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Elmer M. Schell

The University of Montana

1961

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GEOLOGY OF THE MARIELLA MINE AND ADJACENT AREA,
ELKHORN MOUNTAINS, BROADWATER COUNTY, MONTANA

by

ELMER M. SCHELL

B.A. Montana State University, 1959

Presented in partial fulfillment of the requirements for the degree of

Master of Science

MONTANA STATE UNIVERSITY

1961

Approved by:

Chairman, Board of Examiners

Dean, Graduate School

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Date
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The Marietta mine (gold, silver, and minor lead) is located in the Elkhorn Mountains, 15 miles northwest of Townsend, Montana. The Slim Sam formation (upper Cretaceous age), composed of sedimentary tuffs and sandstones, is present in the southwest part of the area mapped. The host rocks for the ore are the upper Cretaceous Elkhorn Mountains volcanics, which are a thick series of interbedded andesitic flows, breccias, and conglomerates. Six small intrusive bodies composed of quartz diorite, diorite porphyry, quartz diorite porphyry, and biotite-augite porphyry are present within the area.

Propylitic alteration of the volcanic rocks is intense. Bleaching and silicification, extending up to 8 feet from the veins, is superimposed on the propylitized wall rock.

The major vein in the Marietta mine occurs in a northwest trending, shallow southwest dipping, fault. This vein has been explored about 2500 feet along strike and 740 feet down dip. Ore widths up to 9 feet are present in areas where the dip of the vein decreases below the average.

The dominant vein minerals are pyrite, arsenopyrite, quartz, and carbonates. The paragenetic sequence is: (1) quartz, (2) pyrite, (3) arsenopyrite, (4) sphalerite, (5) chalcopyrite, (6) cubanite(?) and tennantite, (7) argentiferous galena, (8) carbonates (siderite,
ankerite, and manganocalcite), (9) late quartz, pyrite, and calcite, (10) native gold. Micro-fractures in pyrite, arsenopyrite, and quartz are the host minerals for microscopic grains of gold.

Vertical zonation of the carbonate minerals (siderite, ankerite, and manganocalcite) reflects an increasing temperature gradient downward. Siderite is restricted to the lower levels whereas ankerite and manganocalcite are confined to the upper levels of the mine.

Phase studies of the Fe-As-S system give a maximum temperature during pyrite-arsenopyrite deposition of 491 ± 12°C at 1 bar confining pressure.

The most prominent areas for future exploration are: (1) lateral extensions of the Marietta vein on the No. 4 level; (2) extensions at depth of both the Marietta and Gold Dust veins; and (3) northerly extensions of the Marietta vein on the surface.
INTRODUCTION

Location and Accessibility

The Marietta mine and the surrounding area is located approximately 15 miles northwest of Townsend, Montana in T. 7 N., R. 1 W., Broadwater County, Montana (Figure 1 and Plate I). This area is part of the eastern flank of the Elkhorn Mountains, which extend eastward to the Townsend Valley. To the northwest the Elkhorn Mountains merge into the Boulder Mountains. The Boulder River marks the southwest edge of the range and the 46° parallel delimits the southern extent (Figure 1). Access to the mine and the surrounding area is by the Indian Creek road (Figure 1) which is maintained throughout the year. An alternate route is available by following the Beaver Creek road, south of Winston, Montana, to its confluence with Weasel Creek, then following Weasel Creek to its source and crossing the divide into the area mapped (Figure 1). This route is not maintained throughout the year.

Purpose of the Investigation

The main objective of this investigation is to make the first detailed study of the geology of the Marietta mine and surrounding areas. A further objective is to understand the nature of mineralization in this area. It is hoped that this study will facilitate future exploration within the Marietta mine and adjacent areas.
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Figure 1. Sketch map of the Elkhorn Mountains and adjacent area.
Previous Work

Reconnaissance geologic studies and mineral deposits investigations of the area described in this paper have been made in the past. The earliest geologic work was done by Stone (1911, p. 75-98) in a mineral examination and reconnaissance geologic mapping project of the Elkhorn Mountains. Knopf (1913, p. 1-143) studied the ore deposits of the Helena mining region which lies to the west and northwest of the Marietta area. Billingsley and Grimes (1915, p. 31-56; 1918, p. 284-368) studied the Boulder batholith and surrounding area, including the mineral deposits. The study encompassed the Marietta mine area, however, the regional geology was not studied in detail and the Marietta mine was inaccessible. Corry (1933, p. 1-45) did a reconnaissance study on the gold deposits of Broadwater, Beaverhead, Phillips, and Fergus counties. Pardee and Schrader (1933, p. 1-318) included the Marietta area in their study of the Greater Helena region.

The most extensive previous study of the Marietta mine was done by Reed (1951, p. 1-62) but this work was curtailed considerably by inaccessibility of most of the mine. Klepper, Weeks, and Ruppel (1957, p. 1-82) mapped the geology of the southern Elkhorn Mountains and investigated the ore deposits in that area. Their paper is drawn upon extensively in the discussion of the relationships of the volcanic rocks common to both areas. Regional geological mapping, which included the Marietta area, was done by the U. S. Geological Survey during the summer of 1958. At the present time, however, geologic maps of the area are not available (Klepper, 1960, written communication). In 1959
Sahinen (p. 129-140) compiled published information on the mineral deposits of the Helena mining region. Personnel of several mining companies have studied the mine but no reports have been published and the results of these investigations are not available.

Present Study

Field work was conducted during June through August of 1960. Approximately 50 days were spent in the field, three weeks of which was spent mapping surface geology and the remainder in collecting data and samples from underground workings.

Geologic data were plotted on aerial photographs having a scale of 1:20,000. A Missouri Basin Project topographic map with a scale of 1:20,300 and 20-foot contour intervals was used in conjunction with the aerial photographs. Traverses were made along all of the ridges and most of the stream beds in the area mapped. Lithologic contacts were walked out in all cases.

The geology of the underground workings of the Marietta mine was plotted on Northern Milling Company level maps with a scale of 1 inch equals 50 feet. A representative suite of ore and wall rock was obtained by systematic sampling along drifts, crosscuts, and stopes. All of the accessible underground workings were mapped and sampled. Parts of the upper levels and some of the raises and stopes were inaccessible due to caving or waste filling.

Laboratory investigations during the fall and winter of 1960-1961 involved the following: (1) petrographic study of 34 thin sections of the various rock types in the area, with modal analyses of six of these
thin sections, (2) microscopic study of 30 polished sections of vein minerals, (3) binocular microscope study of about 120 ore samples and 50 rock samples, (4) X-ray diffractometer analysis of a suite of carbonate minerals from the Marietta vein, (5) a stereographic analysis of 272 strikes and dips obtained from joints, (6) an analysis of the vein structure by cross-sectional studies, (7) photomicrography of selected mineralogical relationships in polished and thin sections.

Acknowledgments

The author wishes to thank Mr. P. I. Raber, President, Northern Milling Company, Townsend, Montana for permission, financial assistance, and suggestions for doing this work. Thanks are also extended to Mr. E. F. Wieglenda, Superintendent, Mr. P. H. Sweeney, former company Geologist, and Mr. T. Lee, Engineer, Northern Milling Company personnel, for their helpful comments and criticisms. Thanks are also due to Mr. F. Crowley, Montana Bureau of Mines, Butte, Montana for the loan of five polished sections.

The author is also greatly indebted to Prof. A. J. Silverman for guidance and criticisms. The help of Prof. R. M. Weidman, and the rest of the staff of the Geology Department, Montana State University, with whom many problems were discussed, is greatly appreciated.
PHYSIOGRAPHY

Drainage and Topography

The eastern half of the area mapped is drained by the East Fork of Indian Creek and its tributaries. The Marietta mine is situated in a small basin near the head of Indian Creek. The southwestern part of the area is drained by Eureka and Eagle Creeks, tributaries of Crow Creek. A small portion of the northern part of the area drains into White Horse Creek (Plate I). Water for milling purposes is obtained from Indian Creek and from the mine. Springs are abundant throughout the area.

There is a maximum topographic relief of 2600 feet within the area mapped. The highest point is near the northwest corner of the area, where the elevation is 8660 feet (Plate I). Most of the ridge tops are rounded by erosion. Massive outcrops forming cliffs up to 100 feet high, gulches possessing steep walls, and talus slopes are common throughout the area.

Climate and Vegetation

The average annual precipitation in the Townsend Valley, adjacent to the east side of the area mapped, is about 11 inches. Mountainous areas west of the valley receive slightly more precipitation. The temperature range is characteristic of the Northern Rocky Mountain physiographic province. This province has a cool-temperate, semi-arid climate.
Timber in this area consists chiefly of conifers. The heavier stands of timber are confined to the north slopes whereas the south slopes are only moderately timbered or grass-covered (Figure 2). Small natural clearings in the timbered areas are common throughout the area. Most of the timbers utilized in mining in the region are obtained from the surrounding slopes.
MINING HISTORY

In 1864 placer gold was discovered in Confederate Gulch, about 15 miles northeast of the Marietta mine. This discovery encouraged prospecting in surrounding areas and in 1867 auriferous gravels were washed on the lower reaches of Indian Creek. Shortly thereafter, primary mineralization was discovered in the Marietta area. During the period 1890-1906 the Marietta mine area was intensely prospected and developed. At this time this area was known as the Park mining district. (Reed, 1951, p. 48-49). The town of Mason was located in the vicinity of the Marietta mine during this period and remanents of numerous buildings are still present.

During the period 1906-1951 the Marietta mine was operated intermittently for its gold content (Reed, 1951, p. 49). A period of small-scale operations continued from 1951 to 1958. In 1958 Northern Milling Company acquired the property and active mining and exploration work was initiated and is continuing at the present time. In 1959 a 200-ton per day selective flotation mill was erected on the property to concentrate ore from the mine. On December 7, 1960, the Department of Interior announced the approval of a loan to Northern Milling Company for a lead-zinc exploration program (Engin. and Mining Jour., 1961, p. 130). At the present time this exploratory work is in progress.

Shallow, oxidized ore produced about $1 million in the Park and adjacent Hassel district prior to 1930 (Wade, 1960, p. 39). Reliable figures on the Marietta vein are not available but the total production up to 1956 was valued at about $500,000.
GENERAL GEOLOGY

Stratigraphy

Sedimentary rocks

Sparse outcrops of an incomplete section of the Slim Sam formation are present near the southwest corner of the area. The east boundary of the map area was arbitrarily placed on the contact between the Slim Sam formation and the overlying Elkhorn Mountains volcanics (Plate I; Figure 3). According to Klepper, Weeks and Ruppel (1957, p. 28-29), dark shales of Niobrara age grade upward into the Slim Sam formation (Figure 4) which contains upper Cretaceous fossils.

In the area mapped, the upper part of the Slim Sam formation consists of three units which are from bottom to top: (1) a gray, medium-grained sedimentary tuff composed chiefly of angular feldspar grains in a quartz matrix with minor constituents consisting of micaeous minerals, rock fragments, and opaque minerals, (2) a greenish gray, fine-grained, thinly bedded sandstone, and (3) a gray to greenish gray, fine to medium-grained tuff composed of feldspar, quartz, and dark minerals in a micaceous and clayey matrix. A gradational contact, containing an increase in volcanic components, exists between the Slim Sam formation and the overlying Elkhorn Mountains volcanics.

Exposures of the gradational contact are present on most of the spurs along the southern half of the east boundary. Proceeding northward, where topographic relief and dip of the beds decrease, few outcrops are present and the contact was mapped chiefly on float evidence. Klepper, Weeks, and Ruppel (1957, p. 29-31) measured three sections of
the Slim Sam formation, in the surrounding area and found a maximum thickness of 1182 feet.

The attitude of the Slim Sam formation was not observable in the southwest part of the area; however, to the west Klepper, Weeks, and Ruppel (1957, Plate 1) found that this formation generally dips eastward. Along the southeastern border of the area mapped the Slim Sam formation dips about 25° west (Plate I; Figure 3). Proceeding northward the dip progressively decreases to near horizontal (Plate I).

**Elkhorn Mountains Volcanics**

Volcanic rocks, consisting of andesitic flows, volcanic breccias, conglomerates, and tuffs, overlie the Slim Sam formation both conformably and unconformably and are the major rock type in the area mapped. In mapping to the south and west of this area Klepper, Weeks, and Ruppel (1957, p. 32-35) found that the volcanics also contain lapilli tuff, welded tuff, crystal tuff, basalt flows, and some andesitic and related hypabyssal intrusive rocks that were not distinctive enough to map as separate units.

Klepper, Weeks, and Ruppel (1957, p. 31-32) named these rocks the Elkhorn Mountains volcanics and designated the area where they are found as the Elkhorn Mountains volcanic field. These volcanics are known to exist discontinuously from Townsend Valley westward to the Deer Lodge Valley, and from Helena southward to the Jefferson River. The Boulder batholith is intermittently exposed throughout the central portion of the volcanic field.
Figure 2: View from southeast corner of map area looking N. 45° W. along Indian Creek. The Marietta mine (arrow) is located in the clearing near the head of Indian Creek. Note the paucity of outcrops, vegetative differences between north and south facing slopes, and linear pattern of Indian Creek. The ridge in the center foreground is composed of the intrusive at Locality III (Plate I).

Figure 3: Due north view along east border of the area mapped. Slim Sam formation (Kₙ) dips 25° W. and underlies the west dipping Elkhorn Mountains volcanics (Kᵥ).
Figure 4: Generalized stratigraphic section of west-central Montana (Modification of Figure 3, Klepper, Weeks, and Ruppel, 1957, p. 41).
A thickness of more than 5000 feet of Elkhorn Mountains volcanics was mapped by Klepper, Weeks, and Ruppel and the total accumulation in and around the Elkhorn Mountains is thought to be more than 10,000 feet (1957, p. 31-37). According to these same authors the volcanic rocks are divisible into three units on the basis of gross lithology. In the area of this study the lithology of the volcanics corresponds most closely to the lower member; however, part of the middle member may be present. To the southwest the lower member is in the order of 2000-2500 feet thick (Klepper, Weeks, and Ruppel, 1957, p. 34-35). The underlying sedimentary rocks found along the east and west side of the area mapped also indicate the presence of the lowest Elkhorn Mountains volcanic unit. Thickness of the volcanics in the area mapped was undeterminable owing to the lack of bedding. Differentiation of the volcanics on the basis of lithology was unsuccessful because of variance in lithology over short distances (often within one outcrop), paucity of outcrops, and the lack of bedding in the volcanics.

**Tuffs**

Tuffaceous rocks are prevalent in the area mapped. They are massive in outcrop and weather quite readily into rubbly fragments. The tuffs are varicolored in shades of red, green, gray, and brown. In hand specimen the tuffs consist of rock fragments, feldspar, quartz, and opaque minerals in an aphanitic groundmass. Streaks and clots of clay minerals and chlorite are evident in some of the tuffs.

In thin section the tuffs consist of a mixed aggregate of chlorite, calcite, altered feldspar, sericite, quartz, hematite, pyrite, brownish to gray argillaceous minerals, and glass fragments.
Chlorite and hematite appear to be mainly secondary, resulting from complete alteration of ferromagnesian minerals. Hematite often forms rims around the earlier ferromagnesian mineral. Pyrite is present in small amounts as anhedral to subhedral grains and usually is partially oxidized to unidentified iron oxides or hydroxides.

Plagioclase grains are mostly sub-angular and up to 1.5 mm in diameter. They are intensely altered to sericite, clay minerals, and calcite. The composition of the plagioclase could not be determined, owing to the intensity of the alteration.

Quartz grains up to 1 mm in diameter are ubiquitous. Glass is present as fragments and as part of the matrix in one thin section examined. The glass has been partially altered to clay minerals. Rock fragments, observable in hand specimens, were not encountered in thin sections.

In two thin sections of the tuffaceous rocks, small secondary veinlets of quartz and calcite were observed. A zeolite mineral was also present in one of the veinlets.

Propylitization, the alteration of the andesitic flows described in a later section, appears to predominate in the Elkhorn Mountains volcanic tuffs examined by the author. This agrees with Moorhouse (1959, p. 229) who states that alteration of tuffs is similar, in general, to alteration of corresponding lava flows.

Volcanic breccia and conglomerate

Andesitic breccias and conglomerates are distributed over the entire area but are generally more abundant near the east and west borders. Along the east boundary they compose the major rock types
stratigraphically above the Slim Sam formation.

The breccias and conglomerates are massive in outcrop and form some of the ridges and cliffs in the area. They are varicolored in hues of red, brown, green, and gray. The only megascopic difference between the breccia and conglomerate is in the shape of the included material. In both rock types the included fragments range in size from microscopic to boulders up to 2 feet in diameter. The average diameter of the fragments is about 4 to 8 inches (Figure 5). The majority of the breccia and conglomerate is composed of andesite fragments set in an andesitic matrix, although occasional fragments of other rock types have also been incorporated. In general, the matrix material is darker than the included fragments.

Figure 5: Andesitic conglomerate. Rounded fragments of andesitic material incorporated in an andesitic lava flow. A knife near the center of the picture depicts the scale.
Apparently most of the incorporated material is erosional debris derived from pre-existing flows and incorporated in later flows. Some of the breccia and conglomerate fragments may have originated from mud flows, brecciation of a cooling lava flow, or explosion breccia.

**Andesite flows**

Flows are abundant in the area but they were not mappable as separate units and they are all classified as andesites. The flows are massive, highly indurated, and form cliffs up to 100 feet high. Many of the talus slopes are composed of angular andesite fragments. The color of the andesite is generally dark greenish gray but some is dark reddish gray.

Phenocrysts of pyroxene, up to 3.5 mm in diameter, and smaller grains of altered plagioclase are the only minerals megascopically identifiable. Flow banding and bedding is conspicuously absent in the flows.

Most of the flows are altered so intensely that a reliable modal analysis was not possible. Five hundred points of a thin section were counted of a relatively unaltered andesite in order to obtain a semi-quantitative mode of the rock. The optically identified minerals are: plagioclase, 70%; clinopyroxene, 8%; biotite, 5%; quartz, 5%; chlorite, 3%; epidote, 2%; orthoclase, 2%; opaque minerals, 5%; apatite, less than 1%; and traces of zircon.

The plagioclase occurs as lath-shaped, euhedral crystals up to 1 mm in length and commonly displays albite twinning. Most of the grains are at least partially altered to sericite and calcite and in some cases alteration appears to be complete. Plagioclase composition
could not be determined precisely, owing to alteration and complex oscillatory and normal zoning of the individual grains, but it appears to range from An35 to An55.

The clinopyroxenes consist of pigeonite and diopside and occur as anhedral to euhedral grains generally about 1 mm in length. Depending on the orientation in the thin section, the individual grains are either slightly elongate or form eight-sided prisms. Twinning and zoning of the pyroxenes is common. Diopside, the dominant pyroxene, is biaxial positive and has a 2V of about 55° as determined with a universal stage. The N\textsubscript{Y} index is about 1.68. The composition of the diopside, determined from optical data (Hess, 1941, p. 516-519), is Wo\textsubscript{4.9}En\textsubscript{4.5}Fs\textsubscript{10}. Pigeonite has a 2V of about 15°. Both minerals are partially altered to chlorite and epidote.

Biotite occurs as small anhedral grains filling interstices. It is the reddish brown variety typical of basic volcanics and is partially altered to unidentified opaque minerals.

Orthoclase and quartz occur as small interstitial grains. They are poikilitic and enclose numerous euhedral crystals of apatite and occasional zircon grains. The orthoclase is partially sericitized.

**Alteration of the volcanics**

The alteration of the volcanics is principally propylitization. Generally, the alteration is intense and geographically widespread throughout the area mapped. The propylitic alteration is megascopically characterized by the obliteration of most of the original texture, a dark greenish color, a high degree of induration, and feldspar phenocrysts that are less translucent than normal. It is characterized
microscopically by the scarcity of the original mineralogy and the abundance of epidote, clinozoisite, chlorite, sericite, carbonate minerals, pyrite, hematite, serpentine (?), and occasionally albite. Silicification of the andesite, and argillization of the feldspars, evident throughout the area, is most conspicuous adjacent to mineralized areas.

Identification of some of the original mineralogy of the andesite was on the basis of relic forms and remanents of primary minerals. Some plagioclase grains are complexly zoned (oscillatory and normal) and have a composition ranging from An\(_{35}\) to An\(_{55}\). Plagioclase is altered to sericite, carbonate, argillaceous material, and chlorite. The ferromagnesian minerals apparently have been more susceptible to alteration as they have, in most cases, been completely altered to chlorite, epidote, clinozoisite, hematite, pyrite, and serpentine (?). Locally, hematite is abundant as an alteration product giving the andesite a reddish cast. In the Marietta mine, ore does not appear to be associated with andesite containing abundant hematite. However, there is insufficient data to determine the significance of this relation.

Almost all of the thin sections of andesite are cut by tiny stringers containing euhedral crystals of one or more of the following minerals: quartz, carbonate, epidote, clinozoisite, and one or possibly several zeolites. This may represent a late phase in the propylitic alteration.

Age of the Elkhorn Mountains volcanics

Klepper, Weeks, and Ruppel (1957, p. 32-38) have done considerable work on the age of the Elkhorn Mountains volcanics. A summary of
their work is given below.

The beginning of the volcanic period is marked by andesitic detritus in the Slim Sam formation, which contains Niobrara age fossils. The Slim Sam formation is believed to have been deposited rapidly and in places grades upward into the volcanics. Fossils found in a marly layer in a volcanic conglomerate (that is believed to have been deposited at, or near, the end of the volcanic activity) are considered to be Judith River in age. Also, the volcanics are the youngest rocks in the southern Elkhorn Mountains that have been involved in the major episode of Laramide folding.

In summary Klepper, Weeks, and Ruppel (1957, p. 38) state:

"The paleontologic, stratigraphic, and structural evidence indicates to the authors that the Elkhorn Mountains volcanics are almost certainly wholly Cretaceous in age. But the evidence is insufficient to indicate whether they range in age from very late Niobrara or Telegraph Creek time to an upper limit that cannot be fixed more closely than Judith River time, or younger, or are restricted in age to Judith River time." (See Figure 4).

Intrusive Rocks

Six small intrusive bodies, outcropping on the surface (Plate I), and two narrow dikes, exposed underground (Plate II), are present in the area mapped. Three of these bodies are slightly elliptically-shaped and one half mile or less in maximum plan dimension. The remaining three bodies are elongate and from 100 feet to 300 feet in width. Since exposures are poor, the majority of the contacts mapped on the surface are based chiefly on float evidence. Significant amounts of intrusive float were observed in various parts of the area, suggesting that unexposed
intrusive bodies are present. This float was scattered to the extent that no probable contacts could be postulated. Contact metamorphism of the intruded andesite appears to be negligible.

The intrusive rocks were emplaced after, or possibly during, extrusion of the Elkhorn Mountains volcanics. Some of these bodies may be consolidated remanents of volcanic necks or plugs from which andesitic volcanic rocks were extruded.

Mineralogical and structural similarities of intrusive rocks mapped by Klepper, Weeks, and Ruppel (1957, p. 44-48) to the southwest indicate these rocks are genetically related to the Elkhorn Mountains volcanics. These same authors suggest that the small plutons mapped in the southern Elkhorn Mountains may be genetically related to the Boulder batholith.

The intrusive rocks of the area comprise a variety of types. They consist of quartz diorite, diorite porphyry, quartz diorite porphyry, and a biotite-augite porphyry. For convenience in referring to the location of the individual intrusive bodies, locality numbers (Plate I) have been assigned:

- Locality I Quartz Diorite
- Locality II Quartz Diorite
- Locality III Quartz Diorite
- Locality IV Quartz Diorite
- Locality V Diorite Porphyry and Biotite-Augite Porphyry
- Locality VI Quartz Diorite Porphyry

Six thin sections, one from each of the major intrusive bodies, were studied in detail (Table I). Spatial association and mineralogical
TABLE I

MODAL ANALYSES OF SIX THIN SECTIONS

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Locality Number</th>
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<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
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</tbody>
</table>

Note: Due to alteration of the rocks, only 500 points were counted in each thin section. Therefore, these modes are semi-quantitative.
similarities suggest that the intrusives in the area mapped are genetically related to each other and to the surrounding extrusives.

Quartz diorite

The quartz dioritic rocks are the major intrusive bodies in the area. These rocks are easily recognized by contrasting color and textural differences as compared to the andesites, and by formation of coarse rounded fragments on weathering.

In hand specimen, the quartz diorites are light gray and fine to medium grained. Most of the mineralogy is megascopically visible. Microscopically, they are holocrystalline with interlocking grains (Figure 6). A mode of each of the four quartz diorite bodies is given in Table I.

Plagioclase is the dominant mineral in the quartz diorite. It occurs as anhedral to euhedral grains up to 2 mm in length. Composition of the plagioclase in the rocks ranges from An33 to An60. Oscillatory and normal zoning with a more calcic core is common (Figure 7) and indicates disequilibrium conditions during crystallization of the plagioclase. The cause of disequilibrium is speculative. The quartz diorite of Locality I contains less than 1% myrmekitic inter-growth of quartz and plagioclase. A thin section of this rock also contains about 10% microperthite. Alteration products of the feldspars, in decreasing abundance, are sericite, clays, and calcite.

Pigeonite and a more calcic pyroxene are the two clinopyroxenes present in the quartz diorites. Many of the pyroxene grains are twinned and hourglass zoning can be observed. The calcic pyroxene is more abundant than pigeonite. The optic angle of pigeonite ranges from 12°
Figure 6: Thin section No. B-40. Quartz diorite from Locality IV; chiefly plagioclase laths (P), chlorite (C), and interstitial quartz (q). Crossed nicols, x 25.

Figure 7: Thin section No. SE-34. Oscillatory zoning of a plagioclase grain from a Locality III quartz diorite. Plagioclase chiefly surrounded by quartz and some epidote. Crossed nicols, x 75.
to 30° and it is slightly pleochroic. The presence of pigeonite in the quartz diorite indicates rapid cooling of the partially crystallized melt, probably by rapid upward intrusion into the near surface rocks.

The molecular percentages of the calcic pyroxene were determined by measuring 2V with a universal stage and optically determining Ny with the following results: Locality I, Wo45En3Fs12; Locality II, Wo46En40Fs14; Locality III, Wo46En1Fs13; and Locality IV, Wo13En53Fs14. According to the classification of the common non-sodic pyroxenes outlined by Hess (1941, p. 516-519), the calcic pyroxenes from Localities I, II, and III are in the salite field near the salite-augite-diopside intersection. The calcic pyroxene from Locality IV differs considerably and is in the endiopside field.

Pleochroic colors of the hornblende are generally light to dark green. The optic angle of the hornblende varies from 70° to 90°, with an average 2V of about 73°.

Biotite occurs as small euhedral grains up to 1 mm in length in quartz diorite from Localities I and IV. It is pleochroic from light to dark brown. Biotite commonly is altered to chlorite or rimmed by an opaque mineral.

Small, anhedral, interstitial grains of quartz, up to 1 mm in diameter, are present in about equal amounts in all of the quartz diorites. Apatite occurs as euhedral inclusions in most of the other minerals and as separate grains throughout the rock. Small, elongate, euhedral zircon crystals were occasionally observed in the thin sections of the quartz diorite.
Opaque minerals appear to consist chiefly of pyrite and the iron oxides, magnetite and hematite. Pyrite is usually euhedral and is present as grains up to 1 mm in diameter. Hematite and magnetite are present as reaction rims around ferromagnesian minerals.

Diorite and quartz diorite porphyry

The probable contacts of two elongate intrusive bodies (Localities V and VI, Plate I) were mapped on the basis of float evidence. The rock from Locality V is a diorite porphyry and that of Locality VI a quartz diorite porphyry. These rocks are dark gray, fine to medium grained matrix, and contain numerous euhedral pyroxene phenocrysts up to 6 mm in length (Figures 8 and 9). Mineralogically, the porphyritic rocks differ from the quartz diorites (Table I) with respect to minor mineral percentages. Alteration of these porphyritic rocks is analogous to the quartz diorite previously described.

The porphyritic rocks contain euhedral, sericitized, plagioclase (An$_{35}$-An$_{60}$) grains up to 2 mm in length (Figure 8). Chlorite, epidote, and clinozoisite are present as alteration products. Hornblende, similar to that found in the quartz diorite, was observed in the thin section from Locality VI. Biotite and quartz occur as small interstitial grains.

The optically determined composition of calcic pyroxene in the porphyritic rock from Locality V is WO$_{45}$En$_{45}$Fs$_{10}$. The composition of the calcic pyroxene in the rock from Locality VI is WO$_{46}$En$_{40}$Fs$_{14}$. Occasional phenocrysts of pigeonite are also present in rocks from both localities. Apparently the clinopyroxenes were the first minerals to crystallize in the magma. Rapid cooling of the partially crystallized
Figure 8: Thin section No. SE-33. Diorite porphyry from Locality V; clinopyroxene phenocryst in a matrix of sericitized plagioclase laths. Crossed nicols, x 25.

Figure 9: Thin section No. SE-41. Quartz diorite porphyry from Locality VI. Partially altered clinopyroxene (Py), plagioclase (gray), quartz (white), chlorite (C), opaque minerals and holes in section (black), and small euhedral apatite (A). Crossed nicols, x 25.
melt followed its intrusion into the surrounding andesite. As a result, the pigeonite did not invert to orthopyroxene.

**Biotite-augite porphyry**

A biotite-augite porphyry body intruded the andesite and diorite porphyry at Locality V. The biotite-augite porphyry was not mapped separately as only one outcrop, several feet in diameter, was observed near the southeast corner of Locality V. It is a dark gray, fine grained, porphyritic rock consisting of a sub-microscopic crystalline groundmass, phenocrysts of biotite and augite, and subordinate amounts of plagioclase (composition undetermined) and orthoclase (?). Phenocrysts range in size from 0.25 mm to 2 mm and constitute about 20% of the rock. Biotite phenocrysts are most abundant and are rimmed by reaction rims of iron oxides and unidentified pyroxenes.

The texture of this rock and the presence of resorbed biotite phenocrysts indicate a period of early crystallization at high water pressure during which time the biotite phenocrysts developed. As a result of intrusion of the magma, the water pressure dropped rapidly, biotite became unstable and was partially resorbed to iron oxides and pyroxenes. The sub-microscopic groundmass also resulted from intrusion of the melt with a subsequent chilling of the partially crystallized magma.

**Dikes**

Two hydrothermally altered dikes that have intruded the andesite are exposed in the Marietta mine (Plate II). These dikes are observable on the No. 4 and 5 levels of the mine. Both dikes are about 2.5 feet wide, trend northwesterly, and are nearly vertical.
Microscopically the dike rocks consist of a complex aggregate of quartz, chlorite, epidote, clinozoisite, sericite, pyrite, calcite, and clay minerals. The original mineralogy and texture is present only as occasional relict grain boundaries.

Structure

Folding and faulting

In the absence of any definite criteria for establishing the stratigraphic relationships of the Elkhorn Mountains volcanics only a few of the structural details could be delineated.

The dominant structural feature within the area mapped is a broad, north trending syncline. Indirect evidence for this syncline is the presence of a broad, elongate, north plunging domal structure west of the area mapped (Klepper, Weeks, and Ruppel, 1957, Plate I) and west dipping strata east of the area (Plate I). Minor folds are superimposed on major folds west and southwest of the area mapped (Klepper, Weeks, and Ruppel, 1957, Plate I) and also to the southeast (Freeman, Ruppel, and Klepper, 1958, Plate 1). Therefore, it is reasonable to assume that minor folding also occurred within the area mapped. Stone (1910, p. 78) was one of the first to observe that the major folds generally have a northerly trend. In the southern Elkhorn Mountains, Klepper, Weeks, and Ruppel (1957, p. 60) found some of the volcanics deformed as intensely as the underlying sediments, indicating that the culmination of folding and faulting occurred after the accumulation of the volcanics.
Previous mapping in adjacent areas of the Elkhorn Mountains and Townsend Valley has established a northwest trend for the major faults. The northwest trending faults mapped by Freeman, Ruppel, and Klepper (1958, p. 525) in the Limestone Hills are considered to be subsidiary structures of the Lombard Thrust (For location of the Limestone Hills and trace of the Lombard Thrust, see Figure 1). According to Reed (1951, p. 114) many of the known centers of mineralization in the Elkhorn Mountains are confined to the intersection of northwest trending faults and intrusive stocks.

Reed (1951, p. 114) mapped a northwest trending fault about one mile south of the Iron Mask mine (Plate I) and believes this fault continues into the upper Indian Creek basin, which contains the Marietta and related veins. Substantiating evidence for this fault is the linear pattern of Indian Creek in the area mapped (Plate I; Figure 2).

Faulting on a local scale is prevalent in the Marietta mine and adjacent areas (Plate II). Most of the productive lodes were localized in some of these faults. Post-ore faulting is present in the Marietta mine; however, displacement is in inches wherever it could be determined. Detailed discussion of the structure observed underground is reserved for a later section.

Joints

Two sets of northwest trending joints are present within the area mapped. One set is nearly vertical (Plate I) and the average dip of the other set is about 20° southwest (Figure 10).

The attitude of 272 of the shallow southwest dipping joints was recorded from the following localities: 34 attitudes from an outcrop
about 100 yards north of the No. 4 portal of the Marietta mine; 94\(^\circ\) attitudes from the No. 5 level of the Marietta mine; and 114\(^\circ\) attitudes from the Mason tunnel. The poles of the joints from each locality were plotted separately on the lower hemisphere of an equal area net. A contour diagram that includes all 272 attitudes is presented as Figure 10. Most of the poles in the southwest quadrant of Figure 10 are attributable to attitudes obtained from the Mason tunnel. An analysis of the joints was attempted but no satisfactory conclusions as to their origin or to their relationship to the veins could be obtained from the available data.
Figure 10: Contour diagram of 272 joint attitudes in the vicinity of the Marietta mine. Plotted on the lower hemisphere.
Ore Deposits

Mineralization is common throughout the entire area studied. Numerous prospect pits and mines, most of them abandoned, were encountered in mapping (Plate I). The area has produced notable quantities of gold and silver, and lead is an important byproduct. The only operating property in the area at present is the Marietta mine.

The majority of the ore deposits in the area occur in andesites. However, some mineralization occurs in, and adjacent to, the previously described intrusive bodies with the exception of the quartz diorite at Locality II.

All of the veins observed in the area are emplaced along well-defined faults. The Marietta vein trends northwest and has a southwest dip of about 30°. The trend of most of the other veins in the area (wherever the attitude could be determined) is either northeast or northwest and they are generally shallow dipping.

Veins in the Marietta mine

The Marietta, Gold Dust, and Rabidau veins are the three mineralized structures developed in the Marietta mine (Plate II). Andesite flows are the host rock for the veins. The only intrusive rocks present in the mine are two basic dikes which were previously described (Plate II).

The Marietta vein is the most persistent, and economically the most important, structure in the mine. It generally strikes about N. 10° W. and has an average dip of about 30° SW. Near its southern
extremity, on the Intermediate and No. 3 and 4 levels (Plate II), the
vein strikes about N. 40° W. and dips about 20° SW. The strike length
of the Marietta vein is about 2500 feet and its known vertical extent
is about 410 feet (Section A-A', Plate II). It has been discontinuously
mined and explored from the surface for a distance of 740 feet down dip.
On the No. 5 level the vein structure is strong with sulfide widths up
to 4 feet. However, from the sill of the No. 5 level to the bottom of
a 25-foot winze, near Station 518 (Plate II), sulfide widths decreased
to about one foot. At the bottom of this winze the tenor of the ore
decreased below the cut-off point and the winze was temporarily aban­
doned. Exploratory work below the No. 5 level has not progressed far
enough to determine whether or not economic ore is present at greater
depths. Owing to pinching and swelling of the vein throughout the mine,
width variations are common.

The explored northern extremity of the Marietta vein is acces­
sible on the surface and on the No. 3, 4, and 5 levels of the mine
(Plate II). On the surface the vein structure, observed in pits and
bulldozer cuts, consists of sheeted andesite, iron oxides, and sparse,
partially oxidized pyrite. Some of this material from the northern­
most surface pit shown on Plate II was assayed by Mr. T. Lee of Northern
Milling Company and showed a trace of gold and silver (1960, personal
communication). At the northern extremities of the No. 3 and 5 levels
the Marietta vein pinches down to about 4 inches. Near Station 430
(Plate II), on the No. 4 level, the vein increases in dip, curves to
the west, and pinches from 4 feet to about one foot. Four drill holes
(about 50 feet in length) and a raise in this area failed to reveal a
northward continuation of the structure. However, near the end of the 424 N. drift the structure reappears and apparently continues northward (Plate II).

The Gold Dust vein is observable on the No. 4 and 5 levels of the mine. It trends about N. 60° E. and dips about 40° SE. The known vertical extent of this vein is less than 100 feet. It has been explored about 600 feet along strike on the No. 5 level (Plate II). The eastern extremity of the structure appears to split into several small horsetailing veinlets. A small shoot, approximately 10 feet thick, was present where the Gold Dust and the Marietta veins intersect on the No. 4 level. A detailed study of the Gold Dust vein was not feasible owing to inaccessibility of the stopes and part of the drifts.

A small and economically unimportant structure known as the Rabidau vein occurs near the portal of the No. 4 level. The strike averages N. 60° E. and it dips about 35° SE. It consists of 5 inches to 2 feet of oxidized ore, gouge, and sheeted andesite. The vein has been explored about 180 feet along strike (Plate II).

**Internal vein structure**

The Marietta vein has easily recognizable foot and hanging walls. A gouge seam, up to 8 inches wide, is characteristically near or adjacent to one of the vein walls. The andesite wall rock is silicified, bleached, and pyritized for a distance of 6 to 8 feet on either side of the vein. Stringers of sulfides, quartz, and carbonates are common considerable distances from the vein.

The veins in the Marietta mine are of the fissure fill type. Minor amounts of pyrite, arsenopyrite, quartz, and carbonates are
disseminated in the andesite adjacent to the veins. Brecciation of the andesite, during formation of the vein structure and mineralization, occurred locally as shown by occasional pieces of andesite breccia found within the vein material (Figure 11). The breccia has been only partially replaced by sulfides and gangue minerals.

Mineral ratios change rapidly and inconsistently along both strike and dip of the vein. Where the vein is narrow, some of the mineralogy is absent (Figure 12) and two or three minerals constitute the entire vein. Parts of the vein are banded with mono-mineralic or bi-mineralic bands of sulfide and gangue minerals (Figures 13 and 14). None of the banded ore represents simple crustification of a single open structure, but suggests continuous re-opening of the vein during mineralization.

In the Marietta mine a limited number of vugs were found to contain small crystals of quartz and occasionally pyrite and calcite. One vug contained a small cluster of marcasite (?) crystals up to one half inch in diameter. However, this apparently is an oddity as no other occurrence of marcasite was observed.

The Marietta and Gold Dust veins randomly pinch and swell, varying in width from several inches up to about 3 feet. Where the dip of the Marietta vein decreased, the vein has enlarged to form shoots with a maximum width of about 9 feet. The largest, and economically most important, shoot occurs between the No. 3 and 5 levels of the Marietta mine. The entire area has been stoped, with the exception of numerous pillar supports, for a horizontal distance of about 400 feet. Sulfides, gangue, and variable gold were continuously present in this area in
Figure 11: Sample from No. 1 level containing brecciated andesite (A), ankerite breccia (C), quartz breccia (q), and gouge (black).

Figure 12: Specimen from No. 1 level, Marietta vein. Consists of andesite on both sides of the specimen, siderite (light gray), quartz (white), and pyrite (medium gray).
Figure 13: Mono-mineralic banded ore from 503 stope. Contains sphalerite (Zn), andesite (A), galena (Pb), pyrite (P), siderite (C), and quartz (q).

Figure 14: Specimen from 507 stope consisting of quartz (white), pyrite (medium gray), and coarse galena (dark gray).
widths ranging from 6 inches up to 9 feet. Between the No. 3 and 4 levels the shoot was very discontinuous. In this area sulfides and gangue attained widths up to about 6 feet and the gold and silver content was irregularly distributed. Pinching and swelling of the vein, both laterally and vertically, has determined the position of the commercial ore bodies. Only the wider portions of the vein have been amenable to mining.

Numerous smaller shoots were present in the Marietta mine as shown by many discontinuously stoped areas. Most of the stopes are now filled with waste and are inaccessible.

Localization of ore

The ore bodies of the Marietta mine have been localized largely by pre-ore faults. Two ages of faults are present, older faults provided channels for the ore solution movement and deposition, and two younger sets of cross-cutting faults, one of which probably acted as dams to the movement of ore forming fluids.

The Marietta and Gold Dust veins are in the older faults. Near horizontal post-ore movement along the Marietta structure is evidenced by slickensides in the ore and associated gouge seam. In general, the dip of the structure increases towards the surface (Section A-A', Plate II). Ore widths up to 9 feet were present between the No. 4 and 5 levels where the dip of the structure decreased. Between the No. 3 and 4 levels the structure is slightly steeper and narrower widths of ore (a maximum of 6 feet) were present. The dip of the structure increases between the No. 2 and 3 levels and the maximum width of ore is about 3 feet. This strongly suggests that the Marietta structure had
a thrust component of movement which provided open space for ore deposition where the dip decreased. Although not studied in detail, the greater ore widths in the Gold Dust vein most probably resulted in a similar manner.

Assuming that pre-ore movement was similar to post-ore movement, the Marietta structure is the result of a strike slip fault with a thrust component of movement. Petrographic studies of andesite from both sides of the Marietta vein failed to reveal any major compositional differences that may have been useful in determining pre-ore movement along the structure.

The younger, steeply dipping, sets of faults trend either northwest or northeast, almost perpendicular to the Marietta structure (Plate II). They are pre-ore in age as shown by mineralization continuing through the faults without displacement but occasionally show minor post-ore strike slip or dip slip movement. Northwest trending faults are present at both the north and south ends of ore shoots. These faults contain gouge and probably acted as dams, preventing the horizontal spread of vertically rising ore solutions along the main ore channels of the Marietta vein. Some of the northwest trending faults can be projected through several levels of the mine. The northeast trending faults apparently are not important in ore localization.

Ore shoot formation at vein intersections is found at only one locality. Where the Gold Dust vein intersects the Marietta vein on the No. 4 level, a small pod of ore was present (Plate II). However, this shoot did not have a great vertical extent but was confined to a small
area between the No. 4 level and Sub levels, a vertical distance of about 10 feet.

Veins in adjacent area

Very little information can be obtained about other veins in the area mapped. The majority of the underground workings are either completely or partly inaccessible. A detailed study of the mineralogy was, therefore, not possible. Suites of rock and ore collected from mine dumps and drifts show a similarity to the Marietta deposit. Polished sections from several of these workings were studied and will be discussed in a later section.

The Jackson workings, composed of three levels, occur between the Mason tunnel (Plate II) and the ground surface. They are partially accessible and contained a vein that strikes about N. 30° E. and dips steeply southeast. The Cotter drift, a 300-foot cross-cut on the same level as the Mason tunnel, contains a vein that probably is the down dip extension of the structure observed in the Jackson workings. On this level the vein strikes about N. 50° E. and dips 60° SE. Widths of ore up to 2.5 feet were observed. The Mason tunnel (Plate II), developed as an access tunnel for the Cotter drift and Jackson workings, does not crosscut any commercial ore. Some of the faults in this tunnel, and commonly throughout the area, are slightly mineralized, and contain quartz, carbonate minerals, and pyrite.

The White Horse workings (Plate I) are believed to be an extension of the Marietta vein (Reed, 1951, p. 51). This is indicated by small pits showing mineralization which can be followed northward along the trend of the Marietta vein into the White Horse workings. Widespread
pyritization and bleaching of the andesite is evident in the White Horse area. An outcrop of massive quartz about 300 feet long and 20 to 30 feet wide was observed in this locality.

According to Reed (1951, p. 49) the Bullion King lode (Plate I) was a shallow, steeply inclined chimney with a plan area of about 25 square feet. Its long axis plunged northwest. None of the underground workings are accessible.

Approximately 500 feet of drift is accessible on the Little Joe vein (Plate I). This vein strikes N. 70° E. and dips about 25° NW. It is up to 6 inches wide and consists chiefly of quartz and oxidized sulfides.

An inclined shaft allows partial access to the Little Annie vein (Plate I). The vein strikes about N. 80° E. and dips 30° NW. The ore in the accessible part of the mine is entirely oxidized although several sulfide samples were obtained from the dump.

The Jawbone workings (Plate I) are inaccessible. This structure apparently was stoped to the surface as numerous pits are present in a linear pattern which strike N. 65° W. According to Corry (1933, p. 20) "lenses" up to 12 feet wide were mined in these workings.

Numerous other abandoned mines and prospect pits are present in the area mapped. The location of the more extensive workings are shown on Plate I. Most of the prospect pits and abandoned mines show mineralogy similar to that of the Marietta mine but apparently in non-commercial quantities.
Mineralogy

A detailed study was made of 26 polished sections from the Marietta and Gold Dust veins. One polished section each from the Jackson workings, Cotter drift, Little Annie vein, and White Horse workings was also studied. Megascopic and binocular microscope studies of the ore supplemented mineralogic investigation.

The mineralogy of the various veins is strikingly similar. The only exceptions are small amounts of pyrrhotite in a polished section of the White Horse ore, and a small amount of molybdenite in a specimen obtained from a pit along the trend of the Marietta vein.

Relatively high grade oxidized ore was mined from the B level of the Marietta mine during early periods of development. This level is inaccessible at present. Oxidation in the accessible parts of the mine has not been extensive and consists of the formation of small quantities of the supergene minerals, azurite, malachite, and covellite.

Production records from 1901 to about 1951 were compiled by Reed (1951, p. 48-49) and indicate that the average recovered metal content from the Marietta mine has been 1.24 oz. gold, 7.5 oz. silver, and 4.8% lead per ton.

Over 100 ore samples and about 40 rock samples from the area mapped were assayed for beryllium with a beryllometer. All the samples assayed registered less than 0.05%, the minimum sensitivity of the instrument.

Minerals present

Throughout the Marietta mine pyrite, arsenopyrite, quartz,
siderite, manganocalcite, and ankerite constitute most of the vein material, with galena and sphalerite secondary in abundance. Calcite, chalcopyrite, tennantite, cubanite (?), and native gold occur as minor constituents.

**Texture**

Pyrite is ubiquitous in the veins but locally may be present only in microscopic quantities. It is generally intensely fractured. These fractures are filled by later arsenopyrite, sphalerite (Figure 15), galena, gold (Figure 16), chalcopyrite, and carbonates (siderite, ankerite, and manganocalcite). According to P. H. Sweeney and T. Lee (1960, personal communication) gold content increases in areas of fractured and friable pyrite. In local areas a decrease in gold content appears to be inconsistently and fortuitously related to pyrite that is coated with a film of black clay. An X-ray diffractometer pattern shows that the black clay is probably a mixture of kaolinite and chlorite. Megascopically, most of the pyrite appears massive; however, euhedral cubic crystals ranging from microscopic up to 1.5 inches in diameter are common.

Arsenopyrite is present throughout all of the veins in varying proportions. The fractured arsenopyrite also usually contains higher than average gold values. Fractures in the arsenopyrite are filled by the later minerals, sphalerite (Figures 15 and 17), galena (Figures 16 and 18), chalcopyrite, carbonate minerals, and gold. Arsenopyrite in turn fills fractures in pyrite (Figure 15). Most of the arsenopyrite is massive; however, euhedral, elongate crystals, up to 1.5 inches long, are common and are often arranged parallel to each
other and perpendicular to the vein walls, indicating a fissure filling process of mineralization. Small needles and rhombic shaped crystals of arsenopyrite are commonly observed in polished sections (Figure 19).

Sphalerite occurs in small quantities in all of the veins. Generally the sphalerite is fine grained, but cleavage faces up to 0.25 inches in diameter were occasionally observed. The color of the sphalerite varies from abundant quantities which are dark reddish black to small amounts of reddish brown color. The dark iron rich sphalerite has a dark red internal reflection under the microscope and the lighter colored, iron poor, sphalerite has a yellow internal reflection. The dark and lighter colored sphalerite grains are intimately intergrown and no evidence for a depositional time difference could be observed. Sphalerite veins and replaces the earlier arsenopyrite (Figure 18), quartz, and pyrite.

Megascopically visible chalcopyrite is not present in any of the vein material. Chalcopyrite was observed to be microscopically widespread in 24 of the 30 polished sections studied. It is contained either as inclusions in sphalerite (Figure 20), as irregular grains and veinlets in or adjacent to earlier minerals, or both.

The chalcopyrite occurrence and texture were studied in detail to determine mode of occurrence. Less than 50% of the chalcopyrite is present as inclusions in sphalerite. Chalcopyrite grains and veinlets are present along sphalerite grain boundaries, where replacement commonly occurs. Both the darker and lighter colored sphalerite contains chalcopyrite inclusions but not all sphalerite grains contain visible chalcopyrite. There is no systematic distribution of chalcopyrite in
sphalerite. A small percentage of the chalcopyrite inclusions are present as narrow, elongate rods with a preferred orientation in the sphalerite (Figure 20). Some of these elongate inclusions have matching walls. Baker (1960, p. 393) noted in his study of exsolution chalcopyrite in sphalerite that the ends of the elongate inclusions are enlarged, suggesting that the ends of the rods drained chalcopyrite from a larger area. He also found abundant tiny irregular chalcopyrite grains throughout the sphalerite and these were especially numerous close to the elongate inclusions. With a few exceptions, the ends of the rod like inclusions tend to pinch out rather than show enlargements. Very little of the criteria for exsolved chalcopyrite given by Baker were noted in the present study. It was concluded that there is not enough reliable evidence to determine if the chalcopyrite-sphalerite relationship is due to replacement, exsolution, co-precipitation, or a combination of two or more of these processes.

Microchemical etch tests as outlined by Short (1940, p. 158) indicate that minor amounts of cubanite (?) are present in the Marietta vein. Cubanite (?) occurs as grains visible only under magnifications of x 250 or greater and is invariably associated with a small grain of chalcopyrite. The associated grains are present as fracture fillings in pyrite and arsenopyrite.

Tennantite was identified in five of the polished sections studied on the basis of microchemical tests outlined by Short (1940, p. 260-263). It occurs in very minor quantities as grains less than 0.1 mm in diameter as inclusions in galena (Figure 21), pyrite, and arsenopyrite. Tennantite is apparently earlier than galena as shown
by corrosion of the tennantite grains.

Galena generally occurs as finely crystalline masses throughout the veins. In the larger shoots coarse galena with curved cleavages faces up to 0.5 inches across are common (Figure 14). Metallurgical tests performed on the ore during design of the mill confirmed that the galena is argentiferous. Silver minerals were not observed in the polished sections studied. Galena fills fractures in, and replaces, pyrite, arsenopyrite (Figures 16, 18, and 21), sphalerite (Figure 19) and quartz.

Native gold is present as extremely fine particles, chiefly in microfractures in pyrite and arsenopyrite (Figure 16). Rarely, specks of gold are observable in microfractures in quartz and as small grains in contact with chalcopyrite. About 80% to 85% of the gold in the ore is present as free gold and the remainder is incorporated in the pyrite and arsenopyrite structures (Sweeney and Lee, 1960, personal communication).

Quartz is abundant throughout the veins and is usually massive and milky white (Figures 12 and 13). Clear, euhedral crystals of the mineral, ranging from microscopic size up to 1 inch long, are commonly seen in vugs, hand specimens, and in polished sections. Most of the massive quartz, and in some cases the euhedral quartz, is fractured and has been replaced by the rest of the vein forming minerals. Quartz also has replaced most of the later minerals (Figures 15, 16, and 17).

X-ray diffraction studies revealed that siderite, ankerite, man-
ganocalcite, and calcite are the carbonate minerals present in the Marietta mine. Siderite is the most abundant and is light tan in color
Figure 15: Polished section No. M-5-33 from No. 5 level. Arsenopyrite (A) filling early fracture in pyrite (P), followed by fracturing. Sphalerite (Zn) and quartz (q) filling in the later fractures. x 60.

Figure 16: Polished section No. M-5-8 from No. 5 level. Galena (Pb) and quartz (q) filling fractures in, and replacing, pyrite (P) and arsenopyrite (A). Gold (Au) also present as fracture filling. x 60.
Figure 17: Polished section No. M-5-8 from No. 5 level. Quartz (dark gray) filling fractures and replacing arsenopyrite (A) and pyrite (P). x 60.

Figure 18: Polished section No. M-1/4-28 from No. 1/4 level. Fractured arsenopyrite (A) being replaced by sphalerite (Zn) and galena (Pb). x 60.
Figure 19: Polished section No. M-4-3 from No. 4 level. Galena (Pb) replacing sphalerite (Zn). Tiny grains in sphalerite are chalcopyrite. Note euhedral outline of arsenopyrite (A) and some of the pyrite (P). x 60.

Figure 20: Polished section No. M-4-3 from No. 4 level. Chalcopyrite (white) in sphalerite (dark gray) as oriented and randomly distributed inclusions. x 60.
Figure 21: Polished section from Cotter drift (Cot. Dr.). Galena (Pb) replacing pyrite (P) and possibly corroding ten-nantite (Te), quartz (q), and sphalerite (Zn). x 60.

Figure 22: Polished section No. M-4-58 from No. 4 level. Siderite (medium gray) replacing galena (light gray) along cleavages. Siderite grains disseminated outward from veinlets. Holes in section are black. x 60.
Figure 23: Paragenetic diagram and relative abundance of vein forming minerals in the Marietta mine.
and fine to coarsely crystalline. Ankerite and manganocalcite are fine grained and chalky. Both these minerals are white but manganocalcite commonly has a slight pinkish cast. Siderite, ankerite, and manganocalcite vein and replace galena along cleavages, and by outward incipient replacement from carbonate veinlets (Figure 22). Calcite is not abundant and is only found as small crystals in vugs or on cleavage planes of galena and is therefore considered to be a late mineral.

Paragenesis

The paragenetic sequence of the vein forming minerals in the Marietta mine is summarized in Figure 23. Quartz was the first mineral deposited in the veins with subsequent pyrite and later arsenopyrite deposition. Considerable overlap of quartz, pyrite, and arsenopyrite deposition is shown by fracture filling and replacement textures in polished sections of the ore (Figures 15 and 17). Quartz and pyrite appear to have been deposited in small amounts throughout the entire mineralizing period, as shown by cross-cutting relationships in the younger minerals.

Movement along the vein structure fractured the early quartz, pyrite, and arsenopyrite. These fractures were then filled by sphalerite which also replaced the host minerals. It could not be determined whether chalcopyrite replaced, exsolved from, or co-precipitated with sphalerite, or if a combination of these processes occurred.

Owing to the paucity of cubanite (?) and tennantite, their relative position in the paragenetic sequence could not be definitely determined. However, they appear to have been deposited after sphalerite and before galena.
Galena is the next mineral in the paragenetic sequence. It has replaced, and filled fractures in, all the major older minerals. The carbonate minerals (siderite, ankerite, and manganocalcite) were deposited after galena. A paragenetic sequence for these carbonate minerals was not postulated owing to lack of evidence. The carbonate minerals have vigorously replaced galena (Figure 22) and the older minerals (quartz, pyrite, arsenopyrite, and sphalerite).

The carbonate minerals have been partially replaced by a late stage of pyrite and quartz, which are also present as euhedral crystals, partially filling vugs. The early stage of quartz is generally milky white whereas the late stage chiefly consists of clear euhedral crystals. Calcite is also a late stage mineral and can be observed only in vugs and occasionally as films on cleavage planes of galena.

A late fracturing of the vein minerals occurred before the deposition of gold, which probably was the last mineral to be deposited. Fractures that contain gold can be followed through all of the major earlier minerals, except late quartz and calcite.

Mineral zonation

The carbonate minerals, siderite, ankerite, and manganocalcite, are vertically, but not horizontally, zoned in the Marietta vein. There is no vertical or horizontal zonation of any of the other minerals.

Ankerite and manganocalcite were differentiated by X-ray diffraction study owing to their megascopic similarity. Since siderite is megascopically identifiable only those samples that possibly contained one of the other carbonate phases were studied by X-ray diffraction. The 28 carbonate mineral samples studied by X-ray diffraction included
seven samples from the No. 5 level, five samples from the No. 4 level, and 16 samples from the No. 3 level of the Marietta mine.

Siderite is the dominant carbonate mineral on the No. 4 and 5 levels of the mine. Two samples from the No. 5 level contained manganocalcite. One sample from the 421 stope, about 10 feet above the No. 4 level, contained ankerite. The rest of the carbonate samples X-rayed from the No. 4 and 5 levels of the mine contained only siderite. X-ray diffraction patterns of 16 samples from the No. 3 level showed one occurrence of siderite, one occurrence of siderite and manganocalcite, three occurrences of manganocalcite, four occurrences of ankerite and manganocalcite, and seven occurrences of ankerite.

In summary, siderite is enriched in the lower levels while ankerite and manganocalcite are confined to the upper levels of the Marietta vein. Lack of samples above the No. 3 level prevented a study of the carbonate phase in this area.

Temperature of ore deposition

The vertical zonation of the carbonates described in the preceding section indicates a temperature gradient in the Marietta vein during mineralization. According to Rosenberg (1959, p. 1664) the composition of ankerite in equilibrium with siderite and calcite is dependent on temperature and a possible application in geothermometry is suggested. Unfortunately, pressure-temperature relationships in the system CaCO$_3$-MgCO$_3$-FeCO$_3$-MnCO$_3$ are only vaguely known. Rosenberg (1960, p. 1959) states that it is now possible to construct a preliminary, isothermal, quaternary diagram of the above system. However, this is insufficient to determine the temperature range of the carbonate
assemblage found in the Marietta vein. Shaw's (1959, p. 1674-1685) study of the carbonates in the Bunker Hill mine, Idaho, shows that a zonation of the carbonates exists. Siderite is most abundant in and near the veins, ankerite becomes abundant short distances from the veins, and calcite is no closer than 200 feet from the veins. Shaw proposes that this carbonate distribution can be traced to hydrothermal differentiation during mineralization.

Phase studies by Clark (1960, p. 1371-1379) on the Fe-As-S system show that pyrite and arsenopyrite cannot co-exist as a stable pair above $491^\circ F / 120^\circ C$ at 1 bar confining pressure, providing the vapor was saturated. The slope of the upper stability curve of the pyrite-arsenopyrite assemblage is about $1.8^\circ C$ per 100 bars confining pressure (Clark, 1960, p. 1642). The same author (p. 1374) states that pyrite and arsenopyrite can co-exist in equilibrium at temperatures between $491^\circ F / 120^\circ C$ and some unknown lower limit. Therefore, the maximum temperature of the ore solutions during deposition of pyrite and arsenopyrite in the Marietta mine must be about $491^\circ F / 120^\circ C$.

Comparison with other Deposits

The geology of the numerous veins in the area mapped appears to be similar to that of the veins in the Marietta mine. Some of the outlying veins, however, are associated with exposed intrusive rocks. The association of the ore deposits with intrusive and extrusive rocks throughout the Elkhorn Mountains suggest that the mineralization in the Marietta mine is genetically related to the magma from which the intrusive and extrusive rocks in the area originated.
Knopf (1931, p. 11) states that the ore deposits of the Helena mining region are replacement-fissure lodes commonly enclosed in andesite or intrusive rocks and containing pyrite, arsenopyrite, galena, and sphalerite as the principal sulfides, and tourmaline as one of the gangue minerals. Tourmaline, however, is not a ubiquitous mineral throughout the region. Pardee and Schrader (1933, p. 196) agreed with Knopf and further stated that a characteristic zonalational trend in the region is the increase in the proportion of quartz to sulfides with depth. The Marietta mine generally fits the above descriptions with the exception of a lack of tourmaline and a quartz-sulfide zonation. However, deeper exploration of the Marietta mine may reveal the presence of a quartz-sulfide zonation.

The Marietta ore is generally similar to the "typical epithermal deposits" described by Schmitt (1950, p. 192-194). In epithermal deposits the lodes are generally enclosed in altered andesitic rocks of about the same age and occupy faults in which fissure filling predominates over replacement. Texture and mineralogy is similar to Marietta ore. The Marietta mine, however, contains more sulfides and less quartz than the "normal" epithermal deposit. Increasing fissure complexity upward and downward bottoming into a barren zone, common in epithermal ore deposits, is not observable in the Marietta area owing to erosion and lack of exploration at depth.

Igneous activity and associated ore deposition in the Boulder batholith can be divided in three periods (Billingsley and Grimes, 1918, p. 288-292). These three periods are: (1) an early andesite period (upper Cretaceous), (2) a granite period (lower Tertiary), and
(3) a rhyolite period (probably Oligocene). During the granitic period
the Boulder batholith and the largest number and the most varied types
of ore deposits were emplaced. The Indian Creek region is listed as
one of the districts that probably was mineralized during the granitic
period (Billingsley and Grimes, 1918, Appendix B).

Mineralization in the Marietta area is considered by the author
to be genetically related to the magma from which the Elkhorn Mountains
volcanics and associated basic intrusive rocks in the area originated.
This phase of igneous activity occurred during the andesite period and
therefore, it is reasonable to assume that the mineralization in the
Marietta area was stimulated by this igneous period. Numerous epithermal ore deposits throughout the world are considered to be genetically
associated with basic extrusive rocks, and specifically with altered
andesites similar to those of the Marietta area. Examples of these
epithermal deposits are: the San Juan district (Moehlman, 1936, p.
377-397, 488-504); the Pachuca silver district, Mexico (Wisser, 1937,
p. 482-486); and the Tonapah mining district, Nevada (Nolan, 1935,
p. 28-46).

Suggestions for Prospecting in the Marietta Area

The Marietta and Gold Dust veins below the No. 5 level, and the
northward extension of the Marietta vein on the No. 4 level, are consid-
ered areas that are most likely to contain undiscovered ore. The
Marietta structure extends a minimum of 400 feet further north on the
surface and B level than the known northern extent of the structure on
the No. 4 level (Plate II). The difference in elevation between the B
and No. 4 levels is about 245 feet. Therefore, one may expect the structure to continue northward on the No. 4 level. Exploratory drifting on, and raising from, the No. 4 level appears to be the most feasible method of determining the existence of ore north of the present extent of the No. 4 level.

Exploratory work is presently in progress on the Mason tunnel level. This consists of northward drifting in order to explore a possible westward and deeper extension of the Little Annie vein (Plate I), and the Gold Dust and Marietta veins at depth (Plate II). The difference in elevation between the Mason tunnel level and the No. 5 level of the Marietta mine is about 300 feet (Plate II).

Further exploratory work on the surface may prove fruitful, especially along the trend of the Marietta vein. Lack of outcrops and heavy soil cover would entail removing the overburden by relatively inexpensive methods.

The exploratory work described in this section will involve high capital risk but it is generally agreed that mining exploration must be venturesome, within reasonable economic limits, if new ore bodies are to be found.
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ADDITIONAL REFERENCES


