GEOLOGY AND GEOCHEMISTRY

OF
ORE DEPOSITS AND WALLROCK
OF THE
BUCKSKIN JOE MINE AND VICINITY,
BUCKSKIN - MOSQUITO MINING DISTRICT,
PARK COUNTY, COLORADO

BY
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1965
A Thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Doctor of Science in Geological Engineering.

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INTRODUCTION

The Buckskin Joe Mine is an inactive base and precious metal mine in central Colorado; it consists of veins and replacements in Lower Paleozoic quartzites and carbonates. The objectives of the work described herein were as follows: (1) to investigate and detail the geology of ore deposits of the mine and vicinity, (2) to determine the distribution patterns of elements in and about these deposits and to ascertain which patterns are common to similar ore bodies, (3) to use information from these studies to postulate a genesis for these deposits.

This study was carried out during the period from 1960 to 1965. Surface mapping was done on United States Forest Service aerial photographs enlarged to a scale of approximately 1 inch to 400 feet, and controlled by United States Army Topographic Sheet 4762 1 SE. Soil sampling surveys and an electromagnetic survey used the same map base. Underground mapping on a scale of 1 inch to 20 feet in general utilized existing surveys. Mineralogic and chemical analyses were done chiefly at the Colorado School of Mines.
Location and Accessibility

The Buckskin Joe Mine is approximately 70 miles southwest of Denver and two miles west of the town of Alma in Park County, Colorado (see location map on plate 1). The area investigated is located on the eastern slope of Loveland Mountain, between Buckskin and Mosquito Gulches, in portions of Sections 3, 4, 9 and 10, Township 9 South, Range 78, west of the Sixth Principal Meridian. Geological publications commonly refer to the region as part of the Alma Mining District, whereas claim maps title it the Buckskin-Mosquito District. Loveland Mountain is near the northern end of the Mosquito Range and is immediately west of South Park.

The area may be reached by traveling west from Alma along gravel roads in Buckskin or Mosquito Gulches and thence by mine roads across the property. The latter are usually inaccessible from November to May because of snow accumulations.

Topography Vegetation and Climate

Elevations in the region mapped extend from 10,500 feet in the southeast to 12,300 feet in the northwest (see topography, plate 4) with timberline at approximately 11,500 feet. Below timberline aspen and evergreens are the
principal form of vegetation, whereas above timberline native grasses and alpine flowers dominate. Summers are cool and wet while winters are cold with abundant snow.

**History**

Gold was discovered in the gravel of Buckskin Creek in 1859. A lode was first located on what later became the Buckskin Joe Mine, in 1859, by a Mr. Phillips who soon abandoned it. In 1860 "Buckskin Joe" Higginbottom reclaimed the Phillips Lode, then sold it, and shortly thereafter production began (Flynn, 1932, p. 14).

The deposit consisted of a barite and oxidized pyrite fissure filling and replacement zone in the Sawatch Quartzite below a quartz feldspar porphyry sill. This zone was mined chiefly as a trench with a width and depth of several tens of feet, and a length of approximately 800 feet. Data from Henderson (1926, p. 187) and others indicates that between 6,000 and 16,000 tons of ore were mined with a grade of 2 to 5 ounces per ton in gold and a total production of $500,000 to $800,000 at today's prices. Apparently minor silver and copper with the gold were not recovered. The extension of this Phillips Lode to the southwest is later referred to as the Keytest Vein System.
By 1863 the oxidized ore had been removed and the underlying primary sulfides, grading 0.1 to 0.5 ounces per ton in gold, could not be treated economically so operations ceased (Henderson, 1926, p. 187).

In 1875 approximately 500 tons of pyrite grading 0.3 to 0.5 ounces per ton in gold were mined on the original lode for use as a smelter flux in Alma. From 1879 to 1881 there was a mild boom of interest in mineralization on Loveland Mountain above the Buckskin Joe Mine. Then, in 1884 a Colonel Bond sunk several exploration shafts and located sulfides on the southwestern extension of the Phillips Lode. He sold the property to the Key Test Mining Company of St. Louis in 1887; this organization carried out some mining until 1895 when work was suspended (Jordon, 1948).

In 1936 Buckskin Joe Mines Ltd., owned by Mr. Charles Jordon, acquired the property and opened ore bodies in the Peerless and lower Manitou Formations from which zinc, lead, gold and minor copper and silver were recovered. Operations ceased in 1957.

Other important mines in the area investigated are the Shelby, Mascotte and Orphan Boy (for locations see plate 1).
Figure 1

View of area investigated on Loveland Mountain, looking west.

Figure 2

View of trench where original Phillips Lode was mined, looking southwest.
According to Patton, Hoskin and Butler (1912, p. 150), the Orphan Boy was located shortly after the Phillips Lode, probably in the early 1860's. It was worked for gold intermittently until the early 1900's. After World War II there was again a minor amount of mining, this time for base metals. The Shelby Lode was discovered prior to 1887 since a reference is made to it in the October 13, 1887 issue of the Fairplay Plume newspaper (Galbraith, 1960). Possibly it was worked in the flurry of activity between 1879 and 1881. Additional development was done on it after World War II but no new ore was located. The earliest reference to the Mascotte tunnel is Singewald and Butler (1941) who mapped the area between 1929 and 1931. Charles Jordon carried out some development in the tunnel while working the Buckskin Joe Mine.

The earliest published geological work on the district is by Emmons (1886) who examined the geology of the cliffs of Buckskin and Mosquito Gulches. He also briefly reported the geology of several mines in the area, including the Phillips Lode. In 1912 Patton, Hoskin and Butler published a comprehensive investigation of the geology and ore deposits of the Alma District. The Orphan Boy Mine is described (p. 168-170, 209-215) but only brief mention is
made of the Phillips (p. 162) and Shelby Mine (p. 215).
Singewald and Butler (1941) carried out comprehensive
surface mapping in the area investigated, although again
little is noted on the mines of interest.

Acknowledgments

The writer wishes to acknowledge with thanks the assistance and advice of Professor M. A. Klugman, who initiated the study of trace element patterns in wallrock at the Colorado School of Mines, and who originally suggested the Buckskin Joe Mine as a thesis project. In his capacity as thesis advisor he greatly assisted in obtaining the economic and physical facilities and establishing the atmosphere of free inquiry necessary for the study. Considerable thanks are also due Professor R. E. Bisque who provided numerous useful suggestions on geochemical aspects of the inquiry, including the use of Mg/Ca and Ba/Sr ratios, Professor R. C. Epis who assisted in stratigraphic and petrologic interpretations in the thesis, and Professors N. C. Schieltz, F. A. Rodgers and A. G. Fegis who rendered helpful comments and criticisms during preparation of the report. A portion of the stratigraphic section was prepared under the direction of Dr. R. J. Weimer whose suggestions are sincerely appreciated.
The writer would also like to thank Messrs. G. E. Rouse, W. A. Blood, M. M. Judy and W. Lembeck for their assistance during underground mapping and sampling. As well as assisting in various phases of the program, Messrs. D. E. Bloom, S. H. Pilcher and D. Galbraith provided numerous stimulating discussions. The staff of the Metallurgy Department were highly co-operative during all phases of the investigation, particularly Mrs. F. L. Stewart and Dr. N. C. Schieltz who were often consulted on spectrographic subjects. Similarly, the Chemistry Department, through Dr. R. E. Bisque, provided analytical instrumentation facilities and consultation. The Geophysics Department, through Professors P. A. Rodgers and J. C. Hollister, were especially helpful in providing the use of an ABEM E.M. Gun for an electromagnetic survey. Dr. F. W. Cornwall of Chartered Exploration suggested the rapid burn spectrographic procedure used for analysis. Acknowledgment is also gratefully due Mr. Charles Jordon, owner of the Buckskin Joe Mine, for permission to study the property and for numerous comments on the history and development of the deposit.

The writer particularly wishes to acknowledge the financial assistance, through fellowships, of the National
Science Foundation (G-19065R), the Shell Oil Company and the Colorado School of Mines Research Foundation, Inc. Financial assistance and the mercury analytical facilities were provided by Earth Sciences, Inc.
GENERAL GEOLOGY

The Buckskin-Mosquito District of Central Colorado lies in the northern portion of the Mosquito Range and within the eastern margin of the Colorado Mineral Belt. Structurally, the district occurs in the South Park region of eastward dipping thrust and reverse faults developed during Laramide tectonic activity. The Sawatch uplift is to the west, and the Front Range uplift is to the east. In the area investigated a low-angle thrust fault and numerous northeast trending normal faults dominate the structure.

The lithology of the area consists of approximately 450 feet of eastward dipping pre-Pennsylvanian carbonates, quartzites and shales resting unconformably on Precambrian schist, gneiss, pegmatite and granite. These are cut and intruded by a number of Laramide granodioritic porphyries in the form of sills, dikes and small stocks.

Ore deposits on the property occur as fracture fillings and replacements in quartzites and carbonates, along the northeast trending normal faults. The principal minerals of the ore bodies are sphalerite, argentiferous galena, auriferous pyrite, minor chalcopyrite and injection dolomite.
STRATIGRAPHY AND PETROLOGY

The principal exposures of the thesis area occur on cliffs forming the north and south faces of Loveland Mountain. Precambrian rocks occur on the lower cliff walls while Cambrian to Mississippian strata make up the upper walls and the long gently dipping eastern slope of the mountain. Immediately east of the thesis area the Pennsylvanian Minturn Formation outcrops.

The stratigraphic section in Figure 3 was measured by the writer and D. N. Bloom on the north face of Loveland Mountain. Measurement of the Chaffee and Leadville Formations was impossible to achieve due to lack of exposures.

Detailed studies of the stratigraphy and petrology of the region have been published by Emmons (1896), Patton, Hoskin and Butler (1912), Johnson (1934, 1945), Singewald and Butler (1930, 1941), Behre (1953), Bloom (1961) and Stevens (1961).

Precambrian Rocks

The oldest rocks on the property are medium- to fine-grained greenish-gray-brown quartz mica schists which vary from highly quartzitic to highly micaceous (biotite and
muscovite). They appear to be metamorphosed graywackes similar to those in the Idaho Springs Formation of the Front Range, and indeed, in Archean areas in general. The quartz and mica may be concentrated into layers 1/10 to 1/3 inch thick.

The schist is frequently invaded by pink or gray granite, sometimes in bands 1/10 inch thick along foliation planes, and sometimes up to several feet or more thick either along or across the foliation. The gray granite is commonly a fine- to medium-grained biotite-muscovite-microcline variety while the pink granite is a coarse-grained biotite-muscovite-orthoclase rock. When the foliation planes of the schist are well permeated by granite, the rock is properly referred to as an injection gneiss.

Both the schist and injection gneiss are frequently cut by white granite pegmatites in irregular veins from 1/2 inch to many feet across. In some places pegmatite intrusion forms a type of injection gneiss as well. Commonly the pegmatite consists of 50 percent or more microcline, up to 25 percent quartz and major to minor amounts of biotite and muscovite. Grain size is variable but most often is between 1/2 and 2 inches. Patton, Hoskin and Butler (1912, p. 45) note that rarely (2 cases found) pegmatite may be cut by granite.
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<td>ORDOVICIAN</td>
<td>300</td>
<td>250</td>
<td>Dolomite, cherty, light buff to light gray, very finely crystalline, light gray buff chart lenses and patches increase upward, beds increase from 1/8-2 in. at base to 6-12 in. near top, resistant, weathers light buff ridgley surface.</td>
</tr>
<tr>
<td>LOWER (CANADIAN)</td>
<td>250</td>
<td>200</td>
<td>Dolomite, light gray, very finely crystalline, beds commonly ½-2 in. but thick bedded in lower part, resistant, weathers light gray to light brown.</td>
</tr>
<tr>
<td>CAMBRIAN (FROXIAN)</td>
<td>200</td>
<td>150</td>
<td>Dolomite with interbedded gray shale, light gray, finely crystalline, beds average 2 in., resistant, weathers light brown to light gray.</td>
</tr>
<tr>
<td>CAMBRIAN (FROXIAN)</td>
<td>150</td>
<td>100</td>
<td>Varies upward from dolomite, through siliceous dolomite, dolomitic quartz sandstone, to sandy dolomite, light gray to light buff, commonly fine grained, quartz grains are medium rounded and sorted, well cemented with dolomite and silica, beds commonly 2-12 in., resistant, weathers medium brown.</td>
</tr>
<tr>
<td>CAMBRIAN (FROXIAN)</td>
<td>100</td>
<td>50</td>
<td>Varies upward from sandy dolomite, through dolomite, interbedded, gray shale and dolomite, to &quot;red-cast&quot; edgewise conglomerate at top, commonly light to dark gray, crystalline, beds average 1-6 in., resistant, weathers buff to gray brown.</td>
</tr>
<tr>
<td>PRECAMB.</td>
<td>50</td>
<td>0</td>
<td>Quartzite, dolomitic, buff to white except for upper 6 ft. which is purplish black, medium- to fine-grained, medium rounding, medium sorting, well cemented with silica and dolomite, beds commonly 2 to 3 ft., resistant, weathers dark gray-brown (purple black in upper part).</td>
</tr>
<tr>
<td>PRECAMB.</td>
<td>0</td>
<td>0</td>
<td>Quartzite, white to light buff pink with black mottling toward top, commonly fine grained, well sorted, well cemented with silica, beds average 2 to 3 ft., resistant, weathers brown, rarely minor mica present.</td>
</tr>
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Basal conglomerate, light gray green, quartz pebbles 0.1 to 1 in. diameter in quartzite matrix.

Quartz chlorite mica schist, gray-green.
Paleozoic Rocks

Sawatch Quartzite

Eldridge (1894, p. 6) gave the name "Sawatch Quartzite" to Cambrian rocks in the Crested Butte quadrangle and on the western flank of the Sawatch Range. A typical exposure is on Cement Creek, Section 14, Township 14 South, Range 85 West, Gunnison County, Colorado. Until 1947 the overlying Peerless formation was included as its upper member.

The Sawatch is commonly a massive, buff to white quartzite, often glauconitic in the upper portions (which, along with local patches of iron oxides, seems responsible for a purplish black weathering color), and sometimes slightly dolomitic. The upper contact is conformable, and sometimes gradational, with the Peerless, whereas the lower contact is characterized by a thin, quartz pebble conglomerate resting unconformably on a relatively smooth surface of Precambrian rocks. In the Pando area fossils date the lower Sawatch as Dresbachian (Bicellemus ranges through the whole stage, but is restricted to it, Lochman-Balk, 1956, p. 570). Within the thesis area the Sawatch is approximately 116 feet thick.
Peerless Formation

The term "Peerless Shale" was introduced by Behre (1932, p. 50) as the upper member of the Sawatch quartzite. In 1947 Singewald designated it a formation. Its type locality is on Peerless Mountain, 7 miles east-southeast of Leadville, Colorado. The Peerless has often been called "transition beds", since it represents a gradation from the underlying Sawatch Quartzite to the overlying Manitou Dolomite (Berg, 1960, p. 11). It consists of calcareous sandstone, sandy dolomitic limestone, dolomitic limestone and shale, with glauconitic horizons. Near the top are found "red-cast beds" (so named because of their reddish weathering color), which have variously been interpreted as edgewise conglomerates, pisolites, fossil casts and fusoid markings. All these interpretations are feasible, with edgewise conglomerates and pisolites probably being the most common.

Lochman-Balk (1956, p. 567) describes fossils found in the Peerless in the Sawatch Range as late Franconian to Trempealeauan (uppermost Cambrian stage). Berg and Ross (1959, p. 106-108) reported the Peerless fauna in the Colorado Springs region as Franconian. In the thesis area investigated the Peerless is approximately 41 feet thick.
**Manitou Dolomite**

Cross, in 1894, indicated that C. D. Walcott named the Manitou, but did not designate a type locality or detailed section. The name is from Manitou Springs and Manitou Park (20 miles apart). Brainerd, Baldwin and Kayte (1933) defined the type locality and section at Williams Canyon, El Paso County, Colorado, in Section 32, Township 13 South, Range 67 West.

The "Manitou Dolomite" is a finely crystalline, light-gray to buff dolomite and limestone. Sandstone and shale beds occur in the lower portion while gray to buff chert stringers and lenses may be found throughout the section, but more abundantly in the upper portions. "Red cast beds" are not uncommon near the base in the region from Colorado Springs to Glenwood Canyon, though none were noted in the thesis area proper. A thickness of 148 feet was measured.

No evidence for an unconformity was found between the Peerless and overlying Manitou in the area studied. In the Manitou Park region, Berg and Ross (1959, p. 110) identified the lowermost Ordovician trilobite zones (B, C and D), previously known in Utah. Berg (1960, p. 11) suggests that these zones extend to the Weston Pass area. Since Bass and Northrop (1953) found lowermost Ordovician
fossils immediately above the Clinetop algal limestone (uppermost Peerless) of late Cambrian age at Glenwood Canyon, it seems that the Manitou, at least in the lower portion, is Tremadocian (lowermost Ordovician stage). The upper boundary of the Manitou is marked everywhere by an unconformity. In both the Buckskin Joe Mine and Mascotte Tunnel a regolith 3 to 25 feet thick has been noted between the Manitou and overlying Parting Quartzite. It consists of boulders and pebbles of dolomite and quartzite in a chloritic sericitic clayey rock and represents Devonian subaerial erosion. Tweto (1949, p. 170) has also noted this phenomena in scattered areas in central Colorado.

**Chaffee Formation**

According to Brown (1962, p. 20), Kirk, in 1931, applied the name "Chaffee Formation" to the "Upper Devonian sandstones, shales, dolomites and limestones near Salida (in Chaffee County), Colorado, and suggested its usage in the Alma district". Bloom (1961, p. 30) has summarized the paleontological evidence and notes that the Chaffee Formation is late Devonian in age.

In the Buckskin-Mosquito area the Chaffee Formation is separated into two members, the Parting Quartzite below and
the Dyer Dolomite above. Although nowhere within the thesis area was there a suitable surface section for measurement, scattered outcrops, adjacent areas and construction of cross sections yield an adequate picture of lithology and thickness.

**Parting Quartzite**

According to Bloom (1961, p. 25), Emmons, in 1882, applied the name "Parting Quartzite" to the quartzite unit between the overlying "Blue Limestone" (Leadville and Dyer) and the underlying "White Limestone" (Manitou) in the Leadville Mining District of central Colorado. He notes that the name was given geographic significance when Loughlin gave the name "Parting Spur" to a topographic feature near Leadville.

In the area investigated the Parting is a sub-to-well-rounded light-gray sandstone to quartzite varying in composition from 50 to 95 percent quartz grains, the remainder being dolomite. Grain size varies from very coarse to very fine, sorting is poor, and cementation by dolomite and silica is poor to good. These features result in a moderate resistance to weathering and give the rock a characteristic hobnail weathered surface with white quartz grains standing out in relief above a buff matrix of dolomite and fine quartz grains. Beds vary from 2 inches to 2 feet in thickness while
the entire unit is approximately 15 feet thick. An erosional unconformity, sometimes marked by a regolith, separates it from the underlying Manitou Dolomite. Although the contact is sharp, no evidence was found for an unconformity between the Parting and overlying Dyer Dolomite.

**Dyer Dolomite**

The term "Dyer Dolomite" was introduced by Behre (1932, p. 60) who designated the type section as exposures on Dyer Mountain near Leadville.

In the area studied the Dyer is a very finely crystalline dolomite with beds varying in thickness from 2 inches to 1 foot. It varies downward from light gray dolomite through a dark blue-gray unit with minor argillaceous seams, to a light cream zone which weathers to a light tan color. The Dyer is moderately resistant, particularly the bluish dolomite, which often forms small but distinct ledges. Available evidence indicates that the Dyer may vary in thickness from 20 feet in the east to 40 feet in the west. Less than a mile to the northwest Corn (1957, p. 18) reports the Dyer varying from 40 to 60 feet in thickness.

**Leadville Formation**

According to Brown (1962, p. 25), Eldridge introduced the term "Leadville Limestone" for exposures near Leadville,
Colorado. Kirk (1931, p. 227) proposed that the term Leadville Limestone be restricted to that part of the Blue Limestone (of Emmons, 1882) which occurs between the Chaffee Formation and the Pennsylvanian shales. In 1949, Tweto (p. 177) named the thin sandstone and quartzite unit at the base of the Leadville the "Gilman sandstone" with the type area near Gilman, Colorado. Thus, the Leadville is separated into two members, the Gilman Sandstone and Leadville Dolomite. Only the Gilman and lowermost Leadville beds may be observed in the thesis area. Bloom (1961, p. 32) has reviewed the paleontological evidence and notes that the Leadville is early Mississippian in age (Kinderhookian).

**Gilman Sandstone**

Within the area investigated the Gilman varies, often over a distance of several hundred feet, from a cherty dolomite to a dolomite containing 10 to 20 percent medium-grained quartz sand to a fine-grained almost pure quartzite indistinguishable from pure Sawatch quartzite. Commonly it is cream colored on a fresh surface and buff to medium brown with quartz grains standing out in relief like coarse sandpaper, on weathered surfaces, Grains are medium- to well-rounded, well cemented by dolomite or silica and poorly- to well-sorted. The Gilman is thin- to thick-bedded, approximately 10 feet thick, and moderately easily eroded.
although its resistance to erosion depends on its composition. It often appears gradational into the underlying cream-colored finely crystalline Dyer Dolomite and into the overlying Leadville Dolomite.

**Leadville Dolomite**

In the Buckskin-Mosquito district only the lower Leadville was seen, and this principally in scattered outcrops. Without the presence of the Gilman Sandstone it would generally be indistinguishable from the upper Dyer.

The lower Leadville Dolomite is light to dark gray very finely crystalline, thin- to thick-bedded, moderately resistant to erosion, and commonly weathers buff brown to medium gray. Singewald and Butler (1941, p. 10) report the Leadville Formation in the Alma District to be 140 to 168 feet thick. Both Corn (1957, p. 21) and Brown (1962, p. 24) note that on Mount Bross, just north of the area studied, the Pennsylvanian Minturn Formation was deposited on a strongly eroded karst-type upper Leadville surface.

**Laramide Igneous Rocks**

In the Buckskin-Mosquito district intrusive rocks occur as sills and dikes, commonly several tens of feet thick, throughout the stratigraphic section (see district geologic sections, Plate 2). These rocks are quartz monzonite to
diorite in composition and are part of what Singewald and Butler refer to as the "Gray porphyry group" (1941, p. 16). These units were originally examined by Emmons (1886, p. 74-89, 323-343) and more closely studied by Patton, Hoskin and Butler (1912, p. 74-91). Near Leadville, several miles to the southwest, age dating of intrusives which are both older and younger than the units under consideration indicates that these rocks are between 64 and 70 million years old (Pearson et al, 1962, p. 79). As Pearson notes (p. 80), this is early Tertiary by the 1959 time scale of Holmes, or late Cretaceous according to Kulp's 1961 time scale.

In hand specimen 4 types of porphyry can be distinguished. Since these result in mappable lithologic units, the recognition of which is of economic importance, a field classification has been used on the district geologic map and sections (Plates 1 and 2). Under the microscope differences between these rocks become less distinct and only two basic types are distinguished. These are the diorite porphyry (under which the hornblende feldspar porphyry will be discussed) and the granodiorite porphyry (under which the 3 quartz feldspar porphyries will be described).

**Diorite Porphyry**

The diorite porphyry, called "hornblende feldspar porphyry" for mapping purposes, occurs as a sill 10 to
40 feet thick in the Sawatch Quartzite throughout almost the entire area investigated. In hand specimen it is typically a medium to dark gray rock with black, shiny hornblende prisms 1 to 5 mm. long and stubby white plagioclase phenocrysts of about the same size -- in a dark greenish-gray groundmass. Biotite crystals of similar dimension are often sparsely present, while quartz is seldom seen. The hornblende is often oriented in a plane parallel to the contact of the sill and the Sawatch Quartzite, although it exhibits no definite lineation. The rock weathers dark gray to medium brown, partly due to the development of limonite. In both hand specimen and thin section it is commonly the least altered of the porphyries mapped; near mineralization in the Buckskin Joe Mine, however, it is as markedly altered as the other igneous rocks.

In thin section (Figure 4) the plagioclase phenocrysts are slightly to moderately sericitized subhedral calcic andesine grains (An$_{45}$ to An$_{50}$) commonly making up about 15 percent of the rock. Another 15 to 20 percent consists of slightly chloritic and epidotized subhedral hornblende phenocrysts, while lightly chloritized biotite crystals make up about 5 percent of the rock. The groundmass is a very fine grained intergrowth of hornblende, orthoclase, sodic plagioclase, minor quartz and biotite. Accessory minerals are magnetite,
apatite, zircon and sphene. In addition to alteration
already noted, leucoxene occurs as an alteration product of
hornblende and biotite. Patton, Hoskin and Butler (1912,
p. 89) report that allanite has been found in this rock type
although none was seen in the present investigation. Carbonate
and quartz are relatively common components along permeable
zones in the sill. Pyrite is often present, although its
origin is uncertain. Texturally the rock must be described as
porphyritic.

This rock was termed "porphyrite" by Emmons (1886,
p. 589), "hornblende diorite porphyrite" by Patton, Hoskin and
Butler (1912, p. 87) and "monzonite diorite porphyry" by
Singewald and Butler (1941, p. 19). A chemical analysis by
Hillebrand (Emmons, 1886, p. 589) shows the following per-
centages: SiO₂ = 56.62, Al₂O₃ = 16.74, Fe₂O₃ = 4.94, FeO = 3.27,
CaO = 7.39, MgO = 4.08, K₂O = 1.97, Na₂O = 3.50. Thus, both
mineralogically and chemically this rock seems correctly
referred to as a "diorite porphyry" in the area investigated.

**Granodiorite Porphyries**

Rocks classified as granodiorite porphyry occur as both
sills and dikes and include the 3 varieties of quartz feldspar
porphyry noted on the accompanying geological maps. In hand
specimen they vary in color from greenish-gray through gray-brown, buff-pink and light gray, depending on extent of alteration. They are distinguished on the basis of size of quartz phenocrysts, color, texture and the phenocrysts present other than quartz and feldspar.

The "quartz feldspar porphyry" contains minor biotite phenocrysts (as well as quartz and feldspar), and rarely a few altered hornblende crystals. It is distinguished by the size of its quartz and feldspar phenocrysts which are 2 to 12 mm. in diameter, often averaging about 6 mm.; quartz and feldspar phenocrysts in the other granodiorite porphyries are approximately 1 to 2 mm. in diameter. This porphyry is of economic interest principally because of its lower contact with the Sawatch Quartzite which is locally referred to as the "Orphan Boy Contact". Gold and silver mineralization in pyrite occur where this contact is cut by northeast trending faults in the Orphan Boy Mine, in the Union Mine, and at the original Phillips Lode discovery of the Buckskin Joe Mine. The lack of recognition of this feature led Patton, Moskin and Butler (1912, p. 121) to erroneously suggest that the lowermost porphyry sill on the south face of Loveland Mountain is the same as the lowermost sill on the north face of the mountain.
The "quartz feldspar hornblende porphyry" is distinguished by its dark and light coarse "salt and pepper" texture and by the fact that hornblende is a major constituent of the phenocrysts while biotite is rare. In the other two granodiorite porphyries hornblende is not nearly as abundant, and often not seen. This rock type occurs only as a sill and a dike on the south side of Loveland Mountain.

The distinguishing features of the "quartz feldspar hornblende biotite porphyry" have thus been indirectly stated. Its features are, the small size of its quartz and feldspar phenocrysts, the lack of a coarse salt-and-pepper texture, and the biotite and hornblende phenocryst content (each averaging 3 to 10 percent of the rock). This rock type makes up the lowest sill on the south face of Loveland Mountain, the uppermost sill on the mountain, the porphyry dikes in the Buckskin Joe Mine and the dike north of the Shelby Mine.

In thin section, in all the granodiorite porphyries, it is uncommon to find feldspar phenocrysts which have not been highly to completely sericitized. In the freshest specimens the feldspar phenocrysts consist of calcic andesine (An$_{45}$ to An$_{50}$). Quartz phenocrysts are commonly rounded, clear, relatively strain-free grains, often with deep embayments, and partially replaced by sericite (Figure 5). Biotite and
Figure 4

Photomicrograph of a thin section of hornblende felspar porphyry showing relatively fresh condition of rock (hb = hornblende, and. = andesine).

Figure 5

Photomicrograph of a thin section of quartz feldspar porphyry illustrating sericite replacement of quartz (q = quartz, ser. = sericite).
hornblende vary from moderately chloritized and sericitized to so strongly altered that only ghost outlines remain. As a generalization it may be noted that these porphyries, when fresh, have an approximate phenocryst content of quartz 5 to 20 percent, plagioclase 10 to 30 percent, biotite 0 to 15 percent and hornblende 0 to 20 percent of the rock.

Accessory minerals include sphene, apatite, magnetite and zircon. The fresher specimens examined indicate an original groundmass of quartz, orthoclase, sodic plagioclase and minor hornblende and/or biotite. Alteration minerals include chlorite, sericite, carbonate, epidote, pyrite, magnetite and leucoxene. In addition, a more albite plagioclase seems to result when the rock is strongly altered. Texturally the rock is porphyritic; it also often exhibits poikilitic texture.

These rocks have been termed quartz monzonite by Singewald and Butler (1941, p. 19) who also note that they vary in composition from quartz monzonites to granodiorites. Within the limits imposed by the prominent alteration in the area these names seem valid. Because of the calcic nature of the plagioclase, and to emphasize what appears to be a close genetic relationship to the diorite porphyry, the term "granodiorite porphyry" seems most applicable to these rocks.
Relative Ages and Possible Genesis

The weight of the evidence available indicates that there is no clear-cut sequence in the development of the various porphyry bodies but rather that faulting and the injection of the porphyry units occurred at essentially the same time. In the following description of evidence it is convenient to refer to the porphyries by initials. Following the descriptions a summary is provided, out of necessity.

Section A-A' (Plate 2) shows the geology exposed on the south face of Loveland Mountain. An examination of displacements along the Cooper Gulch thrust fault shows the QFHP sill to be displaced considerably less than the other 3 sills in this section, indicating that it was injected into this particular area later than the other 3. However, in the hanging wall of this thrust is a northeast trending normal fault along which the sedimentary units are displaced about 10 feet, the HFP sill displaced not at all, and the other 3 units moved approximately 8 feet, indicating that the HFP sill was injected into this particular area later than the other 3. Thus, these 2 faults, only 1,000 feet apart, suggest a reversal in age relations of 2 porphyry sills.

Singewald and Butler (1941, geological map), on the north side of Buckskin Gulch, noted where QFP (or QFHP) cut
a sill of HFP; this is certainly not in agreement with relations on the south side of Loveland Mountain. Nearby Corn (1957, p. 46) describes HFP cutting either QFP or QFHBP, which would agree with evidence seen to the south. In the Buckskin Joe Mine, the QFHBP may cut both the HFP and the QFP, although good contacts were never seen. In the sill of gray QFP on the north side of Loveland Mountain a large swirl of what appears to be pink-buff QFHBP was found, suggesting a simultaneous semi-molten condition for these lithologies when the QFHBP was forced into the QFP sill.

In the Buckskin Joe Mine bedding plane thrusts commonly displace northeast trending normal faults, and both displace the dikes and sills in the mine. Although this was often found to be true in surface mapping, it was not always the case. Northeast trending faults were observed displacing thrusts, and also being cut by porphyry injections. Thus, the evidence seems to indicate that faulting and injection of the different porphyry sills and dikes proceeded at essentially the same time. A summary of the preceding evidence is shown below ( < means "younger than").
Location
Cooper Gulch Ft. (S. Loveland Mt.)
Ft. in N.W.
N. side, Buckskin Gulch
" " " "
Buckskin Joe Mine
N. Loveland Mt.

Sequence
QFHP < HFP, QFP, QFHPB sills
HFP < QFHP, QFP, QFHPB sills
QFP or QFHPB < HFP sills
HFP sill < QFP or QFHPB dike
QFHPB dikes < ? QFP, HFP sills
QFP < QFHPB (magma mixing in same sill)

Thrusting and normal faulting are ore-, contemporaneous with-, but dominantly post-porphyry injection.

As previously suggested, the mineralogy of the porphyries suggests that they are closely related genetically. The question then must be -- how could units with the differences these possess be injected, often into the same sedimentary formation, during several pulses from the same magma? In other words, is it reasonable to expect an HFP derivative from a magma, then a QFP, then another HFP injection into the original HFP sill? Clearly this is not sensible. It seems more feasible that a magmatic source injected igneous material into the lower Paleozoic section some distance from the area investigated. (An obvious source may be the magma which formed the Buckskin Gulch granodiorite stock several miles to the northwest, although these sills seem to thicken to the east
rather than to the west!) During Laramide tectonic activity this material may have been squeezed and squirted toward the thesis area in pulses, acquiring different features depending on the rocks through which it passed. Such an origin could account for the close relationship between tectonics and porphyry injection and explains how one sill can appear to have developed before another in one area, but after it a short distance away. This also could explain the mineralogical and textural differences (e.g. rounded quartz grains of either large or small size) in the porphyries, which result in separately mappable units.

It has been suggested, by Singewald and Butler (1941, p. 20), and others, that the widespread alteration characteristics of the sills are principally the result of deuteric and hydrothermal end-phase processes, perhaps originating from solutions within the cooling porphyry itself. Corn (1957, p. 52) also suggests probable chemical interaction between the magma and the host as another cause for this alteration.
STRUCTURAL GEOLOGY

Structural relations in the Buckskin-Mosquito area and surroundings have been previously described by Emmons (1886, p. 128-133, 524-529); Patton, Hoskin and Butler (1912, p. 32-35, 93, 118-127); Singewald and Butler (1930, p. 304-307 and 1941, p. 22-27); Behre (1953, p. 60-87); Corn (1957, p. 54-58) and Brown (1962, p. 37-40). The existing structural features are principally the result of Laramide tectonics and intrusion, probably controlled to a considerable extent by Precambrian structural trends. Badgley’s tectonic analysis of central Colorado (1960) suggests that the Laramide stress application for this region was approximately from a N 80° E direction.

Regional Structure

The Buckskin-Mosquito District of central Colorado lies in the northern portion of the Mosquito Range and within the eastern margin of the Colorado Mineral Belt. This is a northeast trending zone, 10 to 15 miles wide extending approximately 250 miles from Durango in the southwest to Boulder in the northeast (see map accompanying Vanderwilt, 1947). It cuts the north-south fabric of central Colorado and is defined
by numerous mining camps, northeast trending faults, and small Laramide intrusives and extrusives.

Structurally the district occurs in the South Park region of eastward dipping thrust and reverse faults. Approximately 30 miles to the west of the thesis area is the north-northwest trending axis of the Sawatch anticlinal uplift; this is reflected on the property by the dip of the strata at 15° to 20° to the east. Roughly 40 miles to the east is the axis of the north-northwest trending Front Range anticlinal uplift (Curtis, 1960, p. 1) compression from which apparently resulted in the eastward dipping thrust faults in the district. South Park, a structural and topographic basin, is directly east of the thesis area. These and other features of the regional structural setting are noted on Figure 6.

Several miles west of the thesis area is the north-south trending Mosquito fault, the largest nearby fault of regional influence. This is a high angle fault along which Paleozoic units on the west butt against Precambrian rocks on the east. Although the relative movement on the fault is commonly thought to be "east side up", Bloom, from a structural analysis of the Mosquito Range, feels there have also been important right lateral strike-slip movements (1964, personal communication).
Figure 6: Regional structural setting of the Buckskin-Mosquito District (Modified after Curtis, 1960, p. 1)
A mile southwest of the thesis area is the north-northwest trending, eastward dipping London reverse fault which joins the Mosquito fault as shown on Figure 6. This fault, with a displacement of several thousand feet, has been described in detail by Singewald and Butler (1941, p. 23-27) in their discussion of ore deposits associated with it.

Extending into the thesis area is the Cooper Gulch fault, a low angle thrust which will be described in detail in the following section.

Local Structure

Faulting

The dominant structure of the area investigated is the Cooper Gulch thrust fault, illustrated on Plates 1 and 2. This fault enters the southern part of the area as a single fault striking approximately north-south and dipping 30° to the east. It breaks into 3 minor thrusts on the south face of Loveland Mountain (section A-A') dipping at 20°, 25° and 30° as shown. Only the branch dipping at 30° stays within the area investigated, and crosses the mountain with a strike varying from north-south on the southern face to roughly north 50° east on the northern face. In addition, the amount of displacement it causes decreases to the north, indicating
that the fault is dying out. The stratigraphic displace-
ment on the south side of Mosquito Gulch due to this fault
is approximately 400 feet; on the south side of Loveland
Mountain it is 300 feet, whereas toward the north face it is
less than 100 feet.

Cutting across the property are a series of steeply
dipping normal faults commonly striking between north 20°
east and north 50° east (Plates 1 and 2). These faults,
with displacements generally between 1 and 40 feet, are the
zones along which mineralization occurs. Underground mapping
indicates that such northeast trending faults, with displace-
ments of at least an inch, occur approximately every 30 feet
measuring in a northwest direction. Thus, on the surface
geological map only those faults with a significant displace-
ment and which can be traced for a considerable distance are
plotted. Among these are the productive faults of the
Buckskin Joe Mine which have been traced to the Orphan Boy
system of faults and veins to the southwest. The regular
spacing of these faults suggests that the sediments acted as
a rather homogeneous unit during faulting.

It is important to note that in general these faults
were seen only on the north and south faces of Loveland
Mountain and in mine workings. Over most of the area,
however, they contained sufficient water with dissolved salts, plus perhaps disseminated pyrite, to act as weak electrical conductors. Thus, it was possible to trace them by an electromagnetic survey (Plate 3) using an AEM two-man E.M. Gun. Known mineralization along faults also responded as weak electrical conductors, probably because the abundance of dolomite and sphalerite in "ore" preclude the existence of good conductors. The E.M. Gun detects electrical conductors by making use of the principle that when a conductor is subjected to an alternating electromagnetic field, a current is induced in the conductor. An analysis of the resultant field indicates the presence, and to some extent the type of conductor detected. Corrected readings and interpretations are shown on Plate 3. Interpretation procedures are detailed in the manual accompanying the instrument.

Only a very few examples of faults other than the thrust and northeast trending varieties were seen, e.g. the porphyry dikes in the Buckskin Joe Mine which strike north 20° west and dip steeply to the west must have been injected into some type of break. The details of relationships among the different types of faulting and porphyry injections were discussed in a previous section. In summary, the field evidence shows (a) that the porphyry bodies were injected at essentially the
same time relative to one another, (b) that some thrusting and normal faulting occurred before and during porphyry injection, although most of it was later, and (c) that although much of the normal faulting is post thrusting, the opposite was often noted.

Folding

Drag on the Cooper Gulch thrust fault has resulted in the drag folding and overturned beds and sills shown on the upper thrust plate in section A-A', Plate 2 and in Figures 7 and 8. On the south face of Loveland Mountain these folds have a width, measured on the horizontal, of roughly 300 feet, consisting of a steep to overturned western limb and a horizontal to gently dipping eastern limb. Although minor drag occurs where the thrust is seen on the north side of the mountain, the extensive accompanying folding is absent. Patton, Hoskin and Butler refer to the thrust zone as the "Mosquito Gulch fold-fault" (1912, p. 121), while Singewald and Butler (1941, p. 23) term it the "Cooper Gulch fault".

Cooper Gulch is a draw just north of the south face of Loveland Mountain which drains much of the mountain slope (see topographic map, Plate 4). Emmons (1886, p. 130) suggested that the Gulch exists because it is approximately on the axial line of a minor syncline plunging gently to the
east. Bedding attitudes on the western portion of the property somewhat support this suggestion (see Plate 1), although nowhere else can it be confirmed. However, once a drainage begins in a structural feature such as a syncline, it is obviously not axiomatic that the drainage stay in that structure.

Minor folding is caused in the sedimentary strata by the pinching and swelling of porphyry sills, e.g. the quartz feldspar porphyry sill in geological section D-D'. In the Buckskin Joe Mine slight folding with a northwest trending axis can be seen on the longitudinal geological sections of Plates 23 and 24.

Other Local Structure

The strongest joint trends in the area are approximately northeast and northwest while a weaker set has a north-south strike. All are steeply dipping.

Foliations in the Precambrian schists and gneisses commonly strike west to northwest, with steep dips. However, there are many deviations from this, both in this area and in Precambrian rocks exposed to the west.

Bedding attitudes on the property vary in strike from north-south to north 60° east, and in dip from 10° to 25° to the east. The average bedding attitude is approximately north 34° east, 17° east.
Figure 7

View of the Cooper Gulch thrust fault and the stratigraphic section repeated by it, looking northwest.

Figure 8

Closeup view of drag folding against fault plane of Cooper Gulch fault, looking north.
**Laramide Structural History**

The regional and local evidence presented suggests that during Laramide tectonism the Sawatch uplift to the west imparted the general easterly dip to the strata of the Buckskin-Mosquito district. Compression from the direction of the Front Range uplift on the east initiated low and high angle thrusting in the South Park-Mosquito Range region.

With the initiation of thrusting, dilatent tendencies existed along zones of weakness (e.g. bedding planes) of lower dip than incipient thrust faults. These dilatent zones provided natural avenues for the injection and transport of magma known to exist, and to be intruding into nearer-surface portions of the Colorado Mineral Belt, at that time. Thus, the sills in the area may be the result of tectonic pulses squeezing and squirting magma along bedding plane zones into the Buckskin-Mosquito District, attempting to relieve tectonic pressure. When the porphyry sills were nearly solidified, pressure release by thrusting on the already initiated thrust planes could have occurred. Shear planes of weakness may have formed in a northeast direction during the stress buildup prior to thrusting. With pressure release after thrusting, these planes of weakness would then
have been available for release fracturing, particularly on the upper thrust plates, which resulted in the northeast trending normal faults of the district.

Such a picture is consistent with evidence from porphyry sills, faulting, folding, jointing and bedding attitudes noted above. The dominant Precambrian foliation trends were almost certainly in existence in Precambrian time.
SOIL GEOCHEMISTRY

The purpose of the soil sampling phase of the program was to investigate the mobility and dispersion of the ore metals (zinc, lead, silver and copper) over veins in a calcareous and siliceous high-mountain environment. Molybdenum was also determined because its behavior in soils often complements that of copper.

Samples were taken at 200 foot intervals on lines spaced 200 to 400 feet apart, (as shown on Plates 4 to 9). Dried, minus 100 mesh soil fractions were analysed by a rapid burn (10 seconds) D.C. arc procedure, at 15 amperes, on a Baird 3 meter spectrograph. The spectra were interpreted by visual comparison with standard samples on an A.R.L. comparator-densitometer with a magnification of 20. An analytical accuracy and precision within ±40 percent of the values obtained was found to be satisfactory.

The soil of the area is a thin (several inches to several feet) juvenile high-mountain soil with little horizon differentiation. It consists of a surface layer (Å₇) of partially decomposed organic debris several inches thick underlain by partially weathered rock debris. The Å₇ horizon
becomes slightly thicker below treeline. According to Hawkes and Webb (1962, p. 113), "such skeletal soils are known as lithosols and rightly belong to the asonal group (of soils)."

Orientation surveys showed the elements of interest to increase slightly in value with decreasing mesh size of soil from minus 35 to minus 100 mesh; in addition, comparisons from one soil to another are more consistent with finer grain size. At mesh sizes of 200 and less it was often difficult to obtain an adequate amount of soil for study, so the minus 100 mesh fraction was used for the soil geochemical work.

**Mobilization and Fixation of Elements**

In the Buckskin-Mosquito District ore is found associated with northeast trending faults in the Sawatch quartzite and in the Peerless and Manitou carbonates (limestones and dolomites). The principal minerals in a "typical" ore body are gold-bearing pyrite, sphalerite, silver-bearing galena, dolomite and lesser amounts of chalcopyrite and barite. Due to the moist summer climate, oxidation of the pyrite occurs, which releases sulfuric acid. The other sulfides are unstable in a low pH environment and break down, releasing the ore elements to form soluble cations or complexes, the exact nature of which is
incompletely understood (Hawkes and Webb, 1962, p. 114-120). However, they note (p. 120) that strongly acid conditions favor the occurrence of the metals as simple cations.

These solutions move downslope in a soil developed over carbonate wallrock in much of the area. As neutralization and dilution occur, the elements react with other components of the aqueous system and probably form insoluble chlorides, sulfates and carbonates. Evidence for this is that in calcareous terrains it was found that a mobility series existed for the 5 elements, as follows:

(most mobile) \( \text{Zn} > \text{Mo} > \text{Pb} > \text{Ag} > \text{Cu} \) (least mobile)

This series corresponds closely to the solubilities of the common secondary minerals of these ores, as shown below (excluding Mo, since comparable solubility data could not be found for its secondary minerals).

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Element</th>
<th>ppm of element in saturated aqueous solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>AgCl (Cerargyrite)</td>
<td>Ag(^+)</td>
<td>1.5 (at 25°C)</td>
</tr>
<tr>
<td>( \text{CuCO}_3 \cdot \text{Cu(OH)}_2 ) (Malachite)</td>
<td>Cu(^{++})</td>
<td>12 (at 20°C and 0.29 gm. CO(_2)/l.)</td>
</tr>
<tr>
<td>2( \text{CuCO}_3 \cdot \text{Cu(OH)}_2 ) (Azurite)</td>
<td>Cu(^{++})</td>
<td>7 (at 20°C and 0.34 gm. CO(_2)/l.)</td>
</tr>
<tr>
<td>PbCO(_3) (Gerussite)</td>
<td>Pb(^{++})</td>
<td>1.3 (at 18°C)</td>
</tr>
<tr>
<td>( \text{ZnSO}_4 ) (Anglesite)</td>
<td>Pb(^{++})</td>
<td>27 (at 18°C)</td>
</tr>
<tr>
<td>ZnCO(_3) (Smithsonite)</td>
<td>Zn(^{++})</td>
<td>107 (at 18°C)</td>
</tr>
</tbody>
</table>

(Abstracted from Hawkes and Webb, 1962, p. 120)
It should be noted that the solubility of Cu\textsuperscript{2+} decreases rapidly with increasing CO\textsubscript{2} content of the solution; in the carbonate environment it seems reasonable to expect a greater amount of CO\textsubscript{2} in the groundwater, thus decreasing the solubility of Cu\textsuperscript{2+} to less than that of Ag\textsuperscript{2+} and resulting in a series which exactly corresponds with the mobility series. Although some adsorption of these elements probably occurs on clays and iron oxides, the principal patterns appear to be due to the formation of secondary minerals.

In the siliceous environment (Sawatch Quartzite) the mobility series is somewhat the same, although mobility differences among the elements are not as striking as above. Since the quartzite occurs downslope from the carbonate, it is likely that the soil chemistry over quartzite is strongly influenced by the carbonate environment. The mobility sequence in the siliceous environment is as follows:

(most mobile) Mo, Zn, Pb > Ag, Cu (least mobile)

A special environment on the property is a muskeg-type swamp east of the Orphan Boy portal. The only element which seems highly influenced by the swamp is molybdenum, which forms a strong anomaly in the swamp. An explanation is
provided by Vinogradov (1959, p. 158) who indicates that this element is commonly fixed by organic matter.

Results

1. Trends occurring on the geochemical survey maps (Plates 5 to 9) show a good correlation with the northeast trending mineralized faults. The fact that these faults are often outlined by rows of prospect pits (Plate 1) does not affect conclusions on mobility in the different bedrock environments.

2. The dispersion patterns below mine dumps and prospect pits are not as great as might be thought. Depending on pyrite content (and thus acidity of the mine water), amount of sulfide mineralization, and country rock lithology, dispersion patterns extend from zero to 400 feet downslope from mine dumps.

3. The 5 elements studied have essentially background values over the Buckskin Joe Mine. The explanation for this may be that the lithologic section over the mine is too thick for much upward migration of elements along faults to occur. Of equal importance is the fact that much of the drainage in the area passes down the mineralized faults, through the Mine, and out the portal, thus leaching, not enriching the soil above the Mine. Hawkes and Webb note a
number of related examples (1962, p. 131, 135, 156) of such underflow.

4. The general lack of anomalies over the upper sill of quartz feldspar hornblende biotite porphyry suggests that mineralization did not often extend up into this unit.

5. Climate, relief and geology seem to be the strongest factors influencing dispersion patterns in the soil. The fact that the area has abundant glacial till below 11,100 feet, and that treeline exists at 11,500 feet, did not seem to influence the results.

6. Relative mobilities of the ore elements in the soil have been determined and are detailed in the previous section.

7. The following table summarizes the analyses derived from the soil geochemical survey and compares them with analyses of ore-bearing and barren veins, and country rock, on the property. Figures on the amounts of these elements in average limestones, sandstones and soils (Hawkes and Webb, 1962, p. 359-377) are included for general reference. A comparison of values in this table (all in ppm) shows the close relationship between country rock and the soil above it, and veins and the anomalous values associated with them.
<table>
<thead>
<tr>
<th></th>
<th>Zn</th>
<th>Mo</th>
<th>Fe</th>
<th>Ag</th>
<th>Cu</th>
</tr>
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<tbody>
<tr>
<td>Strong ore veins</td>
<td>150,000</td>
<td>&lt; 30</td>
<td>50,000</td>
<td>100</td>
<td>10,000</td>
</tr>
<tr>
<td>&quot;Barren&quot; veins</td>
<td>1,000</td>
<td>&lt; 30</td>
<td>500</td>
<td>10</td>
<td>50</td>
</tr>
<tr>
<td>Background in wallrock</td>
<td>50-100</td>
<td>&lt; 10</td>
<td>50-100</td>
<td>0.5-1.0</td>
<td>20-50</td>
</tr>
<tr>
<td>Background in soil</td>
<td>150</td>
<td>0.5</td>
<td>50</td>
<td>1.0</td>
<td>50</td>
</tr>
<tr>
<td>Threshold in soil</td>
<td>500</td>
<td>1.0</td>
<td>100</td>
<td>3.0</td>
<td>100</td>
</tr>
<tr>
<td>Strong anomalies in soil</td>
<td>10,000</td>
<td>4.0</td>
<td>1,000</td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td>Average LS and SS</td>
<td>5-20</td>
<td>0.1-1.0</td>
<td>5-40</td>
<td>0.2-0.4</td>
<td>5-40</td>
</tr>
<tr>
<td>Average soil</td>
<td>10-300</td>
<td>0.2-5</td>
<td>2-200</td>
<td>0.1</td>
<td>2-100</td>
</tr>
</tbody>
</table>

**Conclusions**

It has been found that the distribution and mobility of elements in soil on the property is directly related to the underlying veins and country rock. Dispersion patterns have also been influenced, both physically and chemically, by relief and climate.
ORE DEPOSITS OF THE BUCKSKIN JOE MINE

The Buckskin Joe Mine, also known locally as the Phillips Mine, is on the south side of Buckskin Gulch, 2 miles west of the town of Alma, in the northeast quadrant of the thesis area (Plate 1). The portal is located well below timberline, at 10,870 feet. Approximately 3 miles of workings are accessible in the mine, most of which were developed between 1936 and 1957. Total production from the property during its intermittent producing period from 1860 to 1957 has been between 30,000 and 50,000 tons with a gross value of several million dollars at today's prices.

Geologic Setting

The geologic setting of the mine and ore is illustrated on district cross section D-D' (Plate 2), mine cross sections 1-1' to 9-9' (Plate 21), mine longitudinal sections (Plates 23 and 24) and on the map of mine workings (Plate 20). Detailed aspects of the deposits are shown on the underground maps of Plates 10 to 19.

Mine sections 1-1' to 9-9' clearly show that sulfides occur along steeply-dipping, northeast trending normal faults and in strataform zones associated with them. Although
mineralization occurs along these faults in variable amounts throughout the stratigraphic section, most of it is concentrated in an 80 foot thick zone constituting the Peerless and lowermost Manitou Formations.

**Distribution and Size**

Excluding the oxidized gold ore of the original discovery, there were 25 lodes recovered from the mine (Plate 20). These ranged in tonnage from 100 to 4,400 tons, averaging about 1,000 tons per deposit. An average ore body would approximate 70 feet in length, 5 feet in width and 30 feet in height. Of the 25 deposits, 2 were in the Sawatch Quartzite while 23 occurred in the Peerless and/or lower Manitou Formations.

**Mineralogy and Grade**

A typical vein along a fault consists of interlaminated sheets of sulfides and white dolomite, each 1 to 6 inches thick, approximately parallel to the fault plane. On a more detailed scale the sulfides are found to consist of very coarse- to fine-grained masses of pyrite and dark-colored sphalerite, with variable (but generally minor) amounts of galena and chalcopyrite. These cut, and are cut by, dolomite stringers from adjacent sheets. Although sheeting is not
Figure 9
General view of portal area of Buckskin Joe Mine, looking southwest.

Figure 10
General view of portal area of Shelby Mine, looking southwest.
always present, it is a common feature of the veins and implies successive waves of mineralization separated by periods of movement on the fault plane. Contacts with quartzite and carbonate wallrock are sharp.

Associated with the veins (often in the hanging wall) may be zones several inches to several feet thick where carbonate beds have been replaced by the sulfides described. Such a zone may have a minor bedding plane fault passing through or above it.

A mineralogic examination of the vein material shows an early stage of quartz appearing as finely crystalline encrustations on the walls of fractures. This was commonly followed by dolomite filling in cavities, although several reversals of this order were noted. (Dolomite also apparently was deposited intermittently throughout the time of deposition of the sulfides.) Following a period of fracturing, pyrite (FeS₂) was introduced, followed by more fracturing. Sphalerite (ZnS) was then deposited which both replaces and fills fractures in the pyrite. Where chalcopyrite (CuFeS₂) is found it occurs associated with and often exsolved from high iron sphalerite (Figure 9), indicating a temperature of formation above 350° to 400°C (Park and MacDiarmid, 1964, p. 46, 200). Galena (PbS) was deposited with, and later than, sphalerite,
Figure 11

Photomicrograph of a polished section illustrating the exsolution of chalcopyrite (cp.) from sphalerite (sp.).

Figure 12

Photomicrograph of a polished section illustrating the fracture filling of pyrite (py) by argentiferous galena (gal).
sometimes replacing or filling fractures in both sphalerite and pyrite (Figure 10). Minor reversals in sulfide paragenesis were noted, possibly due to repeated fracturing and ore influx, as suggested by sheeting. No gold was seen, although assays of pyrite suggest it occurs in submicroscopic distribution in the pyrite. Similarly, spectrographic analyses indicate the principal source of silver to be galena.

Of the secondary minerals noted, melanterite \( (\text{FeSO}_4 \cdot 7\text{H}_2\text{O}) \) and chalcanthite \( (\text{CuSO}_4 \cdot 5\text{H}_2\text{O}) \) were observed along veins while mapping; in thin section, smithsonite \( (\text{ZnCO}_3) \), cerussite \( (\text{PbCO}_3) \) and possibly anglesite \( (\text{PbSO}_4) \) were noted in very small amounts, below ore, in carbonate.

For a typical ore body in the mine the following grade is estimated: \( \text{Zn} = 10-20\%, \text{Fe} = 0-5\%, \text{Cu} = 0-1\%, \text{Ag} = 0-5 \text{ oz./T}, \text{Au} = 0-0.5 \text{ oz./T.} \) At today's prices (February, 1965) these figures indicate ore with a gross value of roughly $330 to $100 per ton.

**Mineralogic Wallrock Alteration**

In quartzite wallrock, chlorite is the most common alteration product. It often is more abundant where mineralization is strong; however, this is not a very reliable guide to mineralization since the abundance of chlorite also seems
dependent on how impure the quartzite was before alteration processes became active. Kaolinite and sericitization were also noted, principally in gouge zones.

Carbonate wallrock frequently shows chloritic and kaolin- itic alteration in argillaceous and shaly zones not particularly related to sulfides. Sericitization is common in the general vicinity of mineralization although examples were seen both where it increased in intensity over several tens of feet toward ore, and where maximum sericitization occurs where no ore is known.

Alteration of the porphyries near ore or near faults commonly involves sericitization of the feldspar phenocrysts, chloritization and/or sericitization of the biotite, chloritization and/or epidotization of the hornblende and corrosion of quartz. In addition, pyrite, magnetite and leucoxene are often developed in the altered ferromagnesian constituents. With intense alteration sericite becomes a dominant phase, commonly replacing portions of quartz phenocrysts. Although sericite is developed in the general vicinity of mineralization, there is generally no mappable buildup of it toward ore.

The above relationships were defined both in hand specimen and in thin section; the thin sections were also necessary to quantify the amounts of each type of alteration mineral and to relate these to chemical analyses.
Ore Controls

In the Buckskin Joe Mine there are a number of features to which ore is empirically related. These may be conveniently grouped as structural and petrochemical features.

Structural Features

1. Ore occurs principally as fracture fillings along northeast trending, steeply dipping normal faults and, to a minor extent, as replacements in adjacent carbonates.

(a) The most striking structural relation of these faults to ore is the fact that their dips often become steeper by 10-20° in the lowermost Manitou and Peerless Formations (see mine sections, Plate 21), then revert to original dip (averaging about 70°) in the Sawatch quartzite. A glance at the stratigraphic section in Figure 3 shows this Peerless-Manitou zone to consist of 80 feet of interbedded calcareous sandstones, dolomitic limestones, and shales. The occurrence of this unit between massive carbonate above and massive quartzite below results in refraction steepening of fault planes passing through it. Normal faulting would then tend to dilate or open this steep portion, making it a favorable location for the deposition of ore.
(b) A feature that may be related to dip steepening is the "double fault" phenomena. Where ore or strong mineralization occurs, 2 or more planes of movement several feet apart, almost invariably are found. Where no ore is found, or mineralization is slight, the fault ordinarily has just one plane of movement. This feature may be due to spalling of 1 wall of a fault into a dilatant zone, as noted above; it might also be due to the repeated fault movements which resulted in vein sheeting.

(c) Changes in strike along faults also are related to ore, as clearly seen on the Keytest level, below ore, at co-ordinates 13,860E, 14,430E and 14,000N, 14,500E. Strike-slip movement along these faults has probably caused the large vertical dimension of these particular deposits (70 feet and 40 feet), as illustrated on the longitudinal geologic section of the Pyrite Vein (Plate 23) at nine sections 5-5' and 6-6'. Both right and left lateral strike slip movement of several feet to several tens of feet have been noted; it is apparently this movement which resulted in dilatancy.

(d) En echelon breaks often make up a fault zone; in certain locations these are spatially related to strong
mineralization (Keytest level, 14,400N, 14,420E) whereas in other areas this is not the case. As with changes in strike on a fault, this feature also results in low pressure areas for mineralization.

(e) Intersecting faults are related to ore in certain locations (Limonite level, 14,130N, 14,280E) and not in others. Such broken areas at fault intersections are common structural traps for ore.

2. Mine sections 1-1' to 9-9' (Plate 21) show that much of the ore occurs in a small graben structure formed by the northeast trending faults. District section D-D' (Plate 2) shows that this appears to be a collapse or tension zone on the upper plate of the Cooper Gulch thrust fault. The faults of this collapse zone have been traced to the Orphan Boy Mine to the southwest (see sections C-C', B-B', A-A'), although the graben form is not always as well exhibited as in the Buckskin Joe area. The principal relation of this structure to ore formation may be that it illustrates the general tensional environment of the upper thrust plate about the time ore was formed.

3. Bedding plane faulting (or shuffling) of several feet displacement occurs in the Peerless Formation, possibly initiated along shale beds which have relatively low resistance to such movement. As may be seen on Plate 20 (mine sections),
these commonly are the latest faults found, displacing both northeast faults and porphyry dikes. The fact that they are in the middle of the main lithologic environment for mineralization is probably not of very great importance to the overall mineralizing process, only to local accumulations. Mapping indicates that sulfides associated with these zones, as bedding replacements, begin at the northeast trending faults and work into the wallrock. The bedding plane faults may act as local rock conditioners (fracturing and dilatency) for ore.

4. It may be noted that, although the ore occurs on northeast striking faults, the ore bodies themselves form a northwest trending belt across the mine area. An examination of the longitudinal geologic sections on Plates 23 and 24 shows a slight synclinal warp with a northwest trending axis, passing through the center of the mineralized zone. This warp is so slight that it could be the result of cumulative errors in surveying, mapping and plotting. However, at present this is the only known geological anomaly associated with the northwest trend to the ore body locations. Further evidence for the existence of this synclinal warp may be the fact that the porphyry dike system, which parallels the synclinal axis, lies on the suggested anticlinal (and tensional) axis adjacent to it.
Petrochemical Features

1. The occurrence of ore in the Peerless and lowermost Manitou Formations is the strongest petrochemical control for the location of ore bodies in the mine. The fact that these are the earliest, and lowest, carbonates in the stratigraphic section has strong genetic implications with respect to precipitation of upward migrating mineralization. This will be discussed fully under "genesis of the ore deposits".

2. The general spatial relation of ore to porphyry dikes and sills may be seen on the geological sections of Plates 21, 23 and 24. Ore is never more than 110 feet from the hornblende feldspar porphyry sill, while the mineralized zone of the mine is transected by the quartz feldspar hornblende biotite porphyry dike system. Since ore is found in faults which displace porphyry bodies, the porphyry was emplaced before ore was formed.

Conclusions and Summary

The above discussion shows that ore occurs in the Peerless and lower Manitou Formations, along northeast trending faults, in a northwest trending synclinal warp. Any structural feature which results in dilatency in these carbonate strata can localize ore although changes in strike
and dip on the northeast faults seem most important. Ore is never more than 110 feet from porphyry.

**Geochemistry**

The objectives of investigating the distribution of elements in wallrock and ore in the Buckskin Joe Mine were as follows: (1) to ascertain geochemical patterns which are common to the deposits, (2) to synthesize this information with stratigraphic, structural and mineralogic data to postulate a genesis for the deposits.

Eight of the 10 levels in the mine were accessible. An orientation study was carried out involving the collection of 3 wallrock samples every 10 feet to ascertain the sampling interval required. It was found that in general a sample spacing of 1 sample every 10 to 20 feet reflected element patterns in the vicinity of mineralization. Samples were taken of all rock types and sulfides, in traverses both along and perpendicular to veins. For comparison purposes every attempt was made to take rock samples which were free of visible sulfides.

Rock samples were cleaned, pulverized to minus 100 mesh, and a representative split taken for analysis. Sulfide samples were treated similarly; in addition, as pure a pyrite
fraction as possible was removed by superpanning (mechanical panning for heavy minerals). Pyrite was further cleaned by the use of a Franz Isodynamic Separator. It was hoped that this would yield a pure pyrite sample for monomineralic comparisons throughout the mine, thus considerably reducing problems caused by varying mineralogy and attendant changing background values. This procedure yielded a sample containing approximately 99 percent pyrite; for trace element work it must be regarded as a pyrite concentrate. (Analyses of the ore elements are too high for substantial amounts of them to occur in solid solution in pyrite -- see Fleischer, 1955, p. 999-1008.) However, samples prepared in this manner had reproducible amounts of associated sphalerite, galena, chalcopyrite and barite. Mineralogic investigations indicated that grain size distribution of the minerals is approximately the same from one pyrite sample to another (probably the principal explanation for the comparability of the samples). The above, and comparison of the results with geology, suggested that the objectives of the monomineralic approach had been accomplished and that the study should be pursued.

Rock and sulfide samples were analyzed by a rapid burn (10 seconds) D.C. arc procedure, at 15 amperes, on a Baird
3 meter spectrograph. The spectra were interpreted by visual comparison with standard samples on an A.K.L. comparator- densitometer with a magnification of 20. An analytical accuracy and precision of ±40 percent of the values obtained was found to be satisfactory. Calcium and magnesium in carbonates were determined by digestion in hydrochloric acid and titration with EDTA as described by Bisque (1961). The accuracy and precision of this method are within ±1% of the value determined. Mercury analyses were accomplished by volatilizing (by heating) the mercury from a pulverized sample and analyzing it by atomic absorption on a Lemaire "Type S" mercury detector. This method has an accuracy and precision of approximately ±20 percent of the value recorded. Gold was determined by standard fire assay procedures.

Of the 30 elements routinely determined by the spectrographic procedure, there were 12 which generally occurred within the upper and lower detection limits of the method, and which yielded some type of pattern in wallrock about mineralization. These were Al, Pb, Cr, Ti, Zn, Ba, K, V, Ag, Mn, Sr and Cu. In addition, analyses for the most important major constituents, Ca and Mg, were carried out. Mercury was found to be related to base and precious metal mineralization,
and a number of wallrock and vein traverses were examined for this constituent.

Vein samples (pyrite in the vein, and wallrock within 5 feet of the vein) were examined in ore bearing and barren portions, principally for Zn, Pb, Cu and Ag in an attempt to trace the path these elements may have followed along the fault during original mineralization and perhaps during later weathering. Other elements were examined where there was a particular need for them. Along a vein with 2 stopes from which gold was extracted, gold assays were carried out for comparison and control.

Investigations of the distribution of elements in wallrock about ore have been carried out by many workers in the past hundred years. Among the earliest work was that by Sandberger, in the 1880's, in central Europe; his investigations led him to propose the theory of lateral secretion as a mechanism for ore formation. Hawkes and Webb (1962, p. 45-73) have adequately summarized much of the data presently available on the distribution of elements about ore.

**Distribution of Elements in Wallrock**

Plate 22 illustrates the distribution of elements, and the Mg/Ca and Ba/Sr ratios, in Peerless and Manitou carbonate
wallrock along traverses approximately perpendicular to ore. The locations of these traverses are shown on Plates 20 and 21. The elements are arranged on Plate 22 so that those with the best and most consistent response to ore are closest to the geologic cross section (Mg/Ca and Mg), while those with the poorest response are farthest away (Sr and Ca). All anomalies are positive, suggesting that their source was from the vein; no negative anomalies occur in the carbonates.

Possible explanations for the distribution of elements may be hypothesized as follows:

1. The Mg/Ca highs about ore seem to represent addition of Mg from the vein to the limestone wallrock and the consequent replacement of Ca to form calcitic dolomite; dolomite veining almost invariably occurs with sulfides and commonly in as great or greater amounts.

2. Mercury occurs in sulfides in the mine. Since it travels as a vapor, its distribution is considerably influenced by fractures. This may be the case on the Blue level X-cut where Hg anomalies occur in the hanging wall of mineralized faults, or near bedding plane faults leading to mineralization below. Another explanation for the shape of the anomalies is that the vein area was too hot during mineralization, and mercury
was driven into the wallrock.

3. Petrographic examination of rock samples along the X-cuts indicates that the Al highs are due to the total alteration mineral content developed in the wallrock about ore (sericite, chlorite, and kaolinite are all high in Al). The fact that these are related to ore, and not stratigraphy, may easily be seen by comparing the positions of Al anomalies on the 3 cross sections.

4. Anomalies in Cr seem directly related to the amount of chlorite noted in the samples in thin section; since Cr can be a constituent of chlorite, this relation seems sensible.

5. Similarly the K content of the wallrock is related to sericite alteration; K is a major constituent of sericite \( \text{KAl}_3\text{Si}_3\text{O}_{10}(\text{OH})_2 \).

6. Barite is frequently noted in the veins in minor amounts and probably is responsible for Ba highs about ore. The great similarity of the Ba and K anomalies, especially along the Blue X-cut, may, however, indicate their occurrence in the same mineral. Alternatively, they may have been derived from the same mineral, e.g. altered orthoclase.

7. The Ba/Sr ratio is an empirical relationship noted early in the program which often seemed to develop anomalies about ore. On this plate it can be seen that it mainly reflects
Ba while Sr remains relatively constant.

8. Titanium highs seem best related to leucoxene, noted only in thin section. Mn may proxy for ferrous iron; secondary manganese-bearing dendrites were often noted. V may substitute for ferric iron, although its mineralogical distribution is uncertain.

9. The ore elements, Pb, Zn, Ag and Cu, probably form anomalies as minute dispersions of sulfides. The fact that Ag and Cu do not form very extensive anomalies may be partly accounted for by their low amounts in the veins, and partly by their relative insolubility in the carbonate environment. It should be noted that these 4 elements exhibit approximately the same mobility in wallrock as they showed in soil above carbonate country rock. However, the weight of the thin section evidence suggests their occurrence in wallrock principally as sulfides, i.e. considerably more ore sulfides were seen than ore carbonates and sulfates.

It should be noted that carbonates of the Peerless and lower Manitou Formations are impure, generally with 20 percent or more non-carbonate minerals. This probably assisted migration of some of the elements and minerals into the wallrock since pure limestone ordinarily would be expected to stop diffusion of most of these elements from such small veins in a few feet.
The reasons for the differences in mobility among the various elements cannot be precisely defined. Indications are that the ore was emplaced at temperatures of at least 350° to 400°C from a supercritical aqueous fluid of unknown anion composition (see genesis below). The chemistry and pressure of this fluid would obviously be a strong influence in determining the distribution of elements in the wallrock.

**Distribution of Elements Along Veins**

Plates 23 and 24 illustrate the distribution patterns of elements along the Keytest and Pyrite vein systems. The locations of these longitudinal sections may be seen on Plate 20. The patterns of each element are detailed as follows:

**Zinc**

In pyrite concentrates from the veins Zn occurs in anomalous amounts in both the massive carbonate above and in the quartzite below stopes from which Zn ore was extracted. That is to say, the veins maintain a "Zn-in-pyrite" content that reflects ore grade Zn, although the vein itself may be very narrow and uneconomic. Although the mineralized nature of the vein is recognizable in mapping, the distinct relation of the anomalies in uneconomic veins to economic mineralization is interesting. The fact that these anomalous conditions extend
to surface samples of pyrite suggests that the distribution pattern is mainly primary. Secondary effects during weathering and pyrite oxidation would have decreased the Zn values near surface by dispersing ZnSO$_4$ in the groundwater system. Finally, the fact that the anomalies continue downward so strongly from existing workings has considerable import on genesis and path travelled by the mineralization.

**Zinc in wallrock** adjacent to veins reflects both ore and quartz feldspar hornblende biotite porphyry dikes on the Pyrite vein. In the Keytest vein system it reflects the margins of ore but not the porphyry dikes. In both zones the Zn anomalies extend from quartzite to carbonate wallrock without discontinuity. This suggests that the zinc was derived from the fissure in a form which was similarly susceptible to deposition in a siliceous or calcareous environment. On the Keytest system, values from the hornblende feldspar porphyry sill were not plotted because of its high Zn background. Nonetheless, adjacent quartzite did not reflect this porphyry sill as it did the porphyry dikes on the Pyrite vein. The Zn anomalies are open downward.

Comparing results from the pyrite and wallrock work, the effect of the monomineralic approach (pyrite sampling) is clearly shown on the Pyrite vein where wallrock anomalies
due to flooding from porphyry dikes are filtered out in the pyrite concentrate diagram. Also, it is interesting to note that highs in pyrite often correspond to lows in wall-rock, and vice versa. No obvious explanation is available; no depletion phenomena were noted about ore on Plate 22.

Copper

In pyrite concentrates, the Cu anomalies are almost identical to the Zn patterns, except that they do not reflect gold stopes on the Keytest vein. This similarity is due to the mineralogical association of chalcopyrite in sphalerite and results in Cu being a good indicator of Zn mineralization. Points already noted on "Zn-in-pyrite" are also applicable to "Cu-in-pyrite".

Copper in wallrock adjacent to veins exhibits quite different patterns than those in Zn. It reflects the margins of ore well, in both quartzite and carbonate, and its patterns are not as affected by porphyry dikes as the Zn patterns. Anomalies extend from quartzite to carbonate without discontinuity and are generally open downward.

A comparison of results in pyrite and wallrock again shows (as with Zn) that in detail, highs in pyrite are often lows in wallrock and vice versa, although both are anomalous in the vicinity of ore.
Lead

In pyrite concentrates, in gross aspect lead anomalies reflect known ore zones. In detail, however, there are often irregularities. This should not be unexpected since the principal ore formed and mined was sphalerite, while galena was of secondary importance.

Lead in wallrock adjacent to veins reflects ore and porphyry dikes on the Pyrite vein, and, in gross aspect, the margins of ore on the Keytest vein as well. Anomalies extend from quartzite to carbonate without much discontinuity and are commonly open downward.

Again, in detail, highs in pyrite tend to occur in the vicinity of lows in the wallrock, although both are anomalous in the vicinity of ore.

Silver

In pyrite concentrates, Ag distribution patterns are rather similar to Pb, reflecting their common occurrence in galena. Although Ag is anomalous in the vicinity of ore it shows the poorest correlation of any element with extracted mineralization.

Silver in wallrock adjacent to veins reflects ore and porphyry dikes in the general vicinity; patterns are quite different than those of Pb. Much of the Ag is confined to the quartzite, particularly on the Pyrite vein system.
This element shows the strongest tendency for the concurrence of highs in pyrite with lows in wallrock, and the reverse.

Barium

In pyrite concentrates Ba exhibits a strong correlation with ore, as illustrated on the Keytest vein where it occurs in anomalous amounts about the 3 stopes. The form of the Ba anomalies (they form similar patterns on the Pyrite vein) makes it tempting to try to interpret them as effects of weathering. If the anomalies were caused by descending groundwater, the Ba should be fixed as BaSO$_4$, thus the anomalies should extend to the surface with the sulfides, which was not the case. Alternatively, if the source of Ba is from below, and associated with the ore forming process, the Ba could be precipitated due to pH changes at the quartzite-carbonate contact, either as BaSO$_4$ (barite) if sulfate was available, or as BaCO$_3$ (witherite). Only barite has been seen. A source of Ba from below seems the best interpretation. Note that the anomalies continue strongly downward.

Barium in wallrock shows background values about ore, and anomalous values outside the margins of ore.

This element provides another good example of a high in pyrite coincident with a low in wallrock, and vice versa.
Mercury

In pyrite concentrates on the Keytest vein mercury provides the opposite picture to that seen so far. It seems to form an anomaly marginal to the ore of the Zn stope, rather than in it. It does not form an anomaly in the area of either Au stope on this vein.

Mercury in wallrock, however, forms anomalies about both Au stopes. It may be that the Hg preferred the cool wallrock to the hot fissure during mineralization and migrated and accumulated in wallrock adjacent to ore. Since its boiling point is 350°C, at standard pressures, and since this ore was formed at a minimum of 350°C to 400°C, such a possibility seems reasonable. This may also be the favored explanation for the Hg anomalies shown on Plate 22.

Gold

In pyrite concentrates Au forms highs in the areas of the gold stopes and grades rather quickly into background values along the vein.

Conclusions

The following summarizes the important points noted in the above descriptions.

1. Elements in pyrite concentrates and wallrock reflect ore. However, they reflect it in quite different ways, and in different locations, in and about the ore.
2. Zn, Pb, Ba and Hg in pyrite concentrates best reflect the Zn ore bodies; Hg and Zn in vein wallrock plus Ba and Au in pyrite concentrates best reflect the Au ore bodies.

3. A prominent and definite zoning of ore metals in pyrite concentrates may be seen. Roughly speaking, zinc and copper occur in maximum grade from lower to upper Peerless, lead maximizes in the middle Peerless to lower Manitou, and silver obtains a maximum in the lower Manitou.

4. The fact that the ore elements have highs in pyrite concentrates coincident with lows in adjacent wallrock, and vice versa, suggests that while this wallrock was in contact with the vein forming fluid, elements relocated themselves in quartzite, carbonate or vein material according to the position in which they were most comfortable (lowest partial molal free energy). The wallrock traverses perpendicular to ore zones (Plate 22) suggest that, except for mercury, this process could not have been effective more than a foot or so into carbonate wallrock. Analyses in quartzite perpendicular to ore suggest a somewhat greater distance of exchange.

5. Carbonate wallrock next to the Pyrite vein was analyzed for Mg and Ca, approaching ore from southwest to northeast. Although the Mg/Ca is high in the vicinity of ore, it varies so irregularly along the vein that no consistent pattern can be reported.
6. The evidence that these patterns are essentially primary may be summarized as follows: (a) Zn anomalies in pyrite continue to surface; (b) the Ba distribution patterns in pyrite seem best explained by ascending rather than descending Ba; (c) the zoning of Cu, Zn, Pb and Ag in pyrite concentrates suggests heat from below during ore formation; (d) it is highly unlikely that Hg anomalies would be formed in and about the vein by descending groundwater since the principal secondary mineral of Hg is elemental Hg. In oxidizing minerals this equilibrates with the atmosphere and is soon gone; (e) secondary minerals seen constitute a very minor portion of the total amount of ore minerals; however their presence indicates that a secondary pattern is in the process of formation.

7. The highs of most anomalies are open downward. The significance of this feature will be discussed under genesis.

**Genesis of the Ore and Distribution Patterns**

In this discussion it will be contended that the most logical source for the ore and the elements which form dispersion patterns in carbonate about ore was the hornblende feldspar porphyry sill. Further, it will be suggested that these elements travelled from the porphyry to the carbonate by migration through a supercritical aqueous fluid, down a
concentration gradient. The physical avenues for migration were dilatent fault zones. The chemical reason for precipitation of sulfides may have been a reduced solubility of the ore metals in the fluid where carbonates were first encountered (pH change).

Evidence

Any theory of ore formation for the pyrite-sphalerite deposits of the Buckskin Joe Mine must take into account the following facts.

Temperature of Ore Formation

The occurrence of chalcopyrite exsolved from high-iron sphalerite indicates a minimum temperature of formation of 350°C to 400°C, as previously explained. As Levering has noted (1958, p. 694) at a temperature of approximately 600°C the siliceous limestones and dolomites (of the Peerless) around ore, would develop wollastonite, tremolite, forsterite, or diopside at pressures in the order of what is expected here. Since these minerals were not found, an upper limit of 600°C as the temperature of ore formation seems reasonable; the mineral assemblage in the ore indicates that 350°C to 400°C is probably close to the temperature of ore formation. In this temperature range it is important to note that the porphyry intrusives of
the area would have crystallized, but that any water-rich phase with them would still be in a supercritical state.

**Lithostatic Pressure During Ore Formation**

Lovering (1958, p. 705), from a number of lines of evidence, determined the stratigraphic cover over the Gilman area (20 miles to the northwest) to be between 1 and 3 miles during Laramide ore formation. This agrees well with Emmons' (1896) estimate of 10,000 feet and is accepted by the writer for the Buckskin-Mosquite District.

**Structural Controls of Ore**

Ore is controlled by dilatent structures on faults, often formed by a change in attitude when these faults pass through the lowermost Manitou and Peerless Formations. In the veins themselves intersheeting of dolomite and sulfides occurs, suggesting pulses of movement and repeated waves of mineralization. Bedding replacement ore is commonly found in the hanging wall of faults, suggesting vapor transport.

**Alteration Features of Porphyries**

Alteration features of the porphyries in the mine which differ from their general nature throughout the district are of importance. The quartz feldspar porphyry occurs only in 1 location in the mine, and exhibits its common strongly altered appearance, with sericite the dominant alteration
product, as previously described. This porphyry, where noted, has not seriously changed the chemical composition of the adjoining quartzite.

The quartz feldspar hornblende biotite porphyry dikes in the mine cut both quartzite and carbonate, generally flooding them with most of the elements noted on Plate 22, including the ore metals. This is well illustrated on Plate 23 which shows distribution patterns along the Pyrite vein. This porphyry is generally well sericitized and its features are the same as these previously described.

The hornblende feldspar porphyry is normally a relatively unaltered rock throughout the district. In the mine it exhibits all variations from quite fresh to highly altered, the altered portions occurring in the general vicinity of ore. Alteration is exhibited by completely sericitized plagioclase phenocrysts and the appearance of ghosts of hornblende, now consisting of chlorite and/or epidote, leucoxene and pyrite. The following table shows the loss of chemical constituents in this porphyry, with progressive alteration. Elements are placed in the same order as the most to least responsive elements in carbonate wallrock about ore, shown on Plate 22. The direction of the arrows indicate decreases in the quantity of an element from one alteration stage to another. All samples are from the Buckskin Joe Mine and all values are in ppm.
<table>
<thead>
<tr>
<th>Element</th>
<th>Moderately fresh HFP</th>
<th>Moderately altered HFP</th>
<th>Highly altered HFP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg</td>
<td>&gt;10,000</td>
<td>10,000</td>
<td>&lt;10,000</td>
</tr>
<tr>
<td>Ca</td>
<td>&gt;10,000</td>
<td>&gt;10,000</td>
<td>10,000- &gt;10,000</td>
</tr>
<tr>
<td>Al</td>
<td>&gt;&gt;10,000</td>
<td></td>
<td>&gt;10,000</td>
</tr>
<tr>
<td>Pb</td>
<td>50?</td>
<td>150-200</td>
<td>50</td>
</tr>
<tr>
<td>Cr</td>
<td>150</td>
<td>120-150</td>
<td>50</td>
</tr>
<tr>
<td>Ti</td>
<td>5,000</td>
<td>3,500</td>
<td>1,000-2,000</td>
</tr>
<tr>
<td>Zn</td>
<td>2,000</td>
<td>1,200-1,500</td>
<td>150</td>
</tr>
<tr>
<td>Ba</td>
<td>3,000</td>
<td>200-1,000</td>
<td>300-500</td>
</tr>
<tr>
<td>K</td>
<td>&gt;&gt;10,000</td>
<td>&gt;10,000</td>
<td>&gt;10,000</td>
</tr>
<tr>
<td>V</td>
<td>300</td>
<td>200-250</td>
<td>100</td>
</tr>
<tr>
<td>Ag</td>
<td>2?</td>
<td>4</td>
<td>0.3</td>
</tr>
<tr>
<td>Mn</td>
<td>10,000</td>
<td>2,000</td>
<td>2,000</td>
</tr>
<tr>
<td>Sr</td>
<td>300</td>
<td>200-500</td>
<td>100-300</td>
</tr>
<tr>
<td>Cu</td>
<td>70</td>
<td>25</td>
<td>20</td>
</tr>
</tbody>
</table>

As is patently obvious from these figures, the hornblende feldspar porphyry, with increasing alteration, loses the exact elements that are gained by ore and by the carbonate wallrock about ore.

**Chemical Distribution Patterns in Veins**

Most anomalies in both pyrite concentrates and vein wallrock continue strongly downward from where last seen in the mine workings. Elements in pyrite (e.g. see Zn, Plates 23 and 24) lead downward toward highly altered hornblende feldspar porphyry (Plate 11) which has been depleted in Zn. No such pattern is shown toward the quartz feldspar hornblende biotite porphyry dikes.
Zoning in pyrite concentrates shows Zn and Cu maximizing in the middle Peerless, Pb maximizing in the upper Peerless, and Ag in the lower Manitou. This distribution is common in other mining camps and seems to denote distance from heat with Ag the farthest away.

The fact that highs in pyrite concentrates are almost always accompanied by lows in vein wallrock, and vice versa, must be accounted for by some factor in the ore forming process which will allow redistribution of elements to positions of minimum chemical potential.

**Chemical Distribution Patterns in Wallrock**

With the possible exception of mercury, all anomalies in carbonate wallrock are positive, suggesting (though not necessitating) a source from the direction of the fissure.

In quartzite it was not possible to define wallrock distribution patterns since there were no uncontaminated quartzite traverses leading from ore. The inadequate data available vaguely suggests depletion in the vicinity of faults which form ore in the carbonate above.

**Wallrock About Ore**

Ore has a marked affinity for the Peerless and lowermost Manitou Formations, the lowest carbonates in the section. Minor mineralization occurs in faults throughout the section, as may be seen on the mine sections of Plate 21.
Genesis

The following origin is suggested for these deposits; it fits the facts noted above.

Following intrusion and crystallization of the hornblende feldspar porphyry sill, but before cooling had dropped the temperature of the mass to below 400°C, the only mobile portion in it was a dispersed supercritical aqueous phase carrying residual sulfur, chlorine and chalcophile elements. Fracturing and the creation of low pressure dilatant zones in the porphyry caused a rush of fluid to such areas, altering the porphyry which attempted to equilibrate with the new environment in the vicinity of dilatant zones. Since the fluid was supercritical, it shot into all portions of the low pressure areas in the faults, thus coming into contact with quartzites and carbonates. There are slight indications that fluids may also have come from the quartzite and porphyry dikes. Immediately, material in the fluid which was unstable in the carbonate environment precipitated. The ore metals apparently had their lowest chemical potential as sulfides, and precipitated as these minerals. With the depletion of metals from the fluid in the carbonate environment, a concentration gradient was set up which transported metals from the fluid
and altered porphyry below to the carbonate region above. Migration may logically have occurred as chloride complexes, as suggested by Helgeson (1964) or as sulfide complexes, as suggested by Barnes (1962), although many modes of transport are possible. Sulfides were also precipitated to a lesser extent in the Sawatch Quartzite, possibly due to the small amount of carbonate in it, and to backwash from action in the Peerless above it.

Mg, probably largely derived from alteration of the ferromagnesian minerals of the porphyry, reacted with limestone and replaced Cd in it to give dolomite veins and Mg/Ca halos about ore. Similarly, other elements lost from altered porphyry were gained by the carbonate wallrock about fissures, either by flooding, reaction, or both. The presence of the supercritical gas phase in the fissure allowed material in the adjacent wallrock to redistribute itself into its most comfortable environment. This is an explanation for the coincidence of highs in the vein pyrite with lows in bordering wallrock. The highs in the vein pyrite apparently directly reflect ore, and the path the ore metals travelled. Metal zoning probably indicates that Ag achieves its most comfortable state at a lower temperature than Zn.

When the dilatant zone was filled and equilibrium had been established, ore formation stopped. However, vein
sheeting suggests that several more periods of fracturing often occurred, and the same process was repeated. It is probable that some parts of the sill were more impermeable than others, thus were not substantially altered nor did they release their metals.

The amount of Zn lost from the sill in the general vicinity of the mine is approximately equal to the amount of Zn located in the ore mined. If this genesis is correct, then the small orebodies located to date are probably indicative of the size and grade of any others to be found since the source rock is of limited extent.

These deposits would probably be classified as mesothermal hydrothermal deposits with lateral secretion overtones.
The Shelby, Mascotte and Orphan Boy Mines were also examined, principally to obtain geological data for correlation with surface mapping. Their locations are noted on Plate 1.

According to Patton, Hoskin and Butler (1912, p. 215), the Shelby produced oxidized ore, particularly lead carbonate, from the Manitou Dolomite. The old workings were inaccessible to the writer, but projection of geology noted on the main level of the Shelby (Plate 25) suggests that much of the work was done in the Fearless Formation. No ore zone of any size was seen on the main level.

The Mascotte Tunnel (Plate 26) provided a particularly useful section of geology in an area almost devoid of outcrops. No ore of any consequence was produced from this mine.

A portion of the Orphan Boy Mine was examined to obtain geology for district cross section B-B' shown on Plate 2. Auriferous pyrite bodies occur along northeast trending faults in this mine, at the lower contact of the quartz feldspar porphyry sill with the Sawatch Quartzite. The mine is briefly described by Patton, Hoskin and Butler (1912, p. 168-170, 209-214).
Figure 13
General view of portal area of Orphan Boy Mine, looking north.

Figure 14
General view of portal area of Mascotte Tunnel, looking north-west.
CONCLUSIONS

The objectives of the work described herein were as follows: (1) to investigate and detail the geology of ore deposits of the mine and vicinity, (2) to determine the distribution patterns of elements in and about these deposits and to ascertain which patterns are common to similar ore bodies, (3) to use information from these studies to postulate a genesis for these deposits. These objectives have been attained.
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