GEOLOGY AND ORE DEPOSITS OF THE
SOUTH-CENTRAL CALICO MOUNTAINS

A Thesis
Presented to the
Faculty of
California State
University, San Diego

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
in
Geology

by
Alan L. Mayo
August 1972
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Approved by:
ACKNOWLEDGMENTS

The writer would like to thank Mr. Brian Hatch, past president of Calico Silver Incorporation, and the late Charles Hatch for their valuable support by providing private mining reports, maps, access to the property and monetary assistance during all phases of this study. Thanks are also extended to Dr. R. Gordon Gastil and Dr. Vincent J. Landis for their aid in the preparation of this manuscript, and to Dr. Allen M. Bassett and Dr. Richard P. Phillips for their assistance during the mapping portion of this study. I would also like to thank Dr. Blakemore E. Thomas for being Chairman of my thesis committee.
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Location

The Calico Mountains lie in the center of the Mojave Desert, which is a wedge-shaped area bounded by the San Andreas and Garlock Faults to the southwest and northwest respectively. California Interstate 15, between Barstow and Yermo, California, runs parallel to the south front of the Calico Mountains (Figure 1). The word Calico is painted on the side of King Hill in large block letters fifty feet high just above the historic ghost town of Calico.

Accessibility

Ten miles east of Barstow on California Interstate 15, a loop road two miles north of the freeway joins Ghost Town and Calico Road offramps. From this road the Odessa Canyon Loop, passable only by four-wheel drive vehicles, or the Mule Canyon Road with a side road via Tin Can Alley, passable by two-wheel drive vehicles, lead to the area.
Figure 1

Index Map
Climate

The climate is arid, which is typical of the Mojave Desert. Summer daytime temperatures range from 100° to 115° Fahrenheit and are often accompanied by dry, dusty winds.

Summer rainfall usually is concentrated in thunderstorms which may result in torrential flows. During the winter months, prevailing low temperatures are accompanied by sporadic rain and snow.

Sparse vegetation is of the arid type and is concentrated in the more level areas and stream valleys.

Topography

The Calico Mountains are approximately ten miles long in an east-west direction, and five miles wide from north to south. The north and south mountain fronts are generally characterized by steep scarps. Gently rising slopes are typical of the east and west mountain fronts. Inter-mountain valleys one to two miles square are separated by steep-sided peaks and ridges. Stream gradients are low at their heads, but frequently increase and form steep-sided canyons, many of which have nearly perpendicular walls up to two-hundred feet high,
near the south front of the mountain. The mapped area occupies the south-central portion of the Calico Mountains. Three northwest trending canyons are separated by steep hills in the mapped area.

**Fieldwork and Methods**

Fieldwork was done during the summer and fall of 1971. The geology was plotted on black and white aerial photographs at a scale of 1:24,000, on colored aerial photographs at a scale of 1:4,800 and on a topographic map at a scale of 1:6,000. Geology was transferred from the aerial photographs to the topographic map which was enlarged from the Yermo Quadrangle, California-San Bernardino County, 7.5 minute Series (Topographic).

Geologic mapping consisted of walking out contacts and fault traces on the ground. Description of rock units were generally made in the field, but refinements of lithologic descriptions were completed in the laboratory using thin sections.

The old workings were examined at and below the ground surface. Numerous samples were taken to determine possible stratigraphic and structural ore controls.
Several stratigraphic sections were sampled and measured. The samples were studied chemically and petrographically.

Silver analysis was done by atomic absorption. It was necessary to develop a new procedure to put the silver ions in solution, as chemical complications were discovered which prohibited using the standard methods.

**Previous Geologic Work**

Surprisingly little previous geologic work has been published on the Calico Mountains considering its historical interest and economic value. The early work by Lindgren (1887), Storms (1893), Weeks (1925, 1929) and others was principally restricted to localized ore bodies with little or no interpretation of the district's geologic setting.

Merriam (1911, 1915, 1919), Striton (1930) and Hall (1930) described the Miocene fauna of the Barstow formation.

Erwin and Gardner (1940) mapped the southern portion of the Calico District and described the ore deposits in general terms. DeLeen (1949) mapped the entire Calico District at a scale of 1:24,000 which
precluded the possibility of detailed mapping in the area covered by this report. The most extensive work done on the Calico Mountains was by McCulloh (1952), who mapped the Lane Mountain Quadrangle north of the Yermo Quadrangle. Although McCulloh's stratigraphic and petrologic work has been widely accepted in the desert region, it does not include the area of this report.

Webber (1965) and Dibblee (1970) produced open-file maps at a scale of 1:12,000 and 1:62,000 respectively.
CHAPTER II

STRATIGRAPHY

Rocks in the Calico Mountains in the vicinity of, but not limited to, the area of this study belong to the Pickhandle, Calico and Barstow Formations, Dry Lake Volcanics and the Yermo Formation.

The granitic basement rocks which underlie much of the Mojave Desert, including the Calico Mountains, are not exposed in the area of this study.

The oldest exposed rocks are andesitic flows, tuffs, ignimbrites and auto-breccias of the Miocene Age Pickhandle Formation. The Pickhandle Formation is unconformably overlain by a thick sequence of lensoidal, in part, andesitic epiclastic and ash fall rocks of the Calico Formation.

The Pickhandle and Calico Formations were originally mapped as the upper portion of the Pickhandle Formation by McCulloh (1952), and was formally named Pickhandle by Dibblee (1967).

The Calico Formation grades upward into a thick sequence of lacustrine deposits of the Miocene Age Barstow Formation.
The highest stratigraphic unit of major importance consists of a series of andesitic to basaltic flows and flow breccias of the Dry Lake Volcanics. The Dry Lake Volcanics are probably Pliocene Age.

Terrace remnants of the Yermo Formation (Bassett, personal communication, 1972) consist of Pleistocene Alluvium.

**PICKHANDLE FORMATION**

**Age and Correlation**

The Pickhandle Formation was first named by McCullough (1952, pp. 112-25) after the type locality, Pickhandle Pass in the western end of the Calico Mountains T. 10 N., R. 1 E. Exposures of the Pickhandle Formation have been described by Dibblee (1967, p. 84) as follows:

... a sequence of mostly pyroclastic rocks exposed in the Waterman Hills four miles north of Barstow in Mud Hills, Opal Mountain—Upper Baise Canyon area and Gravel Hills... rest on eroded, weathered surface of pre-Tertiary crystalline rocks, except in eastern Mud Hills where it conformably overlies Jackhammer Formation...

Thickness of the Pickhandle Formation ranges from seven-hundred feet in the Gravel Hills to 3,700 feet in the Waterman Hills. A thickness of over
five-thousand feet had been reported by McCulloh (1952, p. 121) in the eastern Calico Mountains.

The Pickhandle Formation is similar in lithology to the Gem Hill Formation of Oligocene to middle Miocene Age in the Monolith and Cache Peak areas (Dibblee, 1967, p. 86).

**Units Mapped**

The Pickhandle Formation has been mapped (Plates I and II in pocket in back cover) as two distinctive units which are designated as Mpf and Mpt. The lower member Mpf consists of a series of andesitic flows and inter-beded tuff. The upper member Mpt includes andesitic flows, ignimbrites and a conspicuous auto-breccia. The Pickhandle Formation has been mapped as Mpu (undifferentiated Pickhandle Formation) in areas of uncertainty. The Pickhandle Formation forms the main portion of the volcanic series exposed in Wall Street Canyon, Odessa Canyon and the area between the Garfield Fault and Odessa Canyon. Exposures are also found at the northeast corner of Sweetwater Spring and two miles west of Tin Can Alley.

A minimum thickness of 450 feet has been measured near Wall Street Canyon where the most continuous section is exposed. The total thickness
probably exceeds 1,500 feet in the vicinity of Odessa Canyon.

Flows and Tuffs (Mpf)

The lowest stratigraphically exposed member of the Pickhandle Formation is a series of light grey to purple quartz andesitic flows and inter-bedded siliceous tuffs. The lower portion is a massive to well-bedded (5-15 cm) siliceous tuff which is brown in color, well indurated and resistant to erosion.

The following compositions were determined in thin sections.

Flow (sample number C-8)

60% groundmass, devitrified glass
35% plagioclase, altered
3% quartz
3% opaques
1% biotite

Tuff (sample number C-5)

50% glass, devitrified
38% plagioclase, very highly altered to sericite, broken phenocrysts
7% quartz, euhedral, highly resorbed, to 2 mm
2% opaques, magnetite

phenocrysts are broken, no flow structures, non-detrital, possible ignimbrite
Flows, Ignimbrites and Auto-Breccias (Mpt)

Andesitic flows, ignimbrites and auto-breccias form the upper portion of the Pickhandle Formation. Except for the auto-breccias, the rocks are generally massive. Fresh exposures of this member are generally dark purple in color. The auto-breccias represent highly viscous flows of the aa type which contain angular chunks and blocks of the cooling crust of the flow which were incorporated into the flow as it advanced. Large swirling flow patterns with pseudobedding are visible in many of the flows. All silver mineralization in the Pickhandle Formation is contained in portions of the auto-breccias.

The following compositions were determined in thin sections.

Auto-Breccia (sample number C-15)

60% groundmass, devitrified glass
34% plagioclase, euhedral to subhedral, highly altered
5% opaques
1% quartz, euhedral
1% apatite
1% unknown green fiberous mineral

glossy with phenocrysts
Ignimbrite (sample number C-4)

49% plagioclase, altered to sericite, very angular and broken
40% groundmass, devitrified glass
6% opaques, possible oxy-biotite
5% quartz, euhedral, resorbed

Flow (sample number C-11)

Approximately the same composition as the auto-breccia

**Conditions of Deposition**

The Pickhandle Formation was deposited during an interval of active volcanism in the Calico area. In the south-central Calico Mountains (the area of this study), the Pickhandle Formation is composed primarily of flows and ash fall tuffs. McCulloh (1952) reported a great thickness of hydroclastics and atmoclastics and a general lack of lava flows in the western Calico Mountains. Based on a pronounced eastward thickening (from a location in the western Calico Mountains), McCulloh (1952, p. 123) suggested a volcanic center not far to the east or southeast. The lack of epiclastics and the thickness of the flows and ash falls in the south-central Calico Mountains suggest the center of volcanism was in the area just north and northeast of the present town of Calico.
Numerous fissure-type flows from widely dispersed vents spread lava across a surface of low to moderate relief in the area of this study. Intermittent ash falls deposited thick blankets of tuff. Hot ash cascading from cinder cones inter-tongued with lava flows and ash fall deposits.

CALICO FORMATION

Age and Correlation

Calico Formation is proposed as a new formation name to describe volcanically-derived ash fall and epiclastic rocks in the Calico Basin located between the uppermost Pickhandle Formation and the lower portion of the Barstow Formation. The Calico Basin is defined as a lacustrine sedimentary basin whose known limits (Bassett, personal communication, 1972) extend from the Rainbow Basin ten miles north of Barstow, eastward to the Cave Mountain Quadrangle, which is twenty miles east of the Calico Mountains. The southern limit of the Basin is the Newberry Mountains where Dibblee (1970) described a major buttress unconformity. The northern extent of the Basin is unknown, although the Basin occupied all the area of the present Calico Mountains.
The type section is located on the east side of Wall Street Canyon, 230 feet north of the waterfall, section 15, T. 10 N., R. 1 E., San Bernardino Baseline and Meridian. The following is a description of the type section.

<table>
<thead>
<tr>
<th>Member</th>
<th>Thickness (feet)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Lake Volcanics</td>
<td></td>
<td>Unconformity</td>
</tr>
<tr>
<td>Mca</td>
<td>132</td>
<td>Ash fall tuff: light green to buff, non-resistant, glass shards and plagioclase phenocrysts</td>
</tr>
<tr>
<td>Mcrt</td>
<td>64</td>
<td>Tuff breccia: brown, massive, resistant, siliceous and highly fractured; Clasts - 50 percent tuff, 50 percent andesitic flow</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>Tuff breccia: massive, non-resistant popcorn weathering; Clasts - rhyolitic flows and tuffs</td>
</tr>
<tr>
<td>Mcwt</td>
<td>10</td>
<td>Pebble tuff: greenish gray, well-sorted, bedded</td>
</tr>
<tr>
<td>Member</td>
<td>Thickness (feet)</td>
<td>Description</td>
</tr>
<tr>
<td>---------------</td>
<td>-----------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Mcwt</td>
<td>33</td>
<td>Pebble tuff: white to grey, well-sorted, subrounded clasts - 30 percent rhyolite flow, 70 percent tuff</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>Conglomerate: massive, tuffaceous; Matrix - detrital tuff; Clasts - 20 percent subrounded granite (to four inches), 20 percent subangular, flow banded, andesite from Pickhandle Formation, 60 percent subangular rhyolitic tuffs and flows.</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>Tuffaceous sandstone: massive, dark grey to brown, coarse subrounded detrital grains</td>
</tr>
<tr>
<td></td>
<td>71</td>
<td>Pebble tuff: massive, grey to brown, silica cemented, minor cavernous weathering; Matrix - detrital tuff; Clasts - angular to subangular, rhyolitic flows and tuffs to 10 cm</td>
</tr>
<tr>
<td></td>
<td>108</td>
<td>Pebble tuff: massive, red; Matrix - mostly plagioclase with some biotite; Clasts - rounded to angular rhyolitic flows and tuffs, 2 to 150 mm, lower twenty feet bedded</td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>Lahar: greenish white crystal tuff, mottled appearance</td>
</tr>
<tr>
<td>Calico</td>
<td>Formation</td>
<td>unconformity</td>
</tr>
</tbody>
</table>
There is some question as to the relationship between the Calico Formation and the basal conglomerate of the Barstow Formation reported by Dibblee (1967, p. 86). The description given for the basal conglomerate of the Barstow Formation from the type section at Solomon Canyon is as follows: "Conglomerate, greenish grey; clasts mostly of granitic rocks, few of pegmatite, aplite and andesite—unconformity—Pickhandle Formation."

The Calico Formation does contain some granitic and andesitic clasts, but it is predominantly composed of detrital tuff and clasts of tuff. It is the opinion of the author that the Calico Formation is not the same as the basal conglomerate of the Barstow Formation.

The Calico Formation was originally mapped as the upper portion of the Pickhandle Formation by McCulloh (1952). The stratigraphic and genetic

<table>
<thead>
<tr>
<th>Member</th>
<th>Thickness (feet)</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>Pickhandle Formation</td>
<td>Auto-breccia</td>
<td></td>
</tr>
</tbody>
</table>
continuity between the overlying Barstow Formation and Calico Formation, when combined with the angular discordance between the Calico Formation and the underlying Pickhandle Formation, is significant enough to establish the Calico Formation. The Calico Formation included DeLeen's (1949) Odessa Formation and the dacite tuffs of his Calico Formation.

On the basis of a probable Miocene Age of the underlying Pickhandle Formation and a Miocene Age for the overlying Barstow Formation, the Calico Formation is also considered Miocene. No fossils were found in the Calico Formation.

Units Mapped

The Calico Formation is primarily a series of highly lenticular pebble tuffs. Reworked rhyolitic to andesitic flow and tuff pebbles constitute the majority of the clasts, although a few granitic and limestone clasts are found in some of the members. The matrix of the tuffs and conglomerates ranges from white to red in color and is largely reworked.

The following informal members, from top to base, have been mapped.
<table>
<thead>
<tr>
<th>Member</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mcf</td>
<td>andesitic ash fall</td>
</tr>
<tr>
<td>Mcot</td>
<td>Mcyt and Mcrt undifferentiated</td>
</tr>
<tr>
<td>Mcyt</td>
<td>massive to bedded yellow pebble and detrital tuff</td>
</tr>
<tr>
<td>Mcrt</td>
<td>massive to bedded red pebble tuff</td>
</tr>
<tr>
<td>Mcc</td>
<td>granite and limestone conglomerate</td>
</tr>
<tr>
<td>Mcwt</td>
<td>white, grey or red, non-resistant pebble tuff, basal lahar (in part)</td>
</tr>
<tr>
<td>Mc1</td>
<td>red, bedded, pebble tuff</td>
</tr>
</tbody>
</table>

By and large, the Calico Formation is the least resistant to erosion of all the formations in the area. A minimum thickness of 235 feet is exposed near Wall Street Canyon. Maximum thickness exceeds 1,700 feet near Calico Peak.

**Bedded Pebble Tuff (Mc1)**

On the east side of Wall Street Canyon, south of the waterfall and above the break in slope, the basal member of the Calico Formation is a reddish, bedded, pebble tuff. The basal portion of this member is a lahar deposit which is up to sixty feet thick and is similar to the lahar deposit in portions of basal Mcwt. Vertically, the lahar deposit grades into forty-five feet of well-bedded (three to twenty-four inches) pebble tuffs. Above the bedded tuffs, ten feet of massive pebble tuffs crop out.
Rounded adesite flow, dacite flow and andesite tuff clasts one-quarter to one and one-quarter inches in diameter are found in a matrix of reddish-brown detrital crystal tuff. No granite or limestone clasts are found in this member.

The areal extent of this member is limited to the Wall Street Canyon area, although a similar series of beds are found at the contact between the Pickhandle Formation and the Mcwt member of the Calico Formation in the SW ¼, SE ¼ section 10, T. 10 N., R. 1 E.

**White to Red Pebble Tuff (Mcwt)**

A non-resistant red, white or grey tuff to pebble tuff with a local basal lahar deposit forms the lowest member of the Calico Formation in most of the area mapped.

The lahar deposits contain a greenish-white crystal tuff matrix which weathers brown. Angular clasts, three inches to two feet in diameter, of highly weathered tuff give the lahar a mottled appearance. The angular clasts resemble exposures of weathered tuff in the upper portion of the Pickhandle Formation in Wall Street Canyon. A few rounded clasts of rhyolite to andesite flow rock and
tuff in the lahar, one to three inches in diameter, were also found in the lahar deposits.

Tuffs and pebble tuffs of the lower Calico Formation have been collectively mapped as Mew+, although lateral variations from one portion of the mapped area to another are common. Despite rapid facies changes and the pronounced lenticularity of this member, it is possible to describe the member in general terms.

Tuffs are generally massive and unstratified although they often contain thin beds of pebble tuff. Pebble tuffs are massive or bedded and non-resistant. Cavernous weathering in the tuffs and pebble tuffs, although typical, is not prominent. Well-sorted, subangular to rounded clasts of rhyolite, dacite and andesite flows and tuffs, ten to one-hundred millimeters in diameter, are typical, although clasts as large as thirty centimeters are not uncommon. Granite clasts are rare.

Exposures of Mew+ are extensive throughout the Western Calico Mountains. A white to grey detrital tuff crops out at the Sweetwater Spring. About 1,800 feet west of the Kramer Arch, this member is a whitish green crystal tuff and lahar deposit. In the eastern part of section 9 and the
western part of section 10, the dominant lithology is a red and white pebble tuff.

**Conglomerate (McC)**

A wedge of andesite, limestone and granite conglomerate crops out on both sides of Wall Street Canyon. The wedge thickens west of the Canyon and thins to the north and east. The wedge forms a lens in McCw on the east side of the Canyon. The wedge rests on McC on the west side of the Canyon. The conglomerate forms the cap rock on King Hill north of the Calico Ghost Town.

North of King Hill, on the east side of the Canyon, a series of resistant andesite and granite conglomerate boulders, up to thirty feet in diameter, crop out. Subrounded granite clasts to three inches and subangular andesite flow and tuff clasts are contained in a brown, calcareously cemented, tuffaceous matrix. Limestone clasts, although rare, are occasionally found. At first appearance these boulders resemble many of the mega-breccias common in the eastern Mojave.

The boulders may be traced southward to King Hill where they form a continuous bed of conglomerate. The lithology of the conglomerate changes somewhat
in this area. Andesite clasts predominate. On the eastern side of King Hill the clasts are more rounded and smaller.

Exotic limestone and granite clasts in a matrix of weathered granite and limestone detritus form the main sequence on the west side of Wall Street Canyon. Lensoidal beds, ten to thirty feet thick, which probably represent stream channel fillings, may be traced for short distances. Granite clasts are subrounded to rounded and three to five inches in diameter, although clasts as large as four feet are found. Limestone clasts range in size to 1.5 feet. In-situ weathering is pronounced in the conglomerate.

**Red Pebble Tuff (Mert)**

The lateral continuity of this red, reworked pebble tuff makes it one of the most easily recognized members of the Calico Formation. The tuff is generally highly resistant to erosion forming the prominently stripped dip slopes between Calico Ghost Town and Phillips Drive.

The lower portion of this member is generally massive, although pebble beds without well-defined bedding planes are common. Poorly sorted,
subangular to subrounded rhyolite to andesite flows and tuffs, ten to one-hundred millimeters in diameter, are the common clasts. Locally subrounded granite clasts are found. A coarse-grained red matrix completely surrounds all the clasts.

Measured thicknesses vary from zero feet in the NW ¼, NW ¾, section 14, to sixty feet in the NE ¼, NW ¼, section 23. In the vicinity of Calico Peak, the thickness may exceed 150 feet.

The upper portion is generally a cavernously weathering, well-bedded, pebble tuff. The matrix of the tuff is a ferruginous stained, medium to coarse-grained, tuffaceous sand composed of plagioclase and minor amounts of quartz and biotite. Clasts are similar to those found in the lower portion of this member.

Extensive exposures of MtMt are found throughout the western Calico Mountains. This member is usually found conformably on the MtMt member of the Calico Formation. In the SW ¼, SE ¼, section 14, on Phillips Drive near the loop end, MtMt rests with angular discordance on the Pickhandle Formation,
Yellow Pebble Tuff (Mcyt)

This member is very similar to Mcrt except for color, permeability and amount of silver mineralization. It is highly mineralized in some locations, notably the Bismark Site and the Blackfoot Extension, forming large low-grade silver deposits. Exposures are located in three areas: north of Sweetwater Spring, Bismark Site and as a nearly continuous east-west trending strip just east of the ghost town.

The tuffs north of Sweetwater Spring are light yellow colored. A blocky fracture yields angular weathering detritus one-half to one inch square. The tuff is composed of yellow ferruginous stained, medium to coarse grained quartz and plagioclase detritus. The tuffs in this area form a northward thickening wedge-shaped deposit. The thickness increases from two-hundred feet at the Sweetwater Spring to more than one thousand feet two miles north in the Calico Peak area.

At the Bismark Site and east of the ghost town, Mcyt attains a maximum thickness of two-hundred feet. It is massive at its base and grades upward to a cavernous-weathering, well-bedded, yellow pebble tuff. The pebble tuff is well sorted,
highly indurated, very permeable, partially banded with ferruginous stain and silica cemented. Pebbles similar to those in Mart are present but less abundant. The matrix is a course, yellow, reworked tuff composed mostly of plagioclase. Locally, the tuff grades into a yellow ignimbrite.

**Ash Fall (Mca)**

A siliceous andesitic ash fall is the uppermost member of the Calico Formation. It is light green in color and is generally not resistant to erosion. The ash is composed of glass shards and plagioclase phenocrysts.

Where secondary silica has been introduced, the ash is very resistant and forms topographic highs. Elsewhere, it has been completely eroded away except where it is protected by a capping of the Dry Lake Volcanics. In the area mapped Mca is restricted to the western part of section 15, the eastern part of section 14 and the NW ¼ of section 15. Maximum thickness is 120 feet in the E. ½, section 14.

**Conditions of Deposition**

The Calico Formation was primarily deposited as reworked volcanic pebble tuffs and volcanic
derived conglomerates. The formation was deposited in the Calico Basin. Active faulting and sedimentation continuously changed the configuration of the Basin contemporaneously with the deposition of the Calico materials and to some extent the Barstow Formation.

The basal member of the Calico Formation (Mclt) filled local topographic lows on the low to moderate relief Pickhandle Formation erosion surface. Local basement highs supplied some of the sediments of the Calico Formation. The surface area not covered by the basal tuffs preclude the possible derivation of the bulk of the Calico sediments from flows, tuffs and ignimbrites of the Pickhandle Formation in the immediate area.

Exotic detritus of the Mcl member represent a high energy stream or possible fan deposit which originated west or northwest of the Basin. McCulloh (1952) reported Paleozoic carbonates and Mesozoic granitics eight miles northwest of the Calico Ghost town.

Nearly continuous deposition and eastward increase in coarseness of the Mclt member is considered indicative of a fluvial, moderate energy
environment, which grades eastward into a low energy lacustrine environment.

The pronounced northeastern wedging and increase in detrital fineness of the Mcyt member is considered to indicate this member formed under similar conditions as Mcrt. Occasional granitic clasts in the upper Calico Formation support the westward source theory unless these clasts are reworked Mc1.

The Calico Formation, in general, represents the preliminary filling of the Calico Basin. The area in the vicinity of Calico Ghost Town is the transition zone between terrestrial fan and fluvial deposits and lacustrine sedimentary deposits.

BARSTOW FORMATION

Age and Correlation

The Barstow Formation was named by Merriam (1915, p. 252) to designate a sequence of terrestrial and lacustrine deposits which contain remains of fresh water mollusca, Planorbis and Anodonta, in the Mud Hills north of Barstow. The name Barstow was designated for this faunal assemblage of upper Miocene Age contained in the Barstow Formation. According to Byers (1960, p. 33),
the middle Miocene *Merychippus tehacapiensis* occurs in the lower portion of the Barstow Formation in the Alvord Mountain Quadrangle.

The Formation had been described by Dibblee (1967, p. 86) as a sequence of conglomerates, sandstones, limestones, tuffs, claystones and algal limestones. A thickness as much as three-thousand feet had been reported in the Mud Hills.

**Unit Mapped (Mb)**

The portion of the Barstow Formation considered in this study represents only a small fraction of the entire formation. The Barstow Formation in the Calico Basin has been mapped as undifferentiated lacustrine deposits. The principal lithologic types are siltstones, tuffs, sandstones, limestones, claystones, mudstones and silty limestones. The sequence thickens eastward where it is covered by massive flows of the Dry Lake Volcanics.

The multicolored siltstones and sandstones, for which Calico was named, provide a brilliant display at sunrise or sunset. Limestone beds six inches to three feet thick form protective horizons in the tilted strata. Badlands topography predominates where the limestones have lensed out.
The strata have been severely folded. Rapid lateral changes in lithology and thickness are characteristic of the Barstow Formation in this area.

**Conditions of Deposition**

The sediments of the Barstow Formation in the Calico Basin, near Calico Ghost Town, are predominantly lacustrine. Evidence of a lacustrine environment includes drab colored beds indicating a reducing environment, lack of large clasts usually associated with terrestrial deposits and numerous thin limestone beds.

The clastic sediments were derived from older pyroclastic sediments and, in part, from contemporaneous volcanic activity as indicated by the thick accumulation of tuff-rich beds at some horizons.

Transgressions and regressions of the shoreline are indicated by the common occurrence of rapid changes in lithology from a fine-grained sediment to one of coarser constituents. Rapid changes in grain size cannot be attributed to changes in the source area because of the variability from one member to another.
Localized hot spring activity is indicated by the occurrence of two ten to thirty foot borax beds, principally colemanite, which are located in the NE ¼, section 19, T. 10 N., R. 2 E. (off the map).

**DRY LAKE VOLCANICS**

The name Dry Lake Volcanics is proposed as a new formation name to describe a series of post-Barstovian Age, possibly Pliocene, flows and flow breccias in the Calico Mountains.

**Age and Correlation**

Post-Barstovian Age volcanic rocks in the Calico Mountains have been correlated with the Red Mountain Volcanics by DeLeen (1949) and McCulloh (1952). The Red Mountain Volcanics were first described by Hulkin (1925, p. 55) as a series of Pliocene andesitic flows and breccias in the Randsburg Quadrangle, California. To avoid possible confusion in correlating isolated exposures of terrestrial volcanics forty-five miles apart, I have proposed the name Dry Lake Volcanics for these rocks. The Red Mountain Volcanics and the Dry Lake Volcanics probably represent similar tectonic events during the same time interval.
Unit Mapped (Pv)

All post-Barstovian Age volcanic rocks have been mapped as undifferentiated Dry Lake Volcanics. The following rock types were found in the study area: dacite and andesite flows, andesite breccia including breccia pipes, and andesite dikes.

Andesite flows with zoned labradorite, euhedral augite, subhedral hypersthene and a glass matrix form a protective capping on the Calico and Barstow Formations in many locations.

The following composition was determined in thin sections.

**Flow (sample number C-2)**

- 50% plagioclase
- 25% groundmass, devitrified glass
- 20% augite
- 5% hypersthene

Andesite breccia, flow breccias and breccia pipes are not as common as the andesite flows. The breccias contain angular andesite clasts one to four inches in diameter. The most accessible breccias are located in the NE ¼, SE ¼, section 26, T. 10 N., R. 1 E. and in the SE ¼, SE ¼, section 15, T. 10 N., R. 1 E.

West of Calico Peak (north of the mapped area) andesite dikes are common. Northeast of the Bismark
Site in the SE ¼, section 10, T. 10 N., R. 1 E., the only mapped dike crops out along a four-hundred foot exposure. The dike has the same composition as nearby flows.

Dacite flows with twinned and zoned plagioclase crystals occur as stream channel fillings south of Calico in the SE ¼, section 22, T. 10 N., R. 1 E. and at Tin Can Alley in the SE ¼, section 18, T. 10 N., R. 2 E. Other dacite flows are found north and east of the area mapped.

The following composition was determined in thin sections.

**Flow** (sample number C-31; off mapped area)

- 45% groundmass, devitrified glass
- 25% andesite
- 8% biotite
- 8% anorthoclase
- 5% quartz

Dacites in Tin Can Alley have a pink tint and have been quarried for building stone.

**Conditions of Deposition**

The Dry Lake Volcanics were extruded on a terrestrial surface of relatively high relief. The dikes represent feeders to fissure flows which filled nearby stream canyons with lava. The dacites are younger than the andesites and represent a
probable change in composition of source melt. Volcanic activity was intermittent and not as extensive as the flows in the Pickhandle Formation.
CHAPTER 11

STRUCTURE

Structural complexities in the Calico Mountains may be grouped into three subdivisions, all of which are related to a general doming of the Calico Mountains: 1) regional doming of the Calico Mountains, 2) numerous northwest-trending and subsidiary northeast-trending faults, and 3) asymmetrical anticlinal folding in the Pickhandle and Calico Formations and related intense folding and minor faulting in the Barstow Formation.

Domino

The area north of the Calico Ghost Town has undergone a doming movement as a result of the upward and outward migration of a molten or semi-molten igneous intrusion which is surface manifested as the Dry Lake Volcanics. The center of the east-west elongated dome is located in the upper portion of Wall Street Canyon or in the area slightly to the east. Strata of the Calico Formation in the southern portions of Wall Street, Bismark and Odessa Canyons dip as much as 35° toward the south. East
of Bismark Canyon, the Calico Formation dips eastward. Calico strata north of an east-west trending line through Sweetwater Spring in the vicinity of section 17, T. 10 N., R. 1 E. dip slightly toward the west.

Although the crystalline core of the dome is not exposed, it must lie at shallow depths below the Pickhandle Formation. A shallow depth is particularly evident along the south front of the Calico Mountains where the steep scarp is exposed.

Presumable antithetic and synthetic faulting along the outer margins of the igneous intrusion extend through the Pickhandle and Calico Formations to the surface of the ground. The nearly parallel northwest-trending faults are the surface manifestation of subsurface antithetic faulting resulting from igneous tectonics. Most of the east-west trending faults are likewise of synthetic origin.

The apparent contradiction of contemporaneous extrusion of the Dry Lake Volcanics along faults in the parent magma with the intrusion and faulting in this parent igneous magma is readily explained by Balk (1937) who stated that a similar condition was common where felsitic dikes associated with an
igneous intrusion were injected along antithetic faults which form as the intrusion was emplaced.

**Faulting**

Numerous dip slip faults of antithetic origin, including the Wall Street, Oriental, Bismark and Garfield Faults, have been traced the length of the Pickhandle and Calico Formations in the area mapped. Most are normal faults causing re-exposure of older rocks to the east.

Locally, these faults form a series of parallel or step faults three to five feet apart. Relative separation is generally small, measuring in feet or a few tens of feet, although exceptions as the Garfield occur. The amount of separation on many of the faults varies from one place to another along the fault trace. Steeply dipping fault planes are highly variable, often changing the direction of the dip. Faults may be traced as much as three-hundred feet in depth in some of the underground workings.

Along the periphery of the dome, many of the faults tend to flatten with depth as exemplified in the deeper working of the King and Oriental Mines along the Wall Street Canyon Fault. DeLeen (1949)
considered this as evidence for a general flattening trend of all the faults in the area. Flattening along the periphery, however, is compatible with the development of marginal fractures and does not necessarily indicate a general flattening for all the faults.

The northwest-trending faults intersect numerous east-west trending faults of smaller or insignificant magnitude. Most of these have been left off the map to avoid confusion. Exposed fault planes dipping 45° to vertical in many shafts and adits often have a well slickensided footwall which may be opposed by a barite bearing vein. Displacement on these faults is usually vertical. Poor exposures make it difficult to trace many of these faults more than a few or a few tens of feet.

The earliest faulting is at least contemporaneous with the deposition of the Calico Formation and may be in part pre-Calico. Sporadic faulting continued until after the deposition of the Dry Lake Volcanics. The intermittent movement on various faults partially changed the configuration of the Calico Basin in the area of this study causing erosions of the Calico Formation while the Calico
sediments were being deposited elsewhere in the basin.

**Folding**

Minor folds are found in the Pickhandle Formation. Some of these folds may represent flow structures rather than tectonic features.

The east-west trending anticline in sections 15 and 14, T. 10 N., R. 1 E, breaks into a gravity fault in sections 14 and 13, T. 10 N., R. 1 E. The anticline-fault system is the hinge line between the domed block and the trailing edge of sediments which were not domed. These sediments drape off the up-domed block. Dips north of the anticline are generally less than 20°, while those south are generally greater.

Intense folding is very conspicuous in the incompetent Barstow Formation. Isoclinal, recumbent and asymmetrical folds forming tight fold series are very common. The most intense folding is near the contact between the Calico and Barstow Formations. The doming of the Pickhandle, Calico and Barstow Formations along the south front of the Calico Mountains caused the less competent Barstow Formation to slowly slide off the trailing edge of
the doming surface. The trailing edge of the Barstow Formation underwent severe crustal shortening resulting in intense folding and some faulting.

Faulting in the Barstow Formation, although related to doming, is not a direct consequence of antithetic or synthetic faulting, but is primarily a result of gravity tectonics.
CHAPTER IV

SILVER DEPOSITS

History

Silver was first discovered in the Calico District by John McBride, Larry Silva and Charlie L. Meacham in 1881 (Coke, 1948, p. 5). The period of active mining occurred from 1882 until the early 1890's. High-grade silver ores containing as much as two-hundred ounces of silver per ton were mined. When the price of silver dropped to sixty-four cents per ounce in 1894, most of the activity in the District ceased. An accurate figure of the total production is difficult to determine as complete records were not kept. The most common figures available are around $35 million, with high figures up to $50 million (Billingsley, 1929, p. 1). At one dollar per ounce, total production must have been at least 35 million ounces. In the late twenties and early thirties, a little ore was removed by the Zenda Mining Company. At the present time the only mining activity is in the form of exploration for low-grade deposits.
Mineralogy

The principal silver mineral of the Calico District is cerargyrite (AgCl). It is a soft, waxy mineral which ranges in color from pale grey to green in the Calico area. Embolite (AgBrCl) occurs less commonly. Cerargyrite and embolite are secondary minerals. Primary minerals, such as tennantite, stromeyerite, galena, argentite, chalcopyrite and proustite, were occasionally found. The primary minerals are generally found in the deeper mines.

DeLeen (1949) compiled the following list of minerals found in the Calico District. Most of the minerals are rare.

Anglesite (PbS)₄ occurs as a secondary mineral in the veins of the Leviathan, Silver Bow and Revier Mines. Polished specimens show galena in the process of alteration to anglesite.

Azurite (2 CuCO₃·Cu(OH)₂) stain is abundant with the other copper carbonate and silicates in the oxidized ores.

Argentite (Ag₂S) occurs as a primary and secondary mineral.

Barite (BaSO₄) is the principal gangue of the veins of the Calico District. It occurs in West
Calico as great veins traceable for over a thousand feet. The barite occurs as crystals stained with hematite and limonite.

**Bornite** ($\text{Cu}_5\text{FeS}_4$) occurs as small blebs in specimens taken from the lower working of the Silver King and Oriental Mines.

**Calcite and Siderite**, although not abundant, can be seen as crystalline aggregates in some veins.

**Cerargyrite** ($\text{AgCl}$) is the chief ore mineral. Specimens have a waxy luster and color varies from grey to green. Museum specimens of cerargyrite appear to line vug-like cavities, and when opened have a noticeable odor of chlorine. Fresh crystals are pure white, have a waxy luster and tend to darken to grey on exposure to light. Cerargyrite has been found in the vein deposits with barite, as impregnations in tuff beds and as a cementing material in a breccia along fault zones.

**Cerrusite** ($\text{PbCO}_3$) is found in the oxidized ores.

**Chalcocite** ($\text{Cu}_2\text{S}$) occurs in the lower working of the Silver King and Oriental Mines. It appears to be of secondary origin, replacing chalcopyrite along fractures and crystal boundaries.
Chalcopyrite (CuFeSO₄) occurs as irregular masses with tetrabedrite, galena and argentite.

Chrysocolla (CUSiO₃·2H₂O) occurs abundantly in the working of the Garfield Mine as coatings on breccia fragments.

Embolite (AgBrCl) is a green, waxy mineral associated with cerargyrite in the Garfield Mine.

Covellite (CuS) occurs as filmy delicate layers replacing galena, and is of secondary origin.

Galena (PbS) specimens were collected from the mines of West Calico and from the Carbonate Group in Calico. The specimens were partly altered to anglesite or cerrusite. Crystals of galene occur in the Ballast and the Blackfoot properties east of Odessa Canyon.

Hematite (Fe₂O₃) occurs as a minor constituent in all the veins in grains less than one millimeter in diameter. Massive hematite forms 90 percent of the West Burcham veins.

Hemimorphite (Zn₄Si₂O₇(OH)₂·H₂O) is reported in Dana's "System of Mineralogy," 6th Edition, 1903, p. 1097. This occurrence is doubtful.

Limonite (Fe₂O₃·nH₂O) occurs with hematite, barite and horn silver in the zone of oxidation.
Malachite \( \text{CaCO}_3 \cdot (\text{CuOH})_2 \) is one of the secondary copper minerals occurring as stains in the zone of oxidation.

Proustite \( \text{Ag}_3\text{ASS}_3 \) occurs in the Silver King and Oriental Mines.

Polybasite \( \text{Ag}_3\text{SbS}_3 \) occurs with proustite.

Pyrite \( \text{FeS} \) is common in all the polished sections of unoxidized ore.

Pyrolusite \( \text{MnO}_2 \) is abundant in the oxidized zone with the chlorides and bromides of silver. It occurs as black, sooty masses.

Quartz is one of the vein minerals. Quartz crystals fill vugs and form crustifications on cracks and fissures.

Chalcedony, Chert and Opal form part of the crypto-crystalline vein matter occurring abundantly in and near the veins.

Realgar \( \text{AsS} \) occurs as a secondary mineral in the oxidized zone and may indicate the presence of former arsenosulpho salts.

Silver \( \text{Ag} \) occur with the cerargyrite and embolite minerals. Specimens from the Silver King and Oriental Mines have plates of silver occurring in the wall rocks.


**Stibnite** \((\text{Sb}_2\text{S}_3)\) occurs in the oxidation zone with realgar.

**Stromeyerite** \((\text{AgCu})_2\text{S}\) is found in the Silver King Mine.

**Tetrahedrite** \((\text{CuFe})_{12}(\text{Sb}_4\text{S}_3)\) occurs in some of the deep workings at Calico.

**Wulfenite** \((\text{PbMnO}_4)\) is found in the oxidized zone.

**Gold** occurs as a minor constituent in some of the silver veins with a value up to one dollar per ton. The Burcham, Union and Lone Star Mines are the only potential gold properties in Calico.

**Ore Bodies**

Silver deposits in the Calico District can be divided into two descriptive groups: 1) deposits directly associated with veins along faults, and 2) deposits of irregular form which may be located near faults and are often characterized by "gopher-type" workings. Mined economic ore bodies are restricted to the tuffs and pebble tuffs of the Calico Formation, and to localized areas in the Pickhandle Formation which have a close proximity to the Calico Formation. Mineralized areas of the Pickhandle Formation include portions of the upper member (Mpt)
and localized areas in the lower member (Mpfl) where faulting has brought it into or nearly into contact with the Calico Formation. The yellow pebble tuff (Mcyt) and the red pebble tuff (Mcr1) are the principal mineralized members of the Calico Formation. A few localized areas of mineralization are found in other members of the Calico Formation.

All ore bodies are in the zone of oxidation. Silver mineralization is generally confined to the upper two-hundred feet of this zone. Only the Silver King and Oriental Mines have been developed to the water table which is five-hundred feet below the surface of the ground. The water table at these mines is closer to the surface than at any of the other mines in the District. In the St. Louis, Bismark and Garfield Mines and in portions of the Silver King and Oriental Mines and other mines in the District, mineralization is concentrated near the surface while barren gangue continues to depth. Primary sulfide minerals or indications of primary sulfide minerals, except disseminated pyrite, are generally absent in the zone of oxidation. Minor amounts of Galena occur near the surface in the Leviathan Mine one mile west of the St. Louis Mine.
A brief description of selected mines which typify the District are discussed below. Lindgren (1887), Storms (1893), Erwin and Gardner (1940), Tucker and Sampson (1943) and DeLeen (1949) give a more exhaustive description of all the mines in the District.

Vein-Fault Systems

A baritized and/or jasperized fault breccia containing silver halides in the upper portions is typical of the vein-fault systems. Earthy hematite and pyrolusite are commonly associated with the veins. Some vein-fault systems are composed almost entirely of hematite and red jasper. Usually the vein is entirely in the footwall or the hangingwall and is opposed by a well-slickensided face. The slickensided face may represent a low permeability barrier which helps regulate vein implantation. Earthy hematite is commonly associated with the slickensides. Vein-fault systems occur in both the Pickhandle and Celico Formations.

Silver King and Oriental Mines

The Silver King and Oriental Mines are vein-fault systems in the Wall Street Fault along the south front of King Hill. Splinters of the Wall
Street Fault at King Hill have a variable dip ranging from 60° to vertical. The veins branch and converge in the crushed rock in the various splinters of the Fault. Vein width varies from one inch to two feet. Silver ore of cerargyrite and embolite occur as thin coatings along joints and fractures and as fracture fillings in the gangue of barite and red jasper. Earthy hematite and red jasper are very common. Continued and sporadic movement along the Fault during emplacement of the vein is evident by crushed and recemented barite crystals. The barite has been recemented by barite, quartz, jasper, earthy hematite and silver minerals.

The veins occur in a brown, bedded tuff of the Mwdt member of the Calico Formation. Exposures of Mwdt at King Hill are not typical of this member, but more closely resemble the Mcrf member near the Bismark Site.

_**St. Louis Mine**_

The St. Louis Mine, located on the west rim of Wall Street Canyon in section 15, T. 10 N., R. 1 E., occurs as a series of six veins in closely spaced splinters of the Wall Street Fault. The St. Louis Mine is one mile northwest of the Silver
King and Oriental Mines. The ore of silver chlorides in a hematite-limonite-barite gangue is found in veins which dip to the east at about 80°. Stopes two-hundred to five-hundred feet in length are three to six feet wide and have been developed to a depth of 250 feet.

The veins occur in an auto-breccia of the upper member (Mpf) of the Pickhandle Formation. The Pickhandle Formation is broadly, anticlinally folded, perpendicular to the vein-fault system. The Calico Formation, which is found nearby, has been eroded off the auto-breccia. Before erosion the vein-fault system may have extended into the overlying Calico Formation.

Garfield Mine

The Garfield Mine is located along the Garfield Fault between Bismark Canyon and Phillips Drive. The Garfield Fault is primarily a single fracture which dips 75° to the southwest. The north or footwall has been uplifted several hundred feet. Billingsley (1929) reports as much as eight-hundred feet of uplift.

The ore occurs as silver chlorides in a barite gangue which cements fractured and brecciated
rock in a crushed zone two to five feet wide in the hangingwall. Chrysocolla coatings are common. Stopes up to four-hundred feet long have been developed to a depth of two-hundred feet. Glory holes as much as forty feet in diameter are found in the crushed rock. A tunnel from the Garfield Mine along the Garfield Fault connects with the Odessa Mine one-half mile to the east.

The Garfield Mine is the contact between the Mpt member of the Pickhandle Formation and the Mcyt member of the Calico Formation. The bedded tuffs of the Calico Formation dip eastward into the fault 10°. The ores occur as impregnations of silver chlorides in the bedded tuffs; they dip up and away from the crushed fault zone. East of the major bend in the Fault, just south of the Bismark Site, all the workings are underground and are of the vein-fault type. South of the fault, where the Mcyt member lenses out, the ore occurs in the crushed rock of the Pickhandle Formation.

Bismark Mine

The Bismark Fault strikes north-south and dips westward 45 to 75 degrees. The vein-fault system of the Bismark Mine located in the Bismark
Fault adjoins a large "gopher-type" working of the Bismark Site to the east. The single vein is entirely cerargyrite in a hematite-barite gangue. The principal stope is three to six feet wide, fifty feet deep, 250 feet long and abruptly ends to the north and south where the silver concentration decreased. The productive vein had a maximum thickness of nine inches (Erwin and Gardner, 1940). About 150 feet north of the Bismark Site the vein is massive barite up to two feet thick. The Mcyr member of the Calico Formation contains the vein which is located in the footwall of the Bismark Fault. The barren slickensided hangingwall of the Fault is in the Mcrt member of the same formation.

**Irregular Ore Bodies**

Deposits of irregular form found in permeable beds and favorable horizons are usually near the surface. Although very irregular, they sometimes have a tendency to follow the dip of the beds. A mineralized fault is commonly found nearby at a higher or lower level. The ores in these deposits are of the disseminated type and are usually lower in grade than those associated with vein-fault systems.
**Bismark Site**

The Bismark Site, bounded between the westward dipping footwall of the Bismark Fault and the Garfield Fault to the east, is the principal working at the head of Bismark Canyon. The ore occurs as finely disseminated cerargyrite in the bedded tuffs of the Mcyt member of the Calico Formation. The ores also occur as coatings along numerous fractures in the tuffs. Underground workings connect with the Garfield mine although most of the mining was of the surface "gopher type." The Bismark Site was one of the most productive at Calico.

**Blackfoot Extension**

The Blackfoot Extension is a disseminated deposit at the end of the loop on Phillips Drive. The ore is cerargyrite disseminated in the bedded tuffs of the Mcyt member of the Calico Formation. No major fault is found up or down dip from these beds. Small specks of iron oxide, which may have been pyrite, are disseminated through the ore body. Similar iron oxide occurs at the Bismark Site.

**Ore Deposit Characteristics**

All investigators in the Calico District have recognized certain characteristics of the Calico...
ores which combine to make this a unique ore deposit. The following list summarizes these characteristics.

1. The ores have a tendency to accumulate within two-hundred feet of the surface in the zone of oxidation.

2. The gangue, particularly barite and red jasper, apparently continues to depth without interruption.

3. The principal ore is silver chloride with only minor sulfides.

4. The principal gangue is barite.

5. The ores are found in veins and as disseminated bodies.

6. The major mineralized faults trend northwest and continue unmineralized through the mapped area.

7. The vein-fault ores are: a) contained in a barite-hematite-red jasper gangue or b) contained in fault breccia cement.

8. The disseminated bodies are stratigraphically controlled.

9. The vein-fault systems are stratigraphically controlled as far as the silver is concerned.
10. The principal ore is secondary.

Ore Genesis

Hydrothermal theory. The classical theory for the origin of the ores in the Calico District is one of near-surface deposition from hydrothermal fluids migrating along steeply dipping faults, Lindgren (1887), Weeks (1926, 1929), Erwin and Gardner (1940), DeLeen (1949), Webber (1967), Wright (1967) and others who have worked in the District treated this subject but have not made specific proposals as to the composition of these fluids or as to the composition of the primary mineral deposits. All authors, however, imply secondary enrichment of silver halogens by the oxidation of near-surface primary base metal sulfides which contain silver. Primary sulfides are necessary for their thesis as they recognize the principal mineral in the District--cerargyrite--as a secondary mineral.

The original ore genesis theory has undergone little alteration since established by Lindgren in 1887. Lindgren states on pages 728 to 729:

The examination of the district leaves no room for doubt that the principal deposits are genetically connected with fractures and dislocations, and that their
The origin is of usual fissure veins formed by precipitation or deposition from aqueous solutions.

The most apparent fact regarding the distribution of the silver is its tendency to accumulate at or near the surface. The richest ore bodies have always been found near the croppings or at no considerable depth below them. This tendency is so universally recognized at Calico that the theory of the miners is that the silver has been infiltrated in the fissures from above, or originally deposited at the formation of the tufa [sic]. In almost all the mines the ore has grown poorer or disappeared before any great depth had been reached. . . . On the other hand, the gangue continues apparently without diminishing or changing. Were the whole a product of leaching of cold surface-waters from the walls and surrounding rocks, I can see no reason why the gangue should continue, while the silver-ores diminish or cease, a short distance below the surface.

On the whole, it seems to me most probable that ascending thermals (which may be surface-water in a certain sense) have extracted ore and gangue from the eruptive rock at a certain, although no exceedingly great, depth, and that for chemical and physical reasons the principal precipitation took place near the surface, and their gradual decrease with depth is nothing unusual. Indeed, innumerable instances might be cited, although few so marked as Calico.

While Lindgren was explicit in stating ascending hydrothermal fluids carried both silver minerals and gangue minerals depositing them near the surface, he was not clear as to the origin of the fluids. They may have resulted from groundwater
leaching of volcanic rocks at depth or as emanations from an igneous melt.

Webber (1967) also concluded the ores were hydrothermal in origin. He suggested that the intrusion of lavas, probably the Dry Lake Volcanics, might be responsible for the hydrothermal fluids. Webber states on pages 11 and 12:

The earliest mineralization which formed the belt of primary veins of the Calico District perhaps took place during early late Miocene time. The belt of northwest-trending fractures that the vein matter filled may have represented an ancestor of the present Calico fault zone, in the same area as even ancestral faults have been avenues for upward intrusion of lavas (the probable instigator if not the basic source, of the silver and barite mineralization). . . . events including emplacement of veins, took place at unknown depths, but deep enough so that temperatures must have been relatively high and the chemical systems involved at least partially confined.

The primary, silver-bearing deposits must have formed specifically as the result of the interaction of certain fluids (including waters), or the reaction of fluids with certain rocks. These fluids may have been hydrothermal (which rose along faults from deepseated igneous activity); or they may have been derived from, or associated with, shallow igneous (volcanic) activity; or they may have included connate waters (indigenous waters within the sedimentary rocks) or meteoric (rain) waters circulation through the ground (beneath playa lakes, and within faults, alluvium or other rocks). Any of these fluids may contain at least minute quantities
of practically any element, which may be indigenous or gained by absorption from rocks through which the liquids passed and with which they may have reacted.

Secondary Enrichment of Hydrothermal Deposits

Most base metal sulfide deposits in an oxidizing environment, silver notwithstanding, tend to form secondary minerals which are deposited above or below the water table. Silver accumulates in arid regions (Emmons, 1917) near the surface as cerargyrite. Cerargyrite forms less commonly in humid regions as most of the silver is deposited as secondary sulfide or sulfosalt mineral.

In an oxidizing environment, whether in an arid or humid region, argentite (Ag₂S) will alter to silver sulfate which is slightly soluble in water. The addition of ferric sulfate will increase the solubility. The following reaction shows the formation of silver sulfate.

\[
\text{Ag}_2\text{S} + 2 \text{O}_2 = \text{Ag}_2\text{SO}_4
\]

(argentite) \hspace{1cm} (silver sulfate)

In a humid environment silver sulfate in solution tends to be deposited as a silver sulfide. Cerargyrite (AgCl) forms in arid environments because of the general availability of excess
chlorine ions in groundwater. The following reaction occurs in arid regions.

\[ 2 \text{Ag}^+ + \text{SO}_4^{2-} + 2 \text{Cl}^- = 2 \text{AgCl} + \text{SO}_4^{2-} \]

From the following figures compiled by Latimer (1952), it is obvious that once silver forms as a silver halogen, it will not be readily leached away.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Solubility (H_2O) g/100 cc (25°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AgCl</td>
<td>1.8 \times 10^{-4}</td>
</tr>
<tr>
<td>AgBr</td>
<td>1.3 \times 10^{-5}</td>
</tr>
<tr>
<td>AgI</td>
<td>2.8 \times 10^{-7}</td>
</tr>
<tr>
<td>Ag_2SO_4</td>
<td>0.78</td>
</tr>
</tbody>
</table>

Discussion of Hydrothermal Theory

The principal theorem of the hydrothermal theory of ore genesis in the Calico District is that migrating fluids along fractures deposit silica, barite and sulfide minerals in near-surface veins. Near-surface deposition is indicated by the presence of large quantities of barite (Emmons, 1917). The maximum thickness of the overlying sediments during this time was two- to three-thousand feet. Vein emplacement as shallow as three-hundred feet is considered likely. In the Leviathan Mine, west of
Wall Street Canyon, two barren barite veins 150 feet wide were formed within fifty feet of the surface.

The lack of a secondary enriched zone when considered with possible water table configurations indicates sulfide deposition occurred only in the upper portions of the veins while gangue was deposited without interruption to greater depths.

Time of vein emplacement was after the deposition of the Barstow Formation and the doming of the Calico Mountains. Concurrent emplacement and deposition of the Dry Lake Volcanics is probable. Evidence for this time sequence includes silica replacement of highly folded limestone beds in the Barstow Formation, and the irregular occurrence of silica and barite in the Dry Lake Volcanics. In some locations the Dry Lake Volcanics unconformably overlie mineralized veins.

Using polished sections, DeLeen (1949) determined the first appearance of vein minerals to be in the following order:

silica
pyrite
barite
chalcopyrite
bornite
tetrahedrite
galena
argentite
calcite
Stratabound deposits. Results of this investigation indicate the ore deposits in the Calico District are stratabound. Concentrations of silver mineralization are limited to the Mcyt, Mct and a few localized areas in the Mcwt members of the Calico Formation, and to portions of the Pickhandle Formation which have an immediate proximity to the aforementioned members of the Calico Formation. Barren barite veins are not restricted to these formations.

Silver analysis of samples from the Dry Lake Volcanics and the Barstow, Calico and Pickhandle Formations, which were selected in areas not adjacent to known ore bodies, show the Calico Formation has an anomalously high background silver concentration. Analytical methods allowed measurements to as little as 0.10 ppm. The results are shown in Table 1. Silver content (Boyle, 1967) of some typical igneous and sedimentary rocks are given in Table 2.

Lindgren (1887) discussed the correlation between ore and stratigraphy as noted by the early miners, but he dismissed the idea as he could see no reason for stratabound silver and non-stratabound barite. Because Lindgren did not work out the stratigraphy in detail, it would have been difficult
Table 1
Silver Analysis of Samples from Various Formations

<table>
<thead>
<tr>
<th>Formation</th>
<th>Number of samples</th>
<th>Low (ppm)</th>
<th>High (ppm)</th>
<th>Ave. (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Lake Volcanics</td>
<td>6</td>
<td>0.10</td>
<td>0.40</td>
<td>0.20</td>
</tr>
<tr>
<td>Barstow</td>
<td>5</td>
<td>0.10</td>
<td>0.40</td>
<td>0.25</td>
</tr>
<tr>
<td>Calico</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mcyt member</td>
<td>8</td>
<td>0.80</td>
<td>3.4</td>
<td>1.60</td>
</tr>
<tr>
<td>Mer member</td>
<td>9</td>
<td>0.20</td>
<td>2.40</td>
<td>1.10</td>
</tr>
<tr>
<td>Mcwt member</td>
<td>6</td>
<td>0.20</td>
<td>1.2</td>
<td>0.53</td>
</tr>
<tr>
<td>Pickhandle</td>
<td>7</td>
<td>0.10</td>
<td>0.30</td>
<td>0.21</td>
</tr>
</tbody>
</table>
Table 2
Silver Content of Igneous and Sedimentary Rocks

<table>
<thead>
<tr>
<th>Rock</th>
<th>Location</th>
<th>Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Andesite</td>
<td>Japan</td>
<td>0.08</td>
</tr>
<tr>
<td>Andesite</td>
<td>California</td>
<td>0.07</td>
</tr>
<tr>
<td>Basalt</td>
<td>Japan</td>
<td>0.11</td>
</tr>
<tr>
<td>Basalt</td>
<td>California</td>
<td>0.55</td>
</tr>
<tr>
<td>Sandstone</td>
<td>California</td>
<td>0.40</td>
</tr>
<tr>
<td>Sandstone</td>
<td>Germany</td>
<td>0.10</td>
</tr>
<tr>
<td>Shales</td>
<td>Various</td>
<td>0.07</td>
</tr>
<tr>
<td>Recent volcanic ash</td>
<td>Ecuador</td>
<td>10.00</td>
</tr>
</tbody>
</table>
for him to clearly see the relationship. The occurrence of known ore bodies and the high average of silver content in the Calico Formation clearly indicate that the silver is stratabound and that the barite is not.

It could be argued that the relatively high average silver content of the Calico Formation is a result of weathering processes. If this were the case, there is no reason why there should be such a sharp difference between the concentration of silver in the Calico Formation and the other formations. Furthermore, weathering processes in the zone of oxidation do not satisfactorily explain the occurrence of the irregular ore bodies which are not associated with vein-fault systems. If many of these irregular bodies formed as a result of weathering, the silver halides would have had to travel over horizontal distances as great as three-thousand feet. If this were the case, surely downward vertical movements as little as three to four-hundred feet along the brecciated fault zones would have been possible.

Although many areas of mineralization have undergone some hydrothermal alteration, the Blackfoot
Extension and a low-grade ore body south of the Extension show no alteration.

**Syngenetic Theory**

The stratabound nature of an ore deposit does not indicate the ore forming processes, as such ore bodies may form hydrothermally, magmatically or syngenetically. The hydrothermal theory has already been discussed, and there is no evidence of a magmatic origin. However, there is substantial evidence of a syngenetic origin.

The high average silver content of the Calico Formation and the numerous low-grade deposits are indications of syngenetically deposited, finely disseminated, primary silver minerals. Recent volcanic ash in Ecuador (Boyle, 1967) averaged ten ppm silver. At San Fernando, Ecuador, (Gossens, 1972) silver and disseminated pyrite emanating from hot springs were syngenetically deposited with epiclastic rocks during a period of Pleistocene volcanic activity. Silver in the Calico District could have been introduced into the sediments as hot spring emanations, contemporaneously with sediment deposition. The borate beds in the Barstow Formation formed as a result of hot spring activity (Gale,
1946). The volcanic ash of the Calico Formation is an alternative source of the silver.

Two processes could alter the primary silver minerals, probably argentite, yielding the present ore minerals. It is likely that each process was partially responsible. Weathering in the zone of oxidation and a chemical reaction between localized primary concentrations of silver and hydrothermal fluids, which produced the barite, would yield cerargyrite.

The average silver concentration of two ppm in the Calico Formation may be a reasonable figure for the original concentration of silver in this Formation. The weathering process previously described would essentially allow in-situ formation of cerargyrite. The tight vertical placement of the silver is readily explained by this process. Low-grade disseminated ore bodies not associated with vein-fault systems could form in this manner.

The vein-fault systems containing the richest ore bodies may be explained by the reaction between chemically active hydrothermal fluids intersecting localized concentrations of silver. Thus, the silver deficient Leviathan Mine and the silver rich
St. Louis Mine, both of which are rich in barite, are compatible with the same ore genesis theory.

The reaction between the barium and chlorine rich hydrothermal fluids and the mineral argentite in an oxidizing environment is:

$$\text{Ag}_2\text{S} + 2\,\text{O}_2 + \text{Ba}^{++} + 2\,\text{Cl}^{--} = 2\,\text{AgCl} + \text{BaSO}_4$$

(argentite) (cerargyrite) (barite).

Fluid inclusion work by Roedder (1968) indicates base metals, such as barium, are carried as chlorine complexes and are deposited as sulfides or sulfates.

An oxidizing environment is indicated by the presence of earthy hematite and the near-surface emplacement of the barite veins.

Concentrations of cerargyrite would not be expected to extend considerable vertical distances from the area in which the reaction between the barium rich fluids and the silver sulfides was occurring.

Conclusion

Formation of the ore deposits in the Calico District is not completely explained by the hydrothermal theory of ore genesis. The theory does
not satisfactorily account for stratabound silver mineralization, low-grade ore bodies not associated with faulting, non-systematic hydrothermal alteration, non-stratabound barite mineralization and the high silver background content of the Calico Formation.

An alternative ore genesis theory combining hydrothermal, syngenic and near-surface weathering processes offers a satisfactory answer. Barium rich ascending hydrothermal fluids reacting with locally concentrated syngenetically deposited silver combined with near-surface weathering processes would form the unique ore deposits of the Calico District.
REFERENCES CITED
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———, 1929, The Calico Mining District: Mining and Met., v. 10, pp. 531-534.

The Calico Mining District is located in the Calico Mountains, California. The sequence of exposed rocks in the District filled the Calico Basin during the Miocene. An excess of two-thousand feet of the andesitic Pickhandle Formation is unconformably overlain by 2,500 feet of rhyolitic to andesitic epiclastic rocks of the Calico Formation. A few thousand feet of variable colored lacustrine deposits of the Barstow Formation conformably overlie the Calico Formation. Andesitic to basaltic flows and flow breccias of the Dry Lake Volcanics unconformably overlie the Barstow Formation.

Formation of northwest-trending antithetic faults, at intervals of five-hundred to one-thousand feet, accompanied a general doming of the Calico Mountains. Intense folding of the Barstow Formation resulted from the lake beds sliding off the doming surface.

Ores of silver chloride and other halogens of silver from the zone of oxidation produced 35 million ounces of silver from 1888 to 1894. Silver deposits in the District are of two types: 1) vein-fault systems consisting of cerargyrite in a barite-
hematite-red jasper gangue or as cerargyrite-hematite cement in fault breccias, or 2) as deposits of irregular form often associated with a fault and bedded tuffs. Recent investigations indicate the ore bodies are stratabound primarily restricted to the Calico Formation. Since the early 1890's, the ore has been considered hydrothermal in origin. A syngenetic origin is now proposed.