey of the Marble Peak area and prepared a contour map of the data from both surveys. Figure 21 (in pocket) is a vertical magnetic contour map (after Rugg, 1960) of the Marble Peak area redrawn to the scale of the geologic map.

An explanation of the origins of the magnetic anomalies is provided when Figure 21 is overlain upon the geologic map. Strong magnetic highs occur in the area of the Leatherwood Quartz Diorite contact with altered dolomitic marble of the Abrigo and Martin Formations. The anomalies are related to magnetite mineralization of the dolomitic marble adjacent to the contact. Anomalies of this type occur along the contact north of Marble Peak and southwest of Marble Peak in the area of the Leatherwood mines group and westward.

Strong magnetic anomalies were found associated with lamprophyre dikes near the quartz diorite contact. These anomalies are related to magnetite which occurs in the contact aureole about the lamprophyre dikes. Anomalies of this type occur in the Leatherwood mines area and along the brecciated lamprophyre dike which intrudes marble near the quartz diorite contact east of the Leatherwood mines.

Weak anomalies occur in the area of the Daily and Geesman mines. These anomalies are related to weak magnetite mineralization adjacent to the deformed skarn-marble contact. The anomaly in the
Daily mine area conforms to the drilled out reserves in that area.

Weak magnetic anomalies occur over lamprophyre dikes where they outcrop away from the quartz diorite contact. Anomalies of this type are related to minor magnetite and abundant ferro-magnesian minerals which compose the lamprophyre dikes. A weak anomaly is associated with the brecciated lamprophyre dike which outcrops northeast of Marble Peak.

A 1100-gamma magnetic anomaly was outlined above Hartman Spring by Rugg (1960). The anomaly high occurs 1,200 feet south of where the road crosses the Hartman Spring drainage. Bedrock exposures in this area are poor, but there are enough outcrops along the drainage to make it apparent that the source of the anomaly is buried beneath undifferentiated Paleozoic marble. The anomaly high occurs in the drainage low which would be nearest the buried source. The magnetic high located above Hartman Spring is suggested to be related to magnetite mineralization of altered marble above the intersection of the persistent lamprophyre dike and the Leatherwood Quartz Diorite.

A depth estimate to the top of the magnetic source was calculated from an east-west profile through the magnetic high using the slope method of L. J. Peters (Dobrin, 1960, pp. 312-313). The technique assumes conditions which are only approximated in the Hartman Spring area. The calculated depth by this method is 210 feet below the Hartman Spring drainage.
THEORETICAL CONSIDERATIONS OF IGNEOUS METAMORPHISM AND ORE DEPOSITION

Related Experimental Data

The solubility of calcite in water at normal hydrothermal pressure and temperature ranges is inversely proportional to temperature and directly proportional to the partial pressure of carbon dioxide (Ellis, 1963). Unlike most minerals, calcite is not deposited along a decreasing temperature gradient. Calcite would be less soluble in higher temperature contact aureoles than in the marbles outside contact zones, a phenomenon which may explain the introduction of late calcite into contact aureoles.

Burnham (1967) reacted hydrous solutions at elevated temperatures and pressures with crushed pegmatite. He found that HCl-rich solutions leached alkalies (K⁺, Na⁺, Ca++) so extensively that the residue was no longer granite. Feldspars were converted to micas, aluminum silicates, or both. Quartz was not strongly leached in this solution. Burnham (1967) reacted carbon dioxide-rich solutions with crushed pegmatite, noting that the solution of silica and aluminum was facilitated while the solution of alkalies was depressed. Carbon dioxide-rich solutions leach quartz and depress the reaction of feldspars to mica.

Solutions present at the contact of carbonate sediments with an igneous melt would consist of volatiles derived from both the sediments and the magma. Carbon dioxide would be derived by expulsion
from the heated carbonates. The carbon dioxide would go into solution in magmatic and sedimentary water. Ideally, diffusion of carbon dioxide through the aqueous medium on both sides of the contact would occur until equilibrium is achieved. According to Burnham (1967), silica and alumina would be preferentially dissolved in the carbon dioxide-rich solution while the solution of alkalies would be depressed. Ferric iron, which is atomically similar to Al$$^{+++}$$, can be expected to be concentrated if present as a dissolved specie in the carbon dioxide-rich solution. Movement of Si-Al-Fe solutions from the crystallizing igneous melt through the decarbonated sediments should occur. The silica, alumina, and ferric iron would react with CaO and MgO to yield typical pyrometasomatic assemblages composed of garnet, epidote, diopside, hedenbergite, idocrase, and wollastonite.

If this mechanism is correct for the igneous metamorphism in the Marble Peak area, altered marble at the quartz diorite contact should include Ca-Al-Fe silicates. Igneous metamorphism of dolomitic marble should yield Ca-Mg-Al-Fe silicates. The thickness of the pyrometasomatic zone should be roughly proportional to the permeability of the altered zone and the amount of solution developed. Fractures, faults, and other openings would enhance the movement of the metasomatizing solutions through the contact zone.

**Sedimentary Control of Igneous Metamorphism**

The chemistry of the sedimentary host of igneous metamorphism is a major control of the mineralogy of the exoskarn. Igneous metamorphism of dolomite and dolomitic limestone typically produces skarn
composed of diopside, tremolite, forsterite, serpentine, and magnetite with lesser amounts of garnet, actinolite, quartz, and phlogopite. Igneous metamorphism of limestone yields skarn of garnet, hedenbergite, epidote, quartz, and wollastonite with lesser amounts of hornblende, actinolite, diopside, tremolite, magnetite, and hematite. The association of magnetite and serpentine with altered dolomite and dolomitic limestone is common.

In the study area, magnetite and serpentine occur as igneous metamorphic products of dolomitic marble. Diopside and tremolite occur in altered dolomitic marble but are very minor in altered marble. Wood (1963) described diopside and tremolite as typical products of igneous metamorphism of marble. He interpreted diopside and tremolite as products of magnesium metasomatism of the marble. Data to support this concept were not collected in this study. Andradite, epidote, actinolite, quartz, and calcite are igneous metamorphic products of both marble and dolomitic marble in the study area.

Pyrometasomatism

Lindgren (1905) noted qualitatively that carbonate rocks in contact with quartz monzonite at Morenci, Arizona, received major additions of ferric iron, silica, alumina, copper, zinc, and sulfur. Burnham (1959), in a study of igneous metamorphism at Crestmore, California, noted that the atomic ratio of Si + Al + Fe/Ca + Mg decreases from 1.62 at the inner contact zone to 0.66 at the outer zone. He suggests that the change in chemistry away from the contact is due to silica-alumina-ferric iron metasomatism diminishing outward into the contact aureole.
At the Leatherwood mines area, additions of silica, alumina, iron, copper, and sulfur have produced skarn of garnet, diopside, epidote, magnetite, bornite, and chalcopyrite from essentially pure dolomitic marble. At the Daily-Geesman mines area, silica, alumina, iron, copper, tungstate, and sulfur have been introduced in marble along the contact. A skarn composed of garnet, epidote, quartz, pyrite, chalcopyrite, bornite, and scheelite has been produced.

Igneous Metamorphism Related to Faults and Fractures

Titley (1961) studied igneous metamorphism related to faults at the Linchburg mine, New Mexico. He concluded that pyrometasomatic solutions originating from an unknown source at depth moved along fault conduits altering carbonate beds to skarn and depositing metals. A similar origin is proposed for the Hartman-Homestake and Stratton mines. At these deposits igneous metamorphism is restricted to the area of faults above the Leatherwood Quartz Diorite-sediment contact. The degree of pyrometasomatism of carbonate beds is difficult to assess because of the impurity of the beds. Leakage of iron, copper, lead, zinc, and silver along the fault zones resulted in deposition of sulfides of these metals subsequent to the formation of skarn minerals. The source for these metals was the Leatherwood Quartz Diorite.

On a smaller scale, fracturing related to the formation of rolls at the Daily-Geesman mines and fracturing along the contact of lamprophyre dikes undoubtedly aided the access of solutions. At the Daily-Geesman mines the thickness of the exoskarn is proportional to the
amount of deformation along the contact. Rolls in the contact are pronounced at the mine areas.

**Paragenetic Sequence**

There appears to be unanimity of opinion among student of igneous metamorphic deposits that skarn minerals generally form earlier than sulfides (Perry, 1968). The timing of sulfide deposition with respect to the formation of skarn has been interpreted differently for different deposits. Baker (1962) interpreted a hiatus between formation of skarn minerals and sulfides at Washington Camp, Arizona. Titley (1961) felt that there was essential contemporaneity of sulfide, oxide, and silicate deposition at the Linchburg mine, New Mexico.

In the Marble Peak area, skarn minerals formed prior to deposition of sulfides and continued to form along with the deposition of sulfides. The paragenetic sequence of formation of the major silicate, oxide, and sulfide minerals for the Leatherwood, Hartman-Homestake, and Daily-Geesman mines areas is shown in Table 1. Garnet, diopside, epidote, and amphiboles formed prior to deposition of sulfides as evidenced by sulfides cross-cutting and replacing these minerals. Included sulfide in garnet at the Hartman-Homestake mine suggests that some sulfide may have been deposited early. Late calcite and epidote at the Leatherwood mines, late quartz, calcite, and epidote at the Daily and Geesman mines, and late quartz and carbonate at the Hartman-Homestake mine indicate that the chemical components necessary to form early skarn minerals were present in solution after formation of garnet-diopside had ceased. The preceding evidence which strongly supports the formation of quartz, epidote, and calcite prior to and with sulfides
TABLE 1.—Paragenetic sequence of the Leatherwood, Hartman-Home-stake, and Daily-Geesman mines.

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Early Hypogene</th>
<th>Late Hypogene</th>
<th>Supergene</th>
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</tr>
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<td>epidote</td>
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<td>chalcopyrite</td>
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<td>sphalerite</td>
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<tr>
<td>chalcocite</td>
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<tr>
<td>andradite</td>
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<tr>
<td>epidote</td>
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<tr>
<td>actinolite</td>
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<td>bornite</td>
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<td>calcite</td>
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<tr>
<td>chalcocite</td>
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<tr>
<td>covellite</td>
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does not indicate a hiatus between silicate-stable and sulfide-stable deposition.

At the Daily-Geesman mines area, where pure marble was altered to skarn adjacent to the Leatherwood Quartz Diorite, the solutions which deposited sulfides and late quartz-epidote-calcite contained CaO, CO₂, Al₂O₃, Fe₂O₃, and SiO₂. At the Leatherwood mines area where dolomitic marble was altered to skarn adjacent to lamprophyre dikes, contemporaneity of calcite-epidote and sulfides indicates CaO, CO₂, Al₂O₃, Fe₂O₃, and SiO₂ were contained in the solutions which deposited chalcopyrite and bornite. CaO and CO₂ were derived from the carbonate sediments, whereas Al₂O₃, Fe₂O₃, and SiO₂, copper, iron, and sulfur must have come from the crystallizing igneous melt.

Late quartz, biotite, and calcite formed with sulfides at the Hartman-Homestake mine. It would be mere speculation to predict the source of the constituents which combined to form late quartz, calcite, and biotite. The chemical constituents may have been derived from the impure sediments, the Leatherwood Quartz Diorite, or both.
CONCLUSIONS

Igneous metamorphism and sulfide deposition accompanied intrusion of the post-Paleozoic Leatherwood Quartz Diorite into the carbonate sediments of Marble Peak. The skarn mineralogy, sulfide mineralogy, and paragenetic sequence of deposition is found to be typical of the igneous metamorphic deposit class. At the Daily-Geesman mines area, igneous metamorphism has occurred in areas of structural deformation adjacent to the quartz diorite contact. At the Hartman-Homestake and Stratton mines, igneous metamorphism has occurred along pre-mineral faults. In the Leatherwood mines area, skarn and sulfides occur in contact aureoles adjacent to post-Leatherwood Quartz Diorite lamprophyre dikes.

The timing of lamprophyre dikes with respect to the Leatherwood Quartz Diorite is a problem to understanding the origin of the Leatherwood mines area. The lamprophyres, which are chilled and have assimilated some of the quartz diorite at the lamprophyre-quartz diorite contact, are younger than quartz diorite. The lamprophyre is also older than the last movement along the Geesman fault which has displaced one lamprophyre dike.

The degree of igneous metamorphism adjacent to thin lamprophyre dikes is out of proportion to what would be expected to be derived from the lamprophyre alone. Igneous metamorphic aureoles are commonly greater than twice the thickness of the associated lamprophyre dike. Igneous metamorphism adjacent to lamprophyre dikes is greatest near the
Leatherwood Quartz Diorite contact and decreases along these dikes away from the quartz diorite contact. The situation is shown diagrammatically in Figure 22.

![Diagram of spatial relationship between skarn, lamprophyre dike, and Leatherwood Quartz Diorite.](image)

**Figure 22.** Diagrammatic Representation of the Spatial Relationship of Skarn, Lamprophyre Dike, and Leatherwood Quartz Diorite.

LQD = quartz diorite, l = lamprophyre, m = marble, and s = skarn.

The absence of inclusions of skarn in lamprophyre and the presence of veinlets of bornite which cut lamprophyre indicate that lamprophyre was intruded prior to sulfide deposition and prior(?) to igneous metamorphism. Brecciation and shearing which occur along the lamprophyre contacts in the Leatherwood mines area could have acted as conduits for fluid movement subsequent to intrusion of lamprophyre.

The available data suggest that the lamprophyres intruded along persistent northwest striking, southwest dipping structures subsequent to crystallization of the Leatherwood Quartz Diorite. These structures tapped fluids at depth which moved upwards along the contacts either contemporaneous with lamprophyre emplacement or after crystallization of lamprophyre. These fluids cause pyrometasomatism of the limestone above the quartz diorite contact. The source of the metal-bearing solutions may have been the Leatherwood Quartz Diorite.
Work is now being conducted at The University of Arizona which will add to the understanding of the origin of lamprophyres. Mr. Wayne Colony, a graduate student, is presently studying the petrogenesis of lamprophyre dikes as a Master's problem. Dr. Paul D. Pushkar, a post-doctoral Research Associate in the Laboratory of Isotope Geochemistry, is presently studying the age of the Leatherwood Quartz Diorite and the lamprophyre dikes by the Rb-Sr method. Very preliminary data collected by Dr. Pushkar indicate that the $\text{Sr}^{87}/\text{Sr}^{86}$ ratio of the lamprophyre is less than that of the Leatherwood Quartz Diorite suggesting that these two rocks are not cogenetic. The age of both the lamprophyre and the Leatherwood Quartz Diorite is probably pre-Cretaceous, and perhaps as old as early Mesozoic (Damon, personal communication, 1968).

The entire sequence of sediments which compose Marble Peak have undergone low-grade regional metamorphism. The sandstones and carbonate sediments have been recrystallized to quartzites and marbles. The degree of recrystallization does not decrease away from the quartz diorite contact indicating intrusion of the quartz diorite was not responsible for metamorphism of Marble Peak. The Leatherwood Quartz Diorite was affected by regional metamorphism according to Peirce (1958) and Hanson (1966), which altered plagioclase to epidote and a less calcic plagioclase. The lamprophyres were not epidotized, but fractures which transect both the quartz diorite and lamprophyre are filled with epidote. The timing of lamprophyre with respect to regional metamorphism is uncertain.

Small displacement faulting has displaced the contact zone in the study area. These structures are probably related to shrinkage of the
crystallizing quartz diorite. Displacement occurred along the Geesman fault subsequent to the formation of all rocks. This faulting is probably contemporaneous with orogeny which affected the Santa Catalina Mountains in mid-Tertiary time.

The timing of post-Precambrian events of the Marble Peak area is shown in Table 2. Solid lines which indicate interpreted timing are based upon data supplied in the body of this report. No data were collected which suggest that there was more than one geologic age of skarn formation. The time of skarn formation is interpreted to be late in the crystallization history of the Leatherwood Quartz Diorite.
TABLE 2.—Sequence of geologic events of the Marble Peak area.

Time sequence within the Mesozoic Era is not drawn to scale. Solid lines indicate interpreted timing, dotted lines indicate possible timing.

<table>
<thead>
<tr>
<th>EVENT</th>
<th>Paleozoic</th>
<th>Mesozoic</th>
<th>Cenozoic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition of sediments</td>
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</tr>
<tr>
<td>Leatherwood Quartz Diorite</td>
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<tr>
<td>Intrusion</td>
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<tr>
<td>Crystallization</td>
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<tr>
<td>Formation of skarn</td>
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<tr>
<td>Deposition of metals</td>
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<tr>
<td>Alaskite</td>
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<td>Formation of skarn</td>
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<td>Quartz veins</td>
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<tr>
<td>Metamorphism of sediments</td>
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<tr>
<td>Faulting along Geesman fault</td>
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</table>
RECOMMENDATIONS

The area west of the proven reserves at the Daily mine area, estimated at 300,000 tons of about 2 percent copper, offers good potential for prospecting. In addition, good opportunities for prospecting exist in the area of the Hartman Spring magnetic anomaly. Further exploration in the area should use magnetic methods and perhaps electrical geophysical techniques in conjunction with geology.
LIST OF REFERENCES


Damon, P. E., 1968, Personal communication: Department of Geology and Geochronology, The University of Arizona.


FIG. 4
GEOLOGIC MAP OF THE MARBLE PEAK AREA, PIMA COUNTY, ARIZONA

SCALE 1:20,000

CONTOUR INTERVAL = 100 FEET

DECLINATION, 1957

EXPLANATION
FIG. 17
GEOLOGIC SECTIONS IN THE MARBLE PEAK AREA, PIMA COUNTY, ARIZONA

See Plate I for Explanation and Location

SCALE 1:1,200

Geology by Eric R. Braun, 1967
FIG. 21
VERTICAL MAGNETIC INTENSITY MAP OF THE MARBLE PEAK AREA,
PIMA COUNTY, ARIZONA

EXPLANATION

- 1000 Gamma Contour Interval
- 100 Gamma Contour Interval
- Magnetic Low
- Unimproved Dirt Road
- Jeep Trail

APPROXIMATE MEAN DECLINATION, 1957