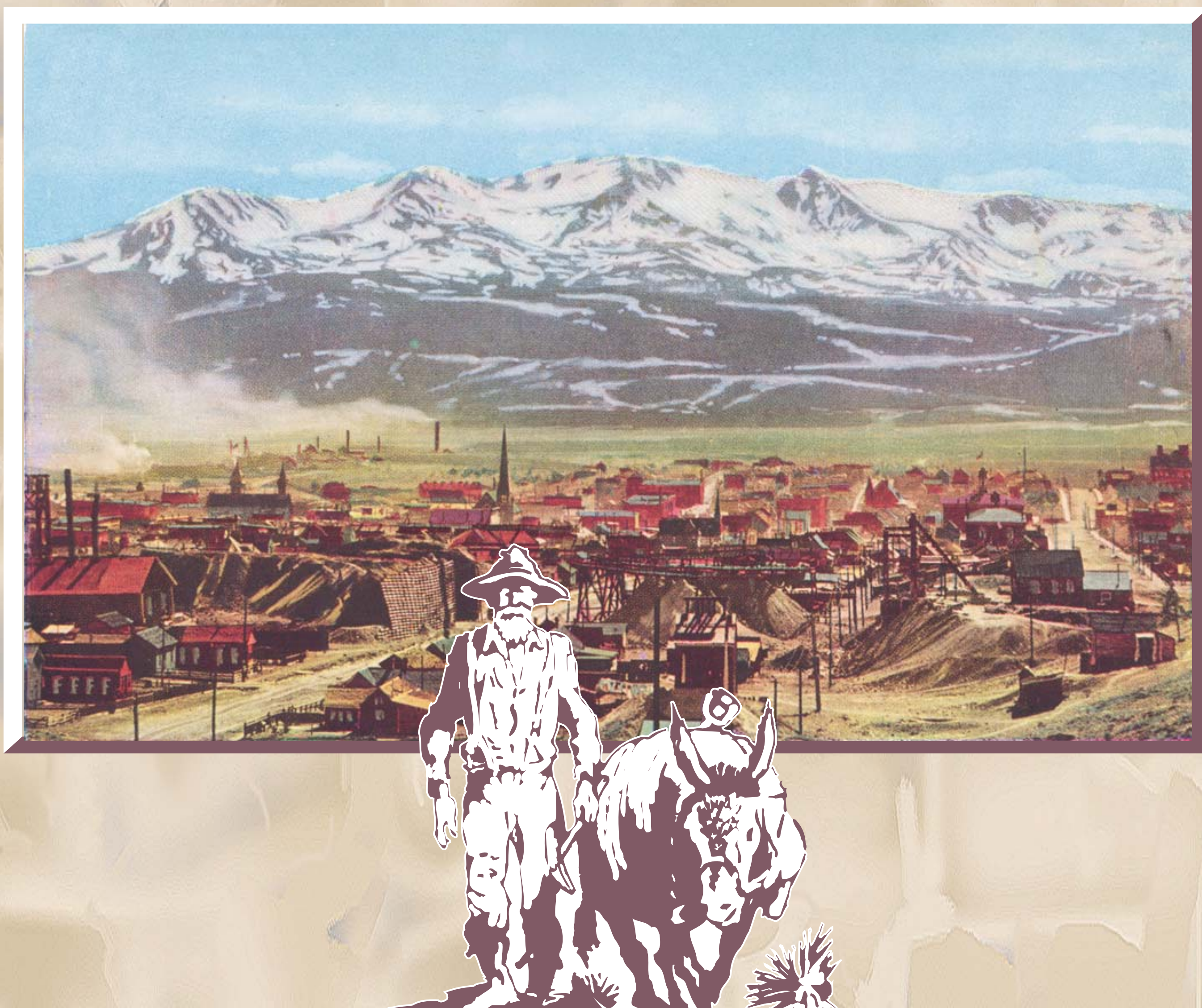
RESOURCE SERIES 42

Geology and Mineral Resources of Lake County, Colorado

By James A. Cappa and Paul J. Bartos



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Harris D. Sherman, Executive Director,
Department of Natural Resources

Vince Matthews,
State Geologist and Division Director
Colorado Geological Survey
Denver, Colorado
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FOREWORD

The Colorado Department of Natural Resources is pleased to present the Colorado Geological Survey Resource Series 42, *Geology and Mineral Resources of Lake County, Colorado.* Its purpose is to describe the geological setting and the various mineral deposits of Lake County. The report discusses known precious- and base metal deposits, molybdenum deposits, and industrial mineral and construction material deposits. The report contains a single 1:50,000 scale geological map of the county. James A. Cappa and Paul J. Bartos wrote this report in 2001 and 2002.

The objective of this publication is to provide geological information to resource developers, government planners, and interested citizens.

Funding for this project came from the Department of Natural Resources Severance Tax Operational Fund. Severance taxes are derived from the production of gas, oil, coal, and metals.

James A. Cappa
Chief, Minerals and Energy Section

Vince Matthews
Division Director and State Geologist

CONTENTS

FIGURES

TABLES

PLATE

APPENDIX I

Introduction

This report describes the geology and mineral resources of Lake County; it includes a 1:50,000-scale geologic map of the county that was compiled from published source materials of various scales (pl 1). The report describes the geologic setting, stratigraphy, and structure of Lake County. The section on Mineral Deposits includes descriptions of the mining districts of Lake County. Lake County boasts two of the most important mining districts in Colorado, the Leadville district and the Climax district. These two districts have played major roles in the history and economic development of the state. Other mining districts of lesser economic importance are also described, as well as areas of potential industrial mineral and construction material deposits.

There is no record of any oil and gas drilling in Lake County. There are no recorded geothermal sites in Lake County, nor any formations known to host coal deposits. No new field investigations of mining districts were made in the course of this study.

Part of this report contains transcriptions of mineral and mine descriptions from the two important U.S. Geological Survey Professional Papers on the Leadville district (Emmons and others, 1927; Behre, 1953; see Appendix 1). The CGS has chosen to preserve these descriptions as originally written.

SUMMARY

Lake County is one of Colorado's smallest counties, it has an area of 384 square miles—only Gilpin and Denver counties are smaller. The County is in the heart of Colorado's Rocky Mountains and has elevations ranging from 8,935 ft to 14,433 ft at Mount Elbert, the highest peak in Colorado. Lake County is surrounded by mountain ranges, the Sawatch Mountains and Collegiate Range in the west and the Mosquito and Ten Mile Range in the east (**Figures 1 and 2**).

The Arkansas River originates in Lake County and is the county's principal waterway. The Arkansas River and its tributary, Tennessee Creek, occupy the wide central valley between the Sawatch Range and the Mosquito Range.

For convenience, the relatively low lying part of Lake County is referred to as the Arkansas River Valley; this geographic area includes the lower reaches of tennessee Creek and other tributaries in addition to the Arkansas River itself.

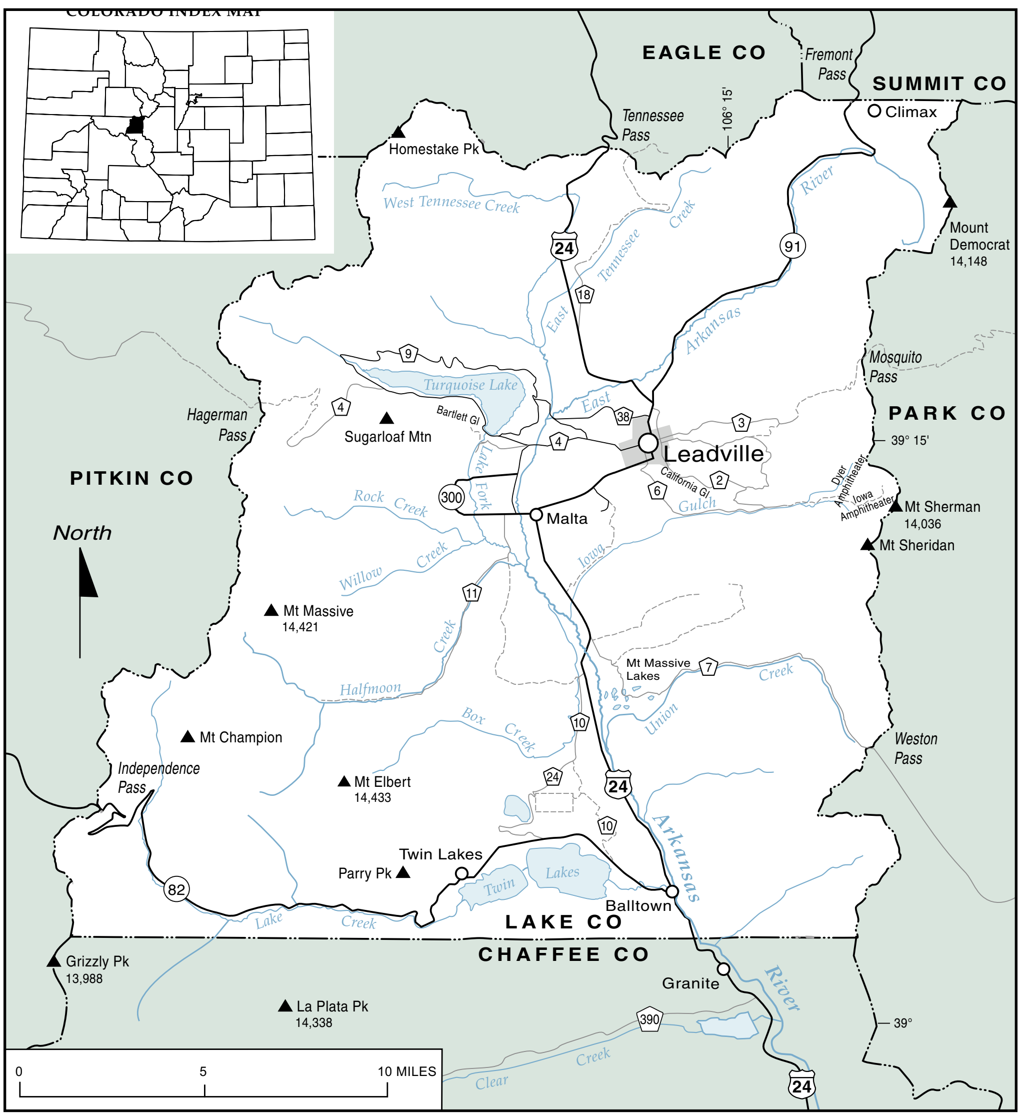


Figure 1. Location map of Lake County.

Leadville is the only city and is the the county seat. According to the 2000 census, the population of Lake County is 8,393 .

The western half of Lake County consists primarily of the Precambrian igneous and metamorphic core of the Sawatch Range (**Figure 2**). The Sawatch Range is a structural antiformal uplift. Well-exposed Paleozoic sedimentary rocks dip generally eastward along the eastern part of the uplift in the Leadville and Tennessee Pass areas of Lake County. The same Paleozoic sedimentary rocks encircle the Sawatch uplift and dip generally to the west along the western part of the uplift. Paleozoic rocks are important ore hosts in the mining districts of Gilman, Aspen, and Tincup.

Lake County falls within the broad region known as the Colorado Mineral Belt (**Figure 3**). This northeast-trending belt is developed over a zone of shearing of Precambrian age (Tweto and Sims, 1963). The Colorado Mineral Belt is defined by numerous porphyritic intrusive rocks of Laramide and Tertiary age that contain or are related to precious- and base-metal deposits. **Figure 4** is a simplified geologic map of the County with the mining districts located on it.

The Paleozoic rocks of Lake County contain strata of Cambrian through Pennsylvanian age and Mesoproterozoic to paleoproterozoic igneous and metamorphic rocks. (**Figures 4 and 5**). Sedimentary rocks of Mesozoic age probably were deposited over the paleozoic rocks, but if so, they have been eroded and are no longer in Lake County. Tertiary continental sedimentary rocks of Miocene to Pliocene age are abundant in the southern part of the County adjacent to the Arkansas River valley.

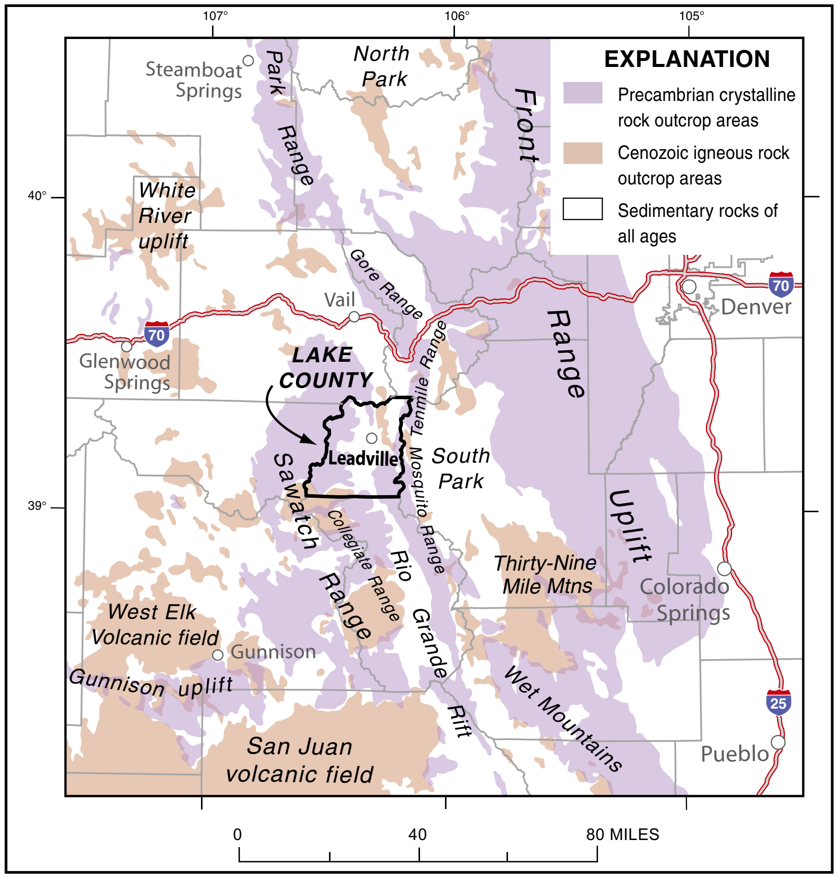


Figure 2. Geological features of Colorado and Lake County.

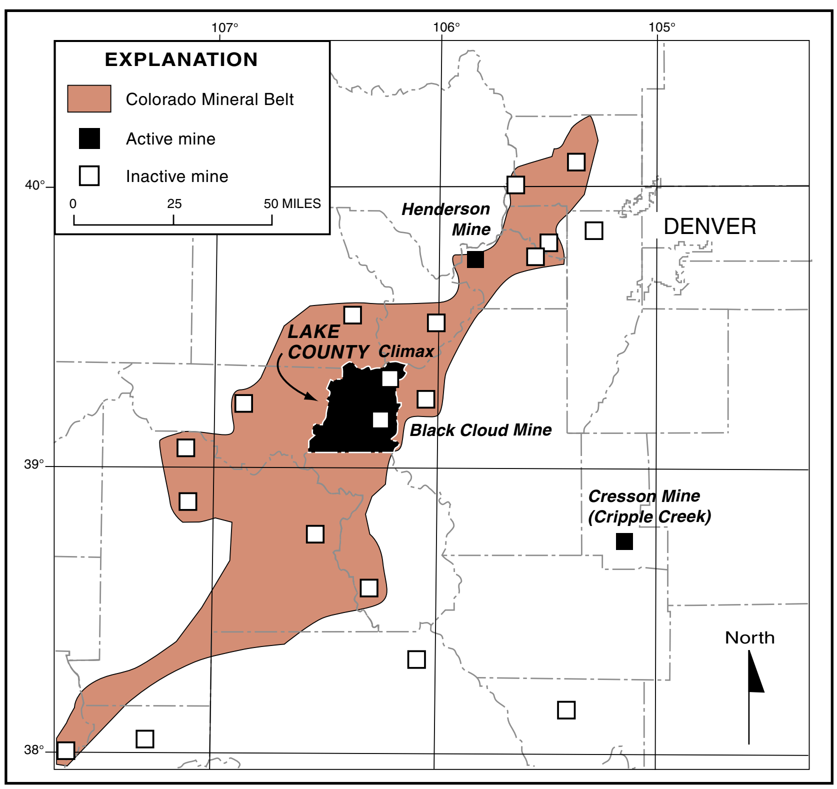


Figure 3. Colorado Mineral Belt showing location of major active and inactive mines. Lake County shown in black.

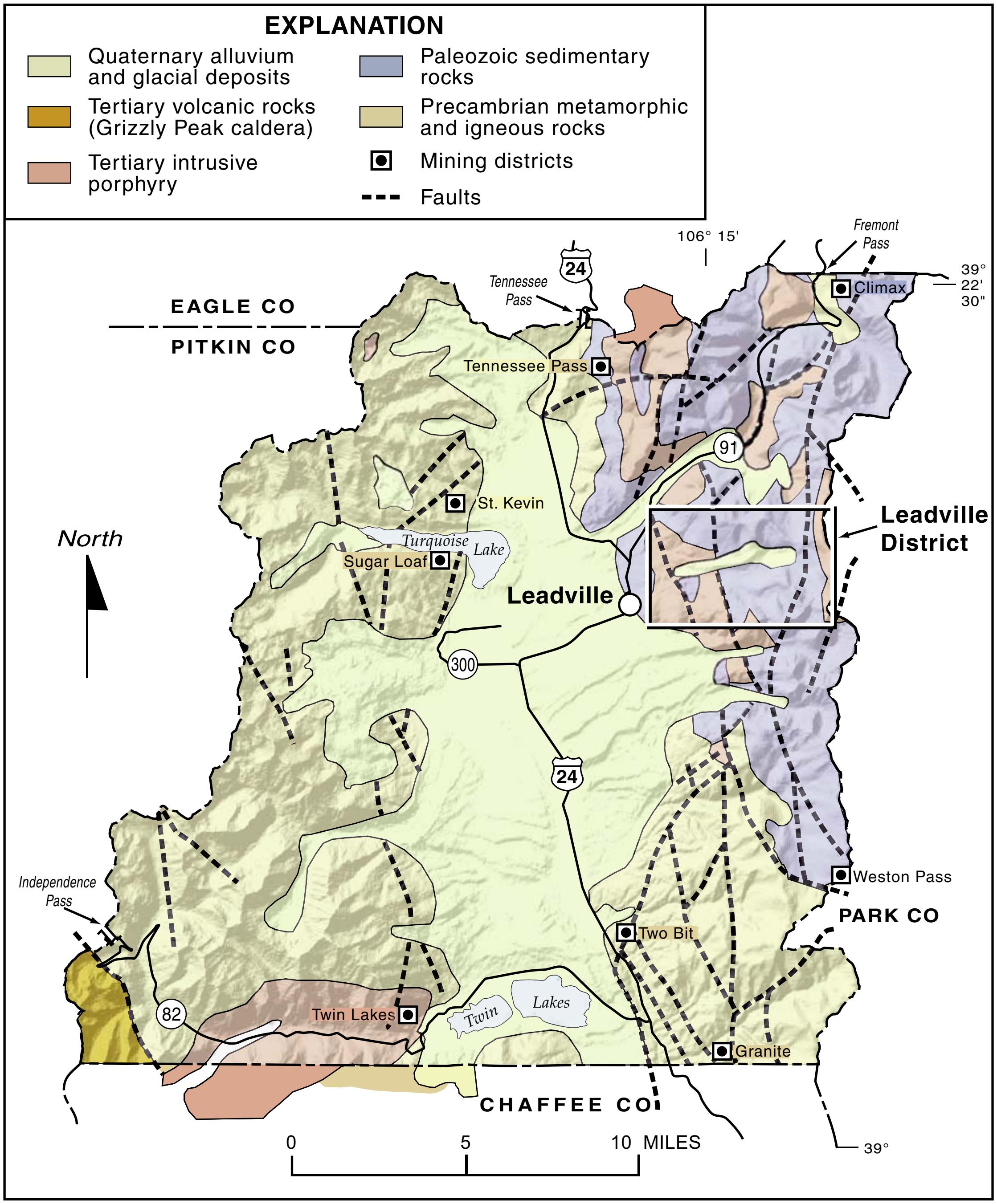


Figure 4. Simplified geologic map of Lake County with mining districts.

Intrusion of porphyritic igneous rocks began in Late Cretaceous time and continued through the mid-Eocene (**Figure 5**). During Oligocene time, magmatic activity consisted of the formation of the Grizzly Peak caldera in the southern part of the county and the intrusion of the Climax Stock in the northern part of the county. There are small exposures of Pliocene to Quaternary age volcanic rocks (not shown on geologic maps in this publication).

During the Pleistocene, much of this region was glaciated. Glaciers deposited sedimentary material of several ages in Lake County.

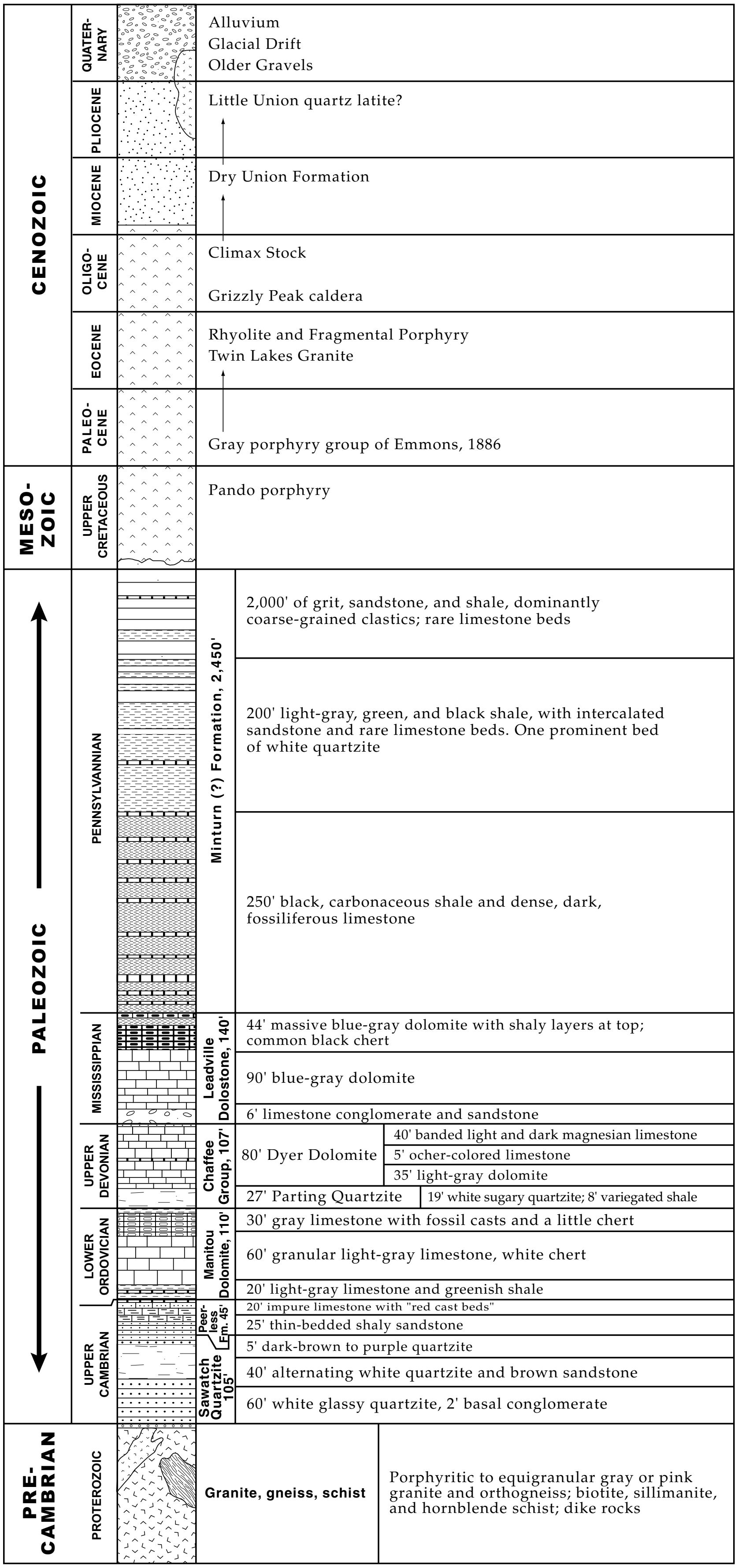


Figure 5. Generalized stratigraphic column of Lake County; thickness in feet; full thickness of Minturn Formation not shown.

PRECAMBRIAN ROCKS

Overview

Precambrian rocks in Colorado are composed of igneous and metamorphic rocks ranging in age from Paleoproterozoic to Mesoproterozoic. In Lake County, the oldest Proterozoic rocks are metamorphic; they primarily consist of biotite gneiss and schist and quartzites, predominantly of sedimentary origin, and hornblende and felsic gneiss of volcanic origin. The protoliths of these metamorphic rocks were deposited before the peak age of metamorphism, which was from 1,775 to 1,700 Ma (million years ago) (Tweto, 1980).

Three periods of igneous activity occured during the Proterozoic in Colorado. Only the two oldest events are represented by rocks in Lake County. The Paleoproterozoic event occurred at about 1,750 to 1,650 Ma. The Paleoproterozoic rocks are variable in composition but are, for the most part, granitic. These rocks were emplaced around the time of peak metamorphism and are locally foliated. Early Mesoproterozoic igneous rocks consist primarily of granite and quartz monzonite ranging in age from 1,480 to 1,350 Ma. These rocks generally lack foliation and are discordant with the surrounding metamorphic rocks (Tweto, 1980).

The youngest Proterozoic igneous event produced the granite of Pikes Peak batholith in the late Mesoproterozoic at about 1,100 to 1,000 Ma. These rocks are not found in Lake County.

Metamorphic rocks

Paleoproterozoic metamorphic rocks are found throughout Lake County, but are generally more widespread in the Sawatch Range. Limited exposures of metamorphic rocks are sparse in the Mosquito Range, which makes up the eastern portion of Lake County. The metamorphic rocks of the Sawatch Range and Mosquito Range are lithologically similar to the Paleoproterozoic metamorphic rocks of the Front Range. Rubidium–strontium age dates from whole-rock and feldspar samples indicate that regional metamorphism occurred about 1,750 Ma (Hedge and others, 1967).

Behre (1953) described three main types of metamorphic rocks of the Mosquito Range, which are generalized in the following to represent all the metamorphic rocks in Lake County. On plate 1, the Precambrian metamorphic rocks are consolidated into the biotite gneiss and schist unit.

Biotite-Hornblende Gneiss

Biotite-hornblende gneiss is dark gray, almost black, and is locally spotted with pink microcline crystals. Under the petrographic microscope, the rock consists of green hornblende, quartz, microcline, partly bleached brown biotite, and small quantities of oligoclase-albite. Accessory minerals include rutile, sphene, and apatite. Sericite and limonite are the most common alteration products. The hornblende, biotite, and quartz are intimately intergrown, but microcline occurs as scattered grains amongst the other minerals and in fine-grained veinlets that cut across the rock.

Quartz-Biotite Gneiss

Quartz-biotite gneiss is a fine-grained, medium-gray rock with a pronounced foliation that Behre (1953) ascribes to original bedding. The gneiss commonly appears as inclusions in the later Proterozoic granitic intrusive rocks. Most of these rocks consist entirely of quartz and biotite; whereas other facies may contain considerable amounts of feldspar. The quartz grains at some places are rounded, which suggests a sedimentary origin according to Behre (1953) .

Locally, in some inclusions on Finnback Knob (near the eastern edge of lake County, just south of Mount Sherman; plate 1), the quartz-biotite gneiss grades into an injection gneiss, which is characterized by numerous stringers of microcline and quartz, 0.5 cm thick or less, that follow schistosity. The veinlets and gneissic banding are minutely crinkled, and, in addition, the biotite is recrystallized to large (1.0 by 0.3 cm) mica tablets.

Biotite-Sillimanite Schist

The biotite-sillimanite schist occurs in isolated localities near Climax and in small but widely distributed masses in the Leadville area. The schist is a gray to black, medium-grained, banded rock that glistens on surfaces parallel to foliation. The bands consist of biotite-sillimanite schist and a more quartz-rich variety with biotite and sillimanite. The sillimanite forms slender, silvery laths as much as two centimeters in length. Plagioclase feldspar is a common accessory mineral.

Biotite-sillimanite schist also been mapped north of Twin lakes in the southern part of Lake County (fig. 1) (Howell, 1919). Here, small amounts of muscovite accompany with biotite. Abundant sillimanite forms radiating or fibrous bundles of prismatic crystals, elongate in the plane of schistosity, both between the quartz and the biotite crystals and within the biotite crystals. Near Mount Champion (southwestern Lake County; plate 1), small, pink to brown almandite garnets in the biotite sillimanite schist have a broken appearance.

Talc Schist

Small areas of talc schist crop out in the area north of Mount Champion (Howell, 1919). The schist is very fractured and is composed almost entirely of talc and quartz. The quartz appears to be both a primary and a secondary mineral. Field relationships of the talc schist and surrounding rocks are obscured by talus slopes of fractured talc schist; however, Howell (1919) suggested that the talc schist is an alteration product of mafic rocks that intruded as sills and dikes in other Precambrian rocks.

Igneous Rocks

There are two groups of Precambrian igneous rocks in Lake County. The earliest igneous rock complex was emplaced during Paleoproterozoic regional metamorphism at about 1,775 to 1,650 Ma. The second group of igneous rocks was emplaced in the middle Mesoproterozoic at about 1,400 Ma. The Precambrian igneous rocks are mapped as three units in plate 1; the fine divisions of the Paleoproterozoic igneous rocks mapped by Fridrich and others (1998) are not shown but are described here.

Paleoproterozoic Granitic Rocks

The early Paleoproterozoic granitic rocks consist of a diverse group of mainly gneissic granite and granodiorite with local bodies of more mafic rocks including diorite and possibly gabbro. The granite and granodiorite are often layered with biotite–rich and biotite-poor layers. Fridrich and others (1998) included detailed descriptions of these rock units, including geochemistry and age dates, in the central Sawatch Range of southwestern Lake County.

The Denny Creek Granodiorite is exposed in the western part of Lake County. The granodiorite is a dark grayish-brown to greenish-black, coarse-grained, equigranular to porphyritic, undeformed to strongly foliated biotite-rich granodiorite. The granodiorite consists of oligoclase, quartz, perthite, biotite, ilmenite, magnetite, and minor amounts of sphene, apatite, allanite, zircon, and chlorite. The granodiorite is distinguished by its abundance of biotite. The Denny Creek Granodiorite is mostly calc-alkalic to alkali-calcic in composition (Fridrich and others, 1998 p. 22–23).

A leucocratic phase of the Denny Creek Granodiorite is exposed in the area north of Lake Creek and south of Mount Elbert. This phase is a tawny-brown to brownish-gray, medium-grained, equigranular, and compositionally layered and foliated biotite granodiorite. It grades into and is chemically similar to the Denny Creek Granodiorite (Fridrich and others, 1998, p. 22).

In the area west of Mount Elbert, the Kroenke Granodiorite cuts the Denny Creek Granodiorite. The Kroenke is a light-gray, medium–grained, equigranular leucocratic biotite granodiorite that is undeformed, but compositionally layered. It's composition is alkali-calcic to calc-alkalic and mildly to strongly peraluminous (Fridrich and others, 1998, p. 20–23). The unit is distinctly sodium rich and has been classified as a trondhjemite (Barker and others, 1976).

The Kroenke Granodiorite in the Sawatch Range has been dated by rubidium–strontium methods. A recalculation of six whole-rock samples by DeWitt yielded an age of 1645 ± 5 Ma date (Fridrich and others, 1998, p. 20). Dikes of medium-grayish-green, medium-grained, equigranular to slightly porphyritic, well flow-foliated plagioclase-hornblende diorite commonly cut the Paleoproterozoic metamorphic rocks. The dikes are cut by Kroenke Granodiorite (Fridrich and others, 1998, p. 24). Howell (1919) described the Mount Champion quartz monzonite in the Twin Lakes district of southern Lake County. The map units of the quartz monzonite shown on Howell's Plate I (1919) correspond to both early and middle Proterozoic intrusive complexes of this study. His rock description of the Mount Champion quartz monzonite is similar to the Denny Creek Granodiorite, rather than the conspicuous two-mica granites of Mesoproterozoic age.

Mesoproterozoic Granitic Rocks

In the Sawatch Range, the Mesoproterozoic granitic rocks are composed primarily of the St. Kevin Granite, a light-tan to pinkish-tan, fine- to medium-grained, equigranular biotite-muscovite granite. The St. Kevin Granite is mostly undeformed; however, locally it is flow foliated and has compositional layering. The granite consists of microcline, quartz, plagioclase, biotite, and muscovite and trace amounts of apatite, zircon, fluorite, and sillimanite. Pegmatite sills and dikes as thick as 35 ft are common (Fridrich and others, 1998, p. 16–17).

The St. Kevin Granite is well exposed in the Sugar Loaf and St. Kevin mining districts, south and north of Turquoise Lake, respectively (fig. 4). At these places, the rock is medium-grained, gray, granular two-mica granite. Locally, the grain size is coarse or fine grained. A few of the feldspar crystals are as long as 1 in. At places, the granite shows a distinct foliation due to dark films of biotite. Large areas of the St. Kevin Granite in the Sugar Loaf and St. Kevin districts have been hydrothermally altered, and the feldspars have been converted to clay minerals, the biotite has been bleached, and the rock is friable and crumbly (Singewald, 1955).

The St. Kevin Granite is alkali-calcic, mildly to strongly peraluminous, and potassic to normal. It has no apparent iron enrichment. In the northern Sawatch

Range, the St. Kevin Granite has a seven-point rubidium-strontium age of 1,420±100 Ma (Fridrich and others, 1998, p. 18).

In addition to the St. Kevin Granite, unnamed Mesoproterozoic granitic rocks are well exposed in the upper part of Iowa Gulch in the Leadville district (the east-central part of pl. 1). In Iowa Amphitheater, the oxidized Mesoproterozoic granitic rocks form a crumbly regolith and are unconformably overlain by the Sawatch Quartzite (**Figure 6**).

Ogden Tweto (1974b) divided the St. Kevin Granite into four subfacies: (1) The fine-grained facies consists of gray, even-grained, strongly to weakly foliated, two-mica quartz monzonite. (2) The normal facies consists of light-gray to light-pink, equigranular to porphyritic, two-mica granite and quartz monzonite. (3) The granodiorite facies is a gray, seriate, porphyritic, fine- to medium-grained, weakly foliated granodiorite. (4) The trachytoid hybrid facies consists of a coarse-grained, nonhomogeneous granite composed of closely packed parallel microcline crystals, 0.5 in. to 1 in. long, in a fine-grained matrix; this facies is common on the borders of the intrusion.

PHANEROZOIC SEDIMENTARY ROCKS

Cambrian Rocks

Paleozoic sedimentary rocks in Lake County consist of shelf carbonate rocks and siliciclastic sedimentary rocks; they lie unconformably upon Proterozoic igneous and metamorphic rocks in the Mosquito Range. Except near Tennessee Pass on the northern edge of Lake County, no Paleozoic sedimentary rocks are exposed in the Sawatch Range of the County. In the Leadville district, the stratigraphic thickness from the base of the Cambrian Sawatch Quartzite to the top of the Mississippian Leadville Dolostone is 507 ft (fig. 5). The Pennsylvanian Minturn Formation overlies the Leadville Dolostone and has a thickness of at least 2,450 ft in the Leadville district.

The Paleozoic section in central Colorado contains several disconformities and unconformities. The top of the Mississippian Leadville Dolostone is the most prominent unconformity; it represents an erosion surface and karst filling formed as the late Paleozoic seas withdrew from Colorado.

Sawatch Quartzite

Emmons and others (1927) described and named the Sawatch Quartzite in this region. Fossil collections described by Behre (1953) indicate a Late Cambrian age for the upper sandy beds of the Sawatch Quartzite. In Lake County, the formation mostly consists of orthoquartzite and a basal quartz conglomerate; the thickness varies from 100 to 150 ft. The Sawatch Quartzite unconformably overlies the Precambrian metamorphic and igneous rocks; in Lake County the contact is a remarkably flat surface (Tweto, 1974a; Behre, 1953). Elsewhere, however, the contact has been interpreted as an originally irregular topographic surface that is thought to have contributed to the significantly greater variations in thickness in some areas (Myrow and others, 2003).

The basal conglomerate unit is about 2 ft thick and consists of well-rounded pebbles of bluish-white or white quartz; the matrix is composed of fine-grained white quartz grains, which is locally somewhat micaceous or argillaceous. The lower 60 ft of the Sawatch Quartzite above the conglomerate consists of white, glassy orthoquartzite in beds averaging about 3 ft thick. Some of these beds weather to a pinkish color (fig. 6). The upper 40 ft of the Sawatch Quartzite consists of impure, gray, buff, or brownish-gray sandstone. Many of these darker beds have calcareous cement, and their weathered surfaces become pitted or honey-combed. The common interbedding of darker sandstone with white orthoquartzite gives the upper Sawatch Quartzite a distinctive striped appearance. The upper beds average about 1 ft thick and are commonly crossbedded. Glauconite is common in the upper part of the unit (Gerhard, 1972). A bed of purple or black quartzitic sandstone marks the top of the Sawatch Quartzite. This unit grades into the overlying Dotsero Formation (Myrow and others, 2003).

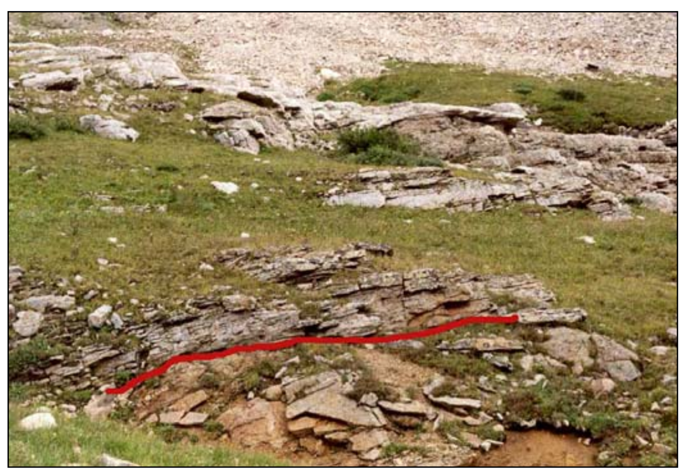


Figure 6. Precambrian—Cambrian Sawatch Quartzite contact—Iowa Amphitheater.

Dotsero (Formerly Peerless) Formation

Emmons and others (1927) called the shale unit above the quartzites of the Sawatch Quartzite the "transitional shales." Behre (1932) applied the name Peerless Formation to these shales, called the "red-cast beds," for exposures on Peerless Mountain, 7 mi south of Leadville. Myrow and others (2003) revised the Cambrian and Ordovician stratigraphy of central Colorado; they suggested the elimination of the name "Peerless" and included these rocks in the Dotsero Formation, a unit defined by Bass and Northrup (1953) in the White River uplift northwest of Lake County. The formation is about 50 ft thick in the Leadville area. Tweto (1974b) described thicknesses of as much as 110 ft in the Holy Cross quadrangle in northern Lake County. He further characterized the Dotsero (formerly Peerless) Formation as thin-bedded, buff, green, and maroon sandy dolomite, dolomitic sandstone, dolomite, and dolomitic shale. Gerhard (1972) described the Dotsero (formerly Peerless) Formation as having a Late Cambrian fauna. Myrow and others (2003) confirmed that the Dotsero Formation as exposed at Horseshoe Mountain about 500 ft east of the Lake-Park County line contains conodonts of the Eoconodontus Zone, which indicates a Late Cambrian age.

In the Mosquito Range, the lower part of the Dotsero Formation consists of thin-bedded shaly sandstone that contains a few quartzitic layers as thick as 1 ft. The upper part is mostly brick-red, impure sandy and shaly limestone as thick as 2 ft (**Figure 7**) (Behre, 1953).

Figure 7. Outcrop of Peerless Shale in Iowa Ampitheater —well exposed outcrop is approximately 15 feet high.

Ordovician Rocks

Manitou Dolomite

The Manitou Formation is a calcareous dolomite that averages about 110 ft in thickness. The Manitou Formation overlies the Dotsero Formation on a nonconformable contact. The older literature refers to the Manitou Formation as the "White limestone" (Emmons and others, 1927). Kirk (1931) correlated these beds with the Manitou limestone of the Front Range, and Behre (1953) called these beds the Manitou Dolomite, as they consist primarily of dolomite.

The Manitou Formation consists of uniform, finely crystalline, white, light-gray, or very faintly pinkish dolomite. In general, the lower 20 ft of the Manitou Formation consists of light-gray dolomite and intercalated layers of greenish-gray shale averaging about 2 in. thick. A 60-ft-thick section of light-gray, granular dolomite overlies the intercalated dolomite and shale unit. The gray dolomite beds are about 2 to 3 ft thick. White chert in discontinuous beds and nodules is common. The upper 30 ft of the Manitou Formation is similar to the gray dolomite, but contains distinctly lesser amounts of chert (**Figure 8**). The Manitou Formation is nonconformably overlain by the Parting Formation of the Chaffee Group (Behre, 1953; Myrow and others, 2003).

Microscopically, the Manitou Dolomite consists primarily of fine–grained dolomite, ranging from 0.02 to 1.0 mm in diameter. Some calcite surrounds the dolomite crystals. There are minor amounts of quartz and clay minerals.

In the Leadville district, the Manitou Formation typically has been strongly altered. The resulting crumbly and friable texture-commonly referred to as "sugar" texture-is a result of the dissolution of the calcite surrounding the dolomite crystals. Locally on Printer Boy Hill, which is east of Leadville between Iowa Gulch and California Gulch (pl. 1), the Manitou Formation has been altered to small grains of epidote, iron-stained quartz, and a fibrous, light-colored amphibole, possibly tremolite.

Figure 8. Manitou Dolomite in Iowa Ampitheater. Hammer point is resting on a chert layer.

Devonian Rocks

Chaffee Group: Parting Formation, Dyer Formation, Gilman Sandstone

Three divisions of the Devonian Chaffee Group are recognized in Lake County. Campbell (1970) elevated the rocks of the Chaffee Formation to group status and defined two formations, and Tweto and Lovering (1977) included the Gilman Sandstone as the upper part of the Chaffee Group.

The lower unit in Campbell's (1970) twofold stratigraphy is called the Parting Formation, and the upper unit is the Dyer Formation. The Parting Formation is a white to light-buff to pinkish-gray quartzarenite. Crossbedding is common. Quartz grains are not very well rounded; their mean diameter is 0.5 mm. There are sparse flakes of white mica. Silica is the most common cement. Calcareous cement is locally common; in some cases, the beds are sufficiently calcareous to be sandy limestones. The Parting Formation has variable thickness but averages 27 ft (Behre, 1953).

A 2-ft-thick brick-red to light-olive-green shale underlies the quartzarenite. However, the shale is as thick as 22 ft at Weston Pass south of Leadville.

The Dyer Formation is a light-gray or bluish-gray banded dolomitic limestone. In general, the carbonate is well crystallized. The average thickness of the Dyer Formation is 80 ft. A typical stratigraphic section of the Dyer Formation near Dyer Mountain east of Leadville is shown in **Table 1**.

Table 1. Stratigraphic section of the Dyer Formation at West Dyer Mountain. [From Behre (1953)]

Bed no.	Lithology	Thickness (ft)
	Leadville Dolostone: sandy dolomite (Gilman Sandstone) Dyer Formation	
5	Blue-gray, dense dolomitic limestone in massive beds; faintly banded	14
4	Brown-spotted, gray dolomitic limestone, densely granular, weathers into beds about 1 in. thick	37
3	Light-blue-gray dolomitic limestone with platy fracture; weathers to a conspicuous ochre	4
2	Light-gray, buff-weathering dolomitic limestone in massive beds	30
1	Light-buff, very sandy, crystalline dolomitic limestone; medium- to locally coarse-grained	14
	Parting Formation: quartzarenite	
	Total	99

Mississippian Rocks

Leadville Dolostone

The Mississippian Leadville Dolostone, formerly known as part of the Blue Limestone of the Leadville mining district, was first named and described by Emmons (1882) and later modified by Kirk (1931) and Tweto (1949). In much of Colorado this unit is termed the Leadville Limestone because it is composed mostly of calcium carbonate. However, much of the original Leadville Limestone on the east side of the Sawatch uplift is now dolomite; therefore, for this report, this unit is termed the Leadville Dolostone (Behre, 1953; Beaty and others, 1988; Armstrong and others, 1992). The average thickness of the Leadville Dolostone in the Leadville mining district is 140 ft (Behre, 1953). The Leadville Dolostone (**Figure 9**) in the area of the Leadville mining district in Lake County was divided into three members by Nadeau (1972), in ascending order from the base: The Gilman Member was described by Tweto (1949), but later that unit was reassigned to formation status in the Devonian Chaffee Group (Tweto and Lovering (1977); the Redcliff Member was described for exposures near Red Cliff in neighboring Eagle County (the member name is one word, whereas the town name is two words); and the Castle Butte Member was named for exposures at Castle Butte on Aspen Mountain.

Figure 9. Leadville Dolostone in Iowa Ampitheater.

The Redcliff Member consists primarily of micrite and dolomicrite. The basal unit consists of very fine grained, tan to gray, dense dolomicrite from 2 to 8 ft thick. Above the basal dolomicrite, the bedding becomes more massive and consists primarily of fractured micrite. Stromatolitic boundstones and intraformational breccias are common in the Redcliff Member. There is an unconformity between the Redcliff Member and the underlying Chaffee Group (Nadeau, 1972).

The Castle Butte Member marks a change in grain size from the fine-grained micrite of the underlying Redcliff Member to coarse-grained packstone, grainstone, and boundstone. Oolitic, pelletal, skeletal, and composite packstones are found mostly in the lower part of the Castle Butte Member. Composite grainstone with rounded and disarticulated oolites and skeletal fragments is found only in the upper part of the Castle Butte Member (Nadeau, 1972).

Beaty and others (1988) discussed three problems in the Leadville mining district that arise when applying Nadeau's (1972) "Leadville limestone" stratigraphy: (1) No type section of the Leadville exists, only reference sections for the Redcliff Member at Red Cliff and for the Castle Butte Member in Aspen. (2) Away from the reference section at Red Cliff, workers could not identify the unconformity separating the two members. (3) In the Leadville district, the "Leadville limestone" has been dolomitized, and the original texture is obscured; correlations based on texture are therefore meaningless.

Beaty and others (1988) revised the Leadville stratigraphy by using more than 50 drill cores taken for mineral exploration. A well-developed unconformity-the M-2 unconformity-was defined as the contact between the Redcliff Member and the Castle Butte Member. A lithostratigraphy using dolomite grain sizes was established, and a reference section for the Leadville Dolostone was established. Dolomitization of the carbonate rocks of the Leadville Dolostone in central Colorado is restricted largely to the eastern flank of the Sawatch uplift, essentially all of Lake County (fig. 3a). Many early investigators thought that the dolomitization was a direct result of the hydrothermal alteration associated with the mineralization on that flank (Thompson and others, 1983). Later workers (Horton and DeVoto, 1990; Armstrong and others, 1992) instead have interpreted that the limestone was converted to dolomite by essentially diagenetic and burial processes during the late Paleozoic.

The Redcliff Member has been altered from micrite to fine-grained dolomicrite. The Castle Butte Member is typically completely recrystallized. Zebra texture as illustrated by Horton and DeVoto (1990, fig. 8) is most common in the Castle Butte Member and is usually associated with sulfide mineralization.

Mississippian(?) and Pennsylvanian Rocks

MOLAS FORMATION

The Molas Formation was first recognized in southwestern Colorado (Cross and others, 1905) where it forms a karst residuum on the top of the Leadville Dolostone. In central Colorado near Minturn in Eagle County, it forms a unit of thin but variable thickness of red to yellow sericitic silty and clayey material, very fine grained sandstone, and fragmental chert (Tweto and Lovering, 1977, p. 32–33). In the Leadville district, Tweto (1968, table II) reported that the Molas Formation is 0 to 40 ft thick and consists of structureless red and yellow siltstone and mudstone containing abundant chert fragments. Armstrong and others (1992) suggested that the Molas Formation might be, in part, of Late Mississippian age.

Pennsylvanian and Permian Rocks

BELDEN SHALE

The Belden Shale is composed of a series of dark-gray to black marine shales that contain thin interbeds of limey mudstone and wackestone and gray to brown, micaceous, fine-grained, feldspathic to arkosic sandstone. Brill (1942, 1944) originally described the Belden Shale. In the Leadville district, it has been previously described as part of the Weber Sandstone(?) (Emmons and others, 1927; Behre, 1953). The Belden Shale unconformably overlies the carbonate rocks of the Mississippian Leadville Dolostone and the Mississippian(?)-Pennsylvanian Molas Formation. The thickness of the Belden Shale varies from about 200 ft to nearly 800 ft in Lake County (Brill, 1944). The Belden Shale in the southern Mosquito Range (south of Lake County) thickens and changes facies across a distance of 35 mi to become more than 1,000 ft of fine- to coarse-grained arkosic sandstone and conglomerate (DeVoto, 1980).

MINTURN FORMATION

The Minturn Formation is about 6,000 ft thick and is composed of dominantly gray, green, and brown lenticular beds of sandstone, siltstone, shale, conglomerate, and limestone stratigraphically above the dark shales of the Belden Shale (DeVoto, 1980). The Minturn Formation was named by Tweto (1949) for exposures along the Eagle River near Minturn in Eagle County. The Minturn Formation is described in detail north of Lake County in the Pando area by Tweto (1949) and in the Copper Mountain area by Widmann and others (2004). Tweto (1956) produced a detailed geologic map of the Tennessee Pass area, which includes the northern part of Lake County; however, for a full description of the Minturn Formation, he referred to his earlier work (1949) in the Pando area. Tweto (1956) recognized three dolomite marker beds in the Minturn Formation around Tennessee Pass: the Wearyman Dolomite Member, the Hornsilver Dolomite Member, and the Resolution Dolomite Member. On his geologic map, however, none of these dolomite members are shown in Lake County. Therefore, the thickness of the Minturn Formation in Lake County remains poorly defined.

Tertiary Sedimentary Rocks

Dry Union Formation

The Dry Union Formation consists primarily of brown, sandy to pebbly, poorly cemented siltstone with local layers of gray to white sandstone, greenish-gray to pinkish-gray clay, brownish-gray gravel, and thin beds of volcanic ash. The thickness of the formation near Leadville is about 1,000 ft; near Malta it is 3,000 ft thick. Tweto (1961) named the Dry Union Formation for exposures in Dry Union Gulch about 5 mi south of Leadville. The units that make up the Dry Union Formation were previously described as "lake beds" by Emmons (1886) and redefined as more alluvial in origin by Capps (1909) and Emmons and others (1927). A complete description of the Dry Union Formation was completed about 30 mi south of the Dry Union Gulch in Chaffee County by Van Alstine (1969). Fossil vertebrate remains in this area indicate a Miocene to Pliocene age for the Dry Union Formation.

Quaternary Deposits

Older Gravels and Alluvium

The older Quaternary gravels and alluvium consist of terrace, outwash, and pediment gravel of pre-Bull Lake age. These gravel deposits include the "high level terraces" described by Behre (1953), Emmons and others (1927), Capps (1909), and renamed the Malta Gravel by Tweto (1961). The "high level terraces" consist of imperfectly stratified gravels, uniformly coarser toward the mountains and finer grained (pebble sized) closer to the Arkansas River Valley. The clasts are generally strongly weathered and in places have a coating of carbonate minerals (Capps, 1909). This gravel unit fills valleys and is of variable thickness. The maximum thickness is between 250 and 700 ft. Pre-Bull Lake deposits are dated at 400 to 500 ka (thousand years) (Nelson and Shroba, 1984).

Older Glacial Drift and Glacial Drift

These drift deposits of unsorted boulders are of Pleistocene age. Older glacial drift deposits have a subdued morainal form or lack a morainal form and are probably of pre-Bull Lake age. These deposits are found in almost all the valleys in both the Mosquito Range and the Sawatch Range. Glacial drift deposits with well-developed morainal form are probably of Bull Lake (130 to 150 ka) and Pinedale age (15 to 30 ka) (Nelson and Shroba, 1984). More detailed descriptions of the Quaternary glacial and alluvial deposits are found in Capps (1909) and Nelson and Shroba (1984).

Landslide Deposits

Landslide deposits consist of unsorted bouldery to sandy to silty deposits formed by mass-movement processes that include landslides, debris flows, talus, rock streams, and slope wash.

PHANEROZOIC IGNEOUS ROCKS

Late Cretaceous and Early to Middle Tertiary Igneous Rocks

Pando Porphyry (Early White Porphyry)

Tweto (1951, 1954) named the Pando Porphyry for exposures along the Eagle River south of Gilman, Eagle County. The Pando Porphyry includes the Early White Porphyry of Behre (1953) and Emmons and others (1927). It is the earliest of the Laramide-age intrusive rocks and has a potassium-argon age on biotite of 71.8 Ma, as reported by Pearson and others (1962) and recalculated by Cunningham and others (1994). The Pando Porphyry is especially well exposed in the Mosquito Range of the Leadville mining district where it forms conspicuous and extensive sills, which at Mount Sherman east of Leadville can attain a thickness of more than 1,000 ft (**Figures 10 and 11**). Sills are exposed along the crest of the Mosquito Range for distances of as much as 5 mi (Behre, 1953).

The porphyry is a white to very light gray granodiorite and has a fine-grained groundmass. Phenocrysts are sparse and generally consist of small crystals, about 0.25 cm, of quartz, plagioclase, and black pseudohexagons of biotite (fig. 10). Variations in the Pando Porphyry are due to grain-size variations in the groundmass. Coarser-grained groundmass minerals are generally found in thicker sills. In the

Figure 10. Pando Porphyry in Iowa Ampitheater. Note black biotite phenocrysts in white felsic matrix.

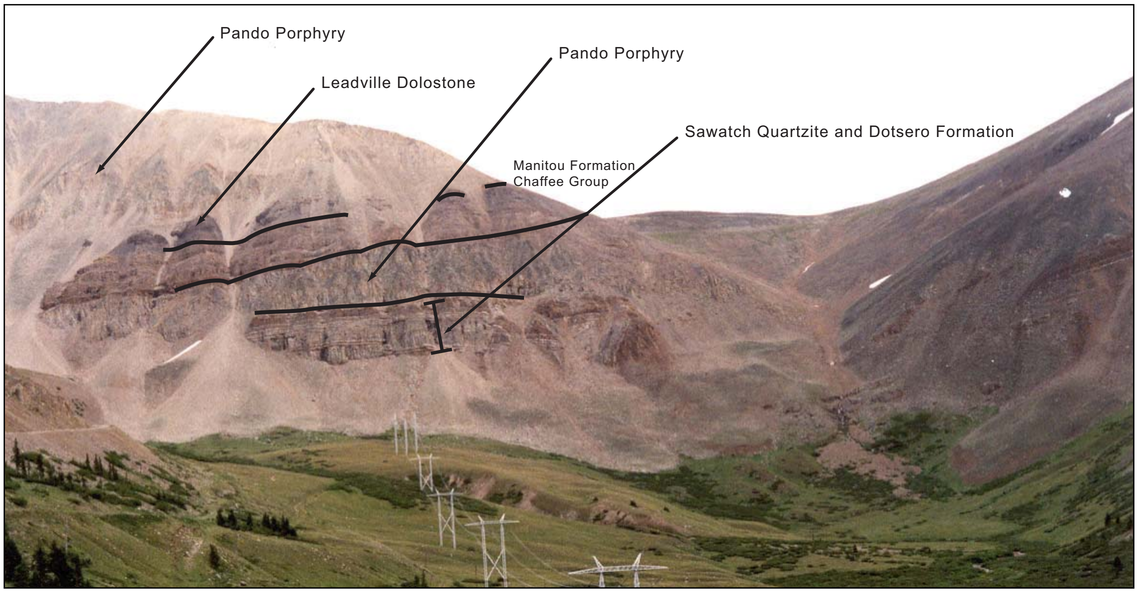


Figure 11. View of Paleozoic section on Mount Sheridan, upper Iowa Gulch. Two sills of Pando Porphyry are shown in this photo.

least altered rocks, the groundmass consists mostly of quartz, biotite, and rare orthoclase. Accessory minerals include magnetite, zircon, apatite, and hornblende. Phenocrysts are generally well formed-especially the quartz crystals, which generally have euhedral outlines. In contrast, later porphyritic rocks contain rounded and embayed quartz crystals. Quartz phenocrysts generally make up 1 to 2 percent of the rock; however, in some places their abundance can be 7 percent. Biotite phenocrysts constitute 1 to 2 percent of the rock. The scarce plagioclase feldspar phenocrysts are generally oligoclase. Alteration minerals in the Pando Porphyry consist of bluish-gray quartz crystals and sericite. Biotite is commonly altered to carbonate and sericite. Feldspar phenocrysts are commonly completely altered to sericite. Epidote and chlorite are also common alteration products (Behre, 1953).

The Late White Porphyry as described by Behre (1953) closely resembles his Early White Porphyry-the Pando Porphyry of this report. However, it contains larger phenocrysts, as long as 4.5 mm, of mostly altered plagioclase feldspar and rare phenocrysts of quartz and biotite. The most conspicuous feature is the amoeboid shape of the groundmass quartz crystals. Sericite is common in the groundmass. This rock resembles the rhyolite described by Emmons and others (1927) in the early report on the Leadville district and the later white porphyry described by Singewald and Butler (1931) in the Alma district of nearby Park County.

Early to Mid-Tertiary Porphyritic Rocks of the Leadville District

The early to middle Tertiary porphyritic rocks of the Leadville mining district were originally described as the Gray porphyries by Emmons (1886). The Gray porphyry group included all grayish-colored, distinctly porphyritic intrusive rocks younger than Precambrian. Later workers, including Emmons and others (1927) and Behre (1953), subdivided the Gray porphyries into several subunits. **Table 2** lists the main characteristics of the subunits of the Gray porphyry group unit of Emmons. The Johnson Gulch Porphyry, which forms most of Breece Hill (the north side of California Gulch, pl. 1), is the most significant subunit because the area around Breece Hill contains most of the major ore deposits of the Leadville district. The Johnson Gulch Porphyry was emplaced at 43.1 Ma (Thompson and Arehart, 1990). The young zircon fission-track age of 34.8±4.9 Ma (Cunningham and others, 1994) shown in Table 2 for the Johnson Gulch Porphyry may represent later annealing caused by a younger intrusion underlying the Johnson Gulch Porphyry.

Other Middle Tertiary Porphyritic Rocks

Porphyritic igneous rocks similar to the Gray porphyry group crop out in other areas of Lake County. In the Climax district, rocks lithologically similar to the Lincoln Porphyry of the Leadville district described in table 2 predate intrusion of the ore-bearing Climax Stock (Wallace and others, 1968). The Twin Lakes Quartz Monzonite Porphyry in the Twin Lakes district of southwestern Lake County was described and named by Howell (1919). His description of the Twin Lakes Quartz Monzonite Porphyry is similar to that for the Lincoln Porphyry of the Gray porphyry group. Fridrich and others (1998) mapped the Twin Lakes Quartz Monzonite Porphyry as the Twin Lakes pluton. A potassium-argon age on biotite of 42.7±1.2 Ma, a

Table 2. Geologic characteristics of the subunits of the Gray porphyry group unit of Emmons (1886) of the Leadville district. [Abbreviations for dating methods: ZFT, zircon fission track; K-Ar, potassium argon]

Composition	Color	Major Phenocrysts	Other phenocrysts	Groundmass	Alteration
Iowa Gulch Porphyry					
Quartz latite	Light gray to light brownish gray	Quartz, 5% Biotite, 3% Plagioclase		Glassy plagioclase in trachytic texture	Less altered than other gray porphyries
Johnson Gulch Porphyry: 43.1±4.3 Ma-ZFT (Thompson and Arehart, 1990); 34.8±4.9 Ma-reset zircons (Cunningham and others, 1994)					
Quartz monozonite	Medium gray	Euhedral plagioclase Euhedral quartz Orthoclase	Biotite, Hornblende Magnetite Apatite Rutile	Quartz Sodic plagioclase Orthoclase	Plagioclase > sericite > calcite
Sacramento Porphyry: 43.9±4.3 Ma-ZFT (Thompson and Arehart, 1990)					
Quartz monzonite	Light gray-green with white plagio-clase crystals	Oligoclase-andesine, 20–30%	Quartz, Green biotite Local hornblende>	Alkali feldspar, Quartz	Plagioclase > sericite Biotite > chlorite > epidote. Hornblende > chlorite
Evans Gulch Porphyry: 46.8±4.4 Ma-ZFT (Cunningham and others, 1994)					
Quartz monzonite	Light pinkish-gray to light-greenish gray	Plagioclase, 25% Quartz, 5% Dark amphibole dark mica	Apatite, Magnetite Rutile	Quartz Alkali feldspar. Tiny grains and microlites	Plagioclase > sericite epidote calcite
Lincoln Porphyry: 64 Ma-K-Ar (Pearson and others, 1962)					
Granodiorite-quartz monzonite	Light gray with pinkish cast	Euhedral orthoclase (≥7.5 cm long) Euhedral quartz Plagioclase, 30%	Hornblende Biotite Apatite Sphene Magnetite	Quartz Alkali feldspar	Plagioclase > sericite > calcite Biotite > chlorite > epidote.
Quartz Diorite Porphyry: Oldest unit of Gray porphyries (Behre, 1953)					
Quartz diorite	Greenish gray	Feldspar (rare) Hornblende (rare)	Apatite, Magnetite	Plagiclase Hornblende Quartz	Plagioclase > sericite > calcite

zircon fission-track age of 45.5±5 Ma, and a rubidium-strontium age of 48.6±4.5 Ma are all listed as times for the intrusion of the Twin Lakes pluton (Fridrich and others, 1998), ruling out an affinity with the Lincoln Porphyry, which has an age of 64 Ma.

Porphyritic rocks similar in appearance to the Pando Porphyry are also found in the Sugar Loaf and St. Kevin mining districts of western Lake County. Plagioclase, biotite, and quartz are the most common phenocryst minerals. The plagioclase is altered to sericite. Biotite is altered and bleached. Groundmass minerals are quartz and orthoclase (Singewald, 1955).

Middle Tertiary Climax Stock

The Climax Stock is exposed along the east side of the Mosquito fault in northernmost Lake County (**Figures 12 and 13**). This stock is the host for the giant Climax molybdenum deposit. From about 33 to 18 Ma, the Climax Stock was intruded in four main phases (Shannon and others, 2006; Bookstrom, 1989; Bookstrom and others, 1988; Wallace and others, 1968): (1) the Alicante stock, formerly called the Southwest Mass, (2) the Bartlett stock, formerly called the Central Mass, (3) the Wallace stock, formerly called the Aplitic Porphyry Phase and Intra-mineral Porphyry dikes, and (4) the Traver stock, formerly called the Porphyritic Granite Phase and Late Rhyolite Porphyry dikes. The four phases of the Climax Stock have essentially the same composition, texture, and minerals. They are all composed of quartz-orthoclase-albite-biotite porphyry. Because of the strong and widespread hydrothermal alteration and similar composition, it is difficult to consistently distinguish the four phases.

Alicante Stock

The Alicante stock of the Climax Stock is an elliptical porphyry intrusion located mostly on the south side of the Climax Stock (figs. 12, 13, **and 14**). Subhedral phenocrysts of quartz and orthoclase average 2 to 3 mm across and are set in a fine-grained matrix of the same minerals. Albite content increases with depth. In places, the porphyry contains numerous ragged crystals of primary biotite, which along with its alteration product, sericite, defines a flow foliation near contacts.

Bartlett Stock

The Bartlett stock is a vertical plug that has an essentially circular plan form with a diameter of 1,200 ft on the Phillipson Level (elevation of 11,463 ft) of the Climax Mine (fig. 14). The Bartlett stock was named

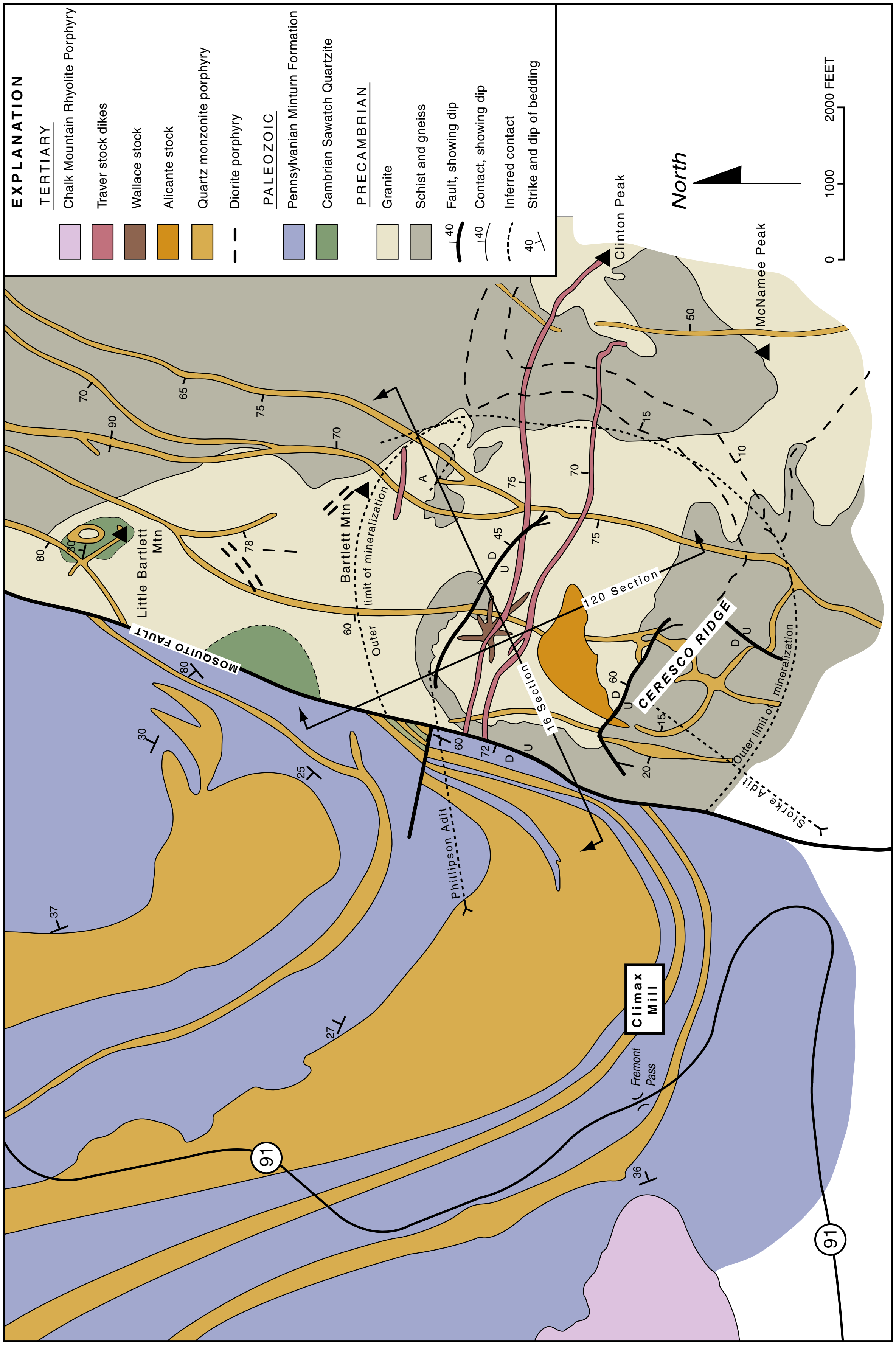


Figure 12. Generalized bedrock geology of the Climax area. (Adapted from Wallace and others, 1968).

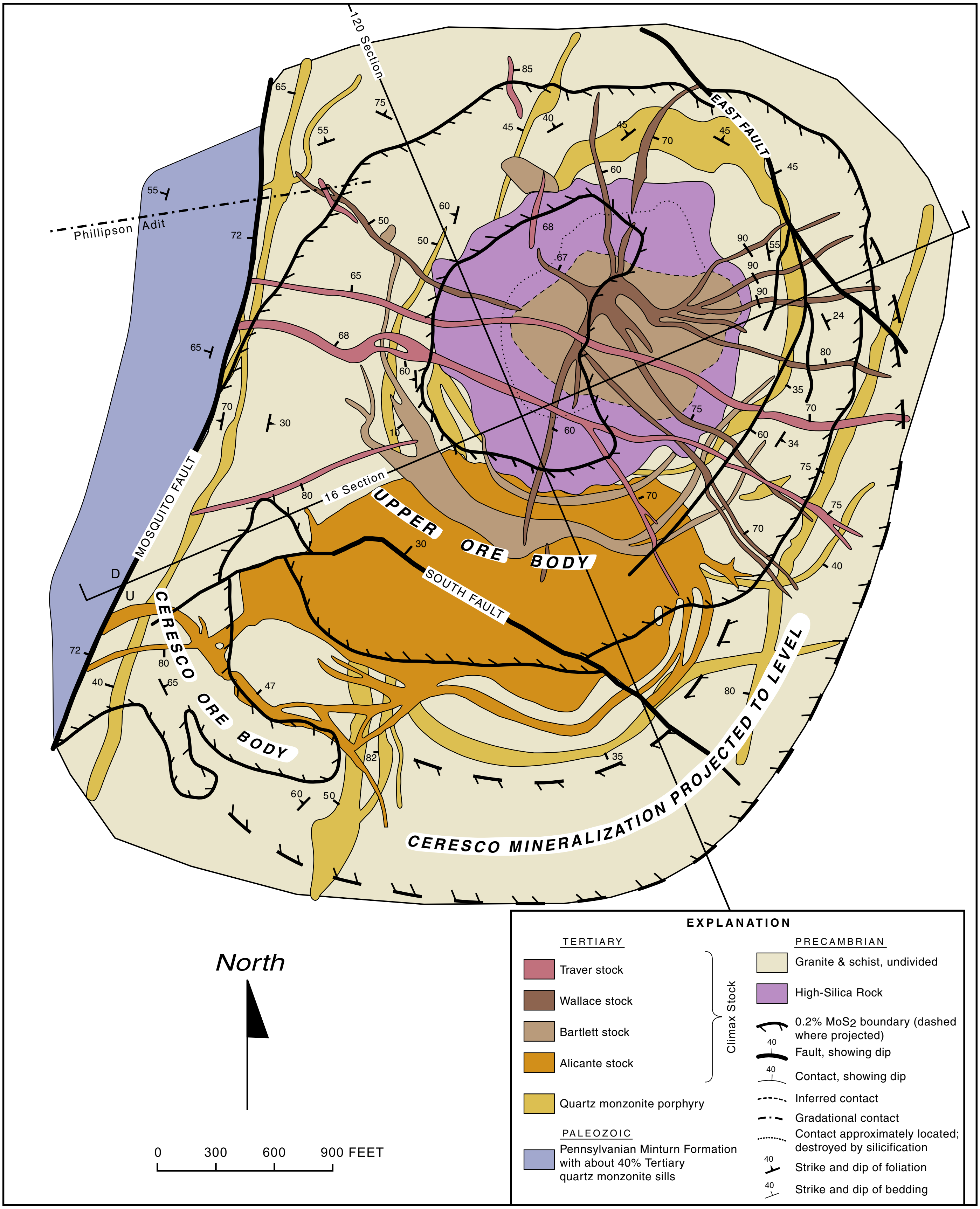


Figure 13. Phillipson Level, Climax Mine, showing generalized geology and ore zones. (Adapted from Wallace and others, 1968).

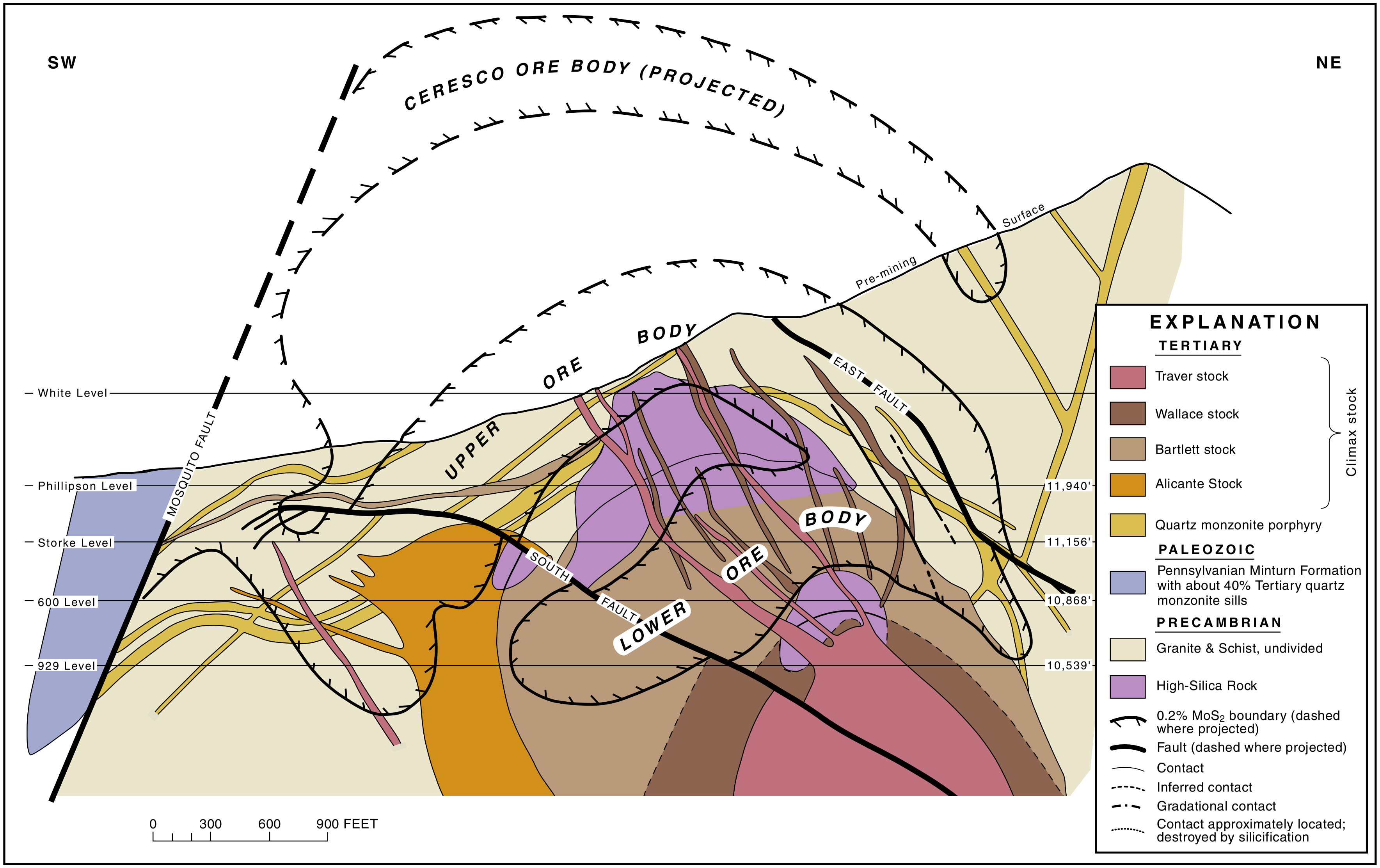


Figure 14. 16 section, Climax Mine, showing generalized geology and ore zones. Line of 16 Section shown on Figure 13. (Adapted from Wallace and others, 1968).

the Central Mass because of its central location relative to the zones of alteration and mineralization of the Climax Stock by Wallace and others (1968). The porphyry of the Bartlett stock is coarser grained and considerably more altered than the Alicante stock porphyry. The orthoclase crystals are notably ragged, and the quartz crystals are circular to oval aggregates of irregular interlocking grains. Plagioclase and biotite are completely lacking above the Storke Level (elevation of 11,168 ft) (fig. 14). A weak flow foliation is developed throughout the Bartlett stock. In the eastern part of the Bartlett stock, a strong, steeply dipping tectonic foliation is expressed in the elongation of quartz crystals.

Wallace Stock and Intra-Mineral Porphyry Dikes

The Wallace stock of the Climax Stock was intruded into the Bartlett stock and generally is about the same size and shape as the Bartlett stock (fig. 13). The Intra-mineral Porphyry dikes were intruded into the radial tension fractures developed within the Bartlett stock and are so named because of their complex and overlapping relationships to the two main mineralization events in the Climax Stock.

The Wallace stock is similar to the other phases of the Climax Stock. It is a fine-grained rock with sparse phenocrysts of quartz in a fine-grained matrix of quartz and alkali feldspar. Coarse-grained to pegmatitic phases of the stock contain smaller amounts of biotite and fluorite.

The Intra-mineral Porphyry dikes are coarser grained than the Wallace stock and contain abundant and large phenocrysts of quartz and orthoclase. The quartz phenocrysts are generally broken and angular fragments, and shards are common. Albite crystals are rarely seen in the dikes. There are two other varieties of the Intra-mineral Porphyry dikes: fine-grained, pyritic rhyolite and biotite porphyry with few phenocrysts of quartz and feldspar. Albite has been observed in many of the dikes, particularly above the Phillipson Level. Many of the quartz phenocrysts are angular and "broken." The groundmass is very fine grained and contains abundant fragmental material.

The Chalk Mountain stock is interpreted to be part of the Climax Stock because of spatial association, age, and whole-rock chemical attributes (Bookstrom and others, 1988). The Chalk Mountain stock is a rhyolite porphyry with abundant, dark, smoky quartz phenocrysts and chatoyant sanidine phenocrysts in a fine-grained groundmass (Shannon and others, 2006).

Traver Stock and Late Rhyolite Porphyry Dikes

The Traver stock, located below the Wallace stock, is a medium- to coarse-grained, xenomorphic-granular assemblage of orthoclase, albite, and quartz, along with small flakes of biotite. Albite both replaces and is replaced by orthoclase.

Late Rhyolite Porphyry dikes are exposed on the Phillipson Level; there, they trend almost due west across the Climax Stock and are terminated by the Mosquito fault (figs. 12 and 13). Other Late Rhyolite Porphyry dikes show a radial pattern around the center of the stock. Some of these dikes intrude the same tension fractures intruded by the earlier Intra-mineral Porphyry dikes.

On the 929 Level the Late Rhyolite Porphyry dikes are cut off by the Traver stock (Wallace and Bookstrom, 1993, p. 38).

Volcanic Rocks of the Grizzly Peak Caldera

Volcanic and associated intrusive rocks related to the development of the Grizzly Peak caldera crop out in the southwest corner of Lake County, south of Independence Pass. Precaldera rhyolite flows are found in and around the Grizzly Peak caldera (Fridrich and others, 1991); however, none of these are in Lake County. Extracaldera rhyolite dikes that intrude cone-shaped fractures are found as far as 13 mi northeast of the caldera rim (Cruson, 1973). These dikes are commonly hydrothermally altered.

The Grizzly Peak Tuff is the product of a single eruptive episode that formed the Grizzly Peak caldera at about 34 Ma. Tuffs are zoned from high-silica rhyolite at the base to low-silica rhyolite at the top. Fridrich and others (1991) divided the Grizzly Peak Tuff into six units on the basis of their composition and the position of two especially thick and widespread breccia units. Mostly intracaldera facies are recognized in the Grizzly Peak Tuff. Fridrich and others (1998) also dated outflow-facies rocks at 33.3 Ma that crop out about 30 mi to the north at Mount Sopris in Pitkin County and about 10 mi east of the caldera in the Arkansas River Valley, just north of the Lake County line.

LATE TERTIARY TO QUATERNARY IGNEOUS ROCKS

Little Union Quartz Latite

The Little Union quartz latite was originally described by Emmons (1886) and later redefined by Behre (1953). This unit is exposed across a small area in Big Union Creek and Little Union Gulch, west and south of Empire Hill (pl. 1). The Little Union quartz latite is a brownish gray that weathers to darker brownish gray with rust-colored spots. It is composed of a groundmass of brownish-gray glass enclosing microlites of quartz, feldspar, and mica; the groundmass constitutes about 60 percent of the rock. The remainder consists of phenocrysts of plagioclase feldspar (25 percent), quartz

(5 percent), biotite (5 percent), and lesser amounts of orthoclase feldspar, magnetite, green hornblende, apatite, zircon, and titanite. Behre (1953) offered the following evidence for the young age of the Little Union quartz latite. Locally, the it contains argillically altered xenoliths of the surrounding older rocks including the Precambrian rocks and fragments of the Pando Porphyry and the Gray porphyry group. The quartz latite outcrops stretch along the trace of the Mike fault; the unit cuts the Pando Porphyry and the Gray porphyry group. The quartz latite is not altered.

Rhyolite and Fragmental Porphyry

Outcrops of rhyolite and Fragmental Porphyry have been mapped in the Leadville district near Breece Hill (pl. 1) and as small pipes in underground workings. In northern Lake County, Chalk Mountain is composed of rhyolite. Megascopically, the rock resembles a fault breccia. Under the microscope, flow bands are observed around the angular fragments. There are subangular phenocrysts of quartz and feldspar and minor magnetite and biotite. The matrix is strongly altered (Behre, 1953). Emmons and others (1927) postulated a late Tertiary age for the rhyolite.

Earlier workers had recognized the breccias that are currently referred to as the Fragmental Porphyry. Loughlin (1926) referred to rhyolite agglomerate in four funnel-shaped pipes in underground workings. Emmons and others (1927) described four breccia pipes in the northern part of the district. Behre (1953) recognized these breccias as rhyolite agglomerate in Iowa Gulch in the southern part of the Leadville district. The name "Fragmental Porphyry" for these breccia bodies came into usage by mine geologists at the Black Cloud Mine in Leadville in the 1970s. Hazlitt and Thompson (1990) described the Fragmental Porphyry as a dense, matrix-supported, heterolithic to monolithic breccia with subangular to rounded "pebble" fragments contained in a rock-flour matrix. Clasts in the Fragmental Porphyry include all rock types in the district, from Proterozoic rocks to Late Rhyolite Porphyry dike fragments, and phenocrysts of quartz and feldspar. Geologic relationships indicate that the Fragmental Porphyry is slightly younger than the ore-forming event, which is thought to have occurred at 39.6±1.7 Ma (Hazlitt and Thompson, 1990).

Structure

Lake County is situated on the eastern flank of the broadly antiformal Sawatch uplift that encompasses the Sawatch Range on the west and the subsidiary Mosquito Range block uplift on the east. The Arkansas Valley graben, part of the Rio Grande rift zone, lies between these two positive structural elements (fig. 2, pl. 1). The western and southeastern parts of the County consist of the Proterozoic cores of the Sawatch uplift and Mosquito Range uplift, respectively; the central part of Lake County consists of east-dipping Paleozoic rocks, which are locally overlain and intruded by Tertiary volcanic rocks and Late Cretaceous to Tertiary porphyritic intrusions. The structure of the eastern part of the County is complicated by many north-trending regional and local faults. The Mosquito fault, the Weston fault, and the Mike fault (pl. 1) are all major north-trending faults in the Mosquito Range. Movement along most of these faults resulted in down-to-the-west offset, except along parts of the Weston fault. The normal faults of the Mosquito Range are nearly vertical. Even the reverse faults have steep dips. The exceptions are the shallowly dipping South Dyer fault and a few minor faults on Mount Sherman and Mount Sheridan. In the northeast part of the County, northeast-trending faults are also prominent. Most of the faults in the Sawatch Range of Lake County trend north.

Mosquito Fault

The Mosquito fault is one of the major fault systems of the Colorado Rocky Mountains. It extends at least from east of Mount Sherman through the Leadville mining district, northward to become the bounding structure for the Climax Stock in the northeastern part of the County, and then north-northeastward to form a bounding structure of the Tenmile Range in Summit County (Widmann and others, 2004).

Downdip displacement on the Mosquito fault is about 600 ft at Ball Mountain in the Leadville district. Just a few miles to the north in Evans Amphitheater, displacement is 5,100 ft (Behre, 1953, p. 66). Wallace and others (1968) estimated more than 9,000 ft of vertical displacement and 1,500 ft of lateral displacement on the Mosquito fault at Climax.

The age of the Mosquito fault system is somewhat controversial. Relationships at Climax and in most of the Leadville district indicate that the fault is postmineralization and therefore younger than 24 Ma. Conflicting evidence-mainly mineralized veins that are parallel to the Mosquito fault-from prospects on Ball Mountain and in the Best Friend Mine and other mines in the Evans Amphitheater indicate that the fault was present prior to mineralization (Behre, 1953, p. 66). It may be that this part of the Mosquito fault is coincident with an older fault, as is common in Colorado (Tweto, 1979, p. 35).

Weston Fault

The Weston fault is a major north-northwest-trending fault system in Lake County. South of Empire Gulch, it is the site of a total vertical displacement of 1,200 ft down dropped to the west. Recent geologic mapping in South Park (Wallace and others, 1999; Wallace and Keller, 2003) indicates that the Weston fault system may extend some 30 mi south of Weston Pass for a total length of more than 50 mi.

South Dyer Fault

The South Dyer fault is well exposed on the south side of East Ball Mountain, West Dyer Mountain, and the Dyer Amphitheater (pl. 1 and **Figure 15**). It is one of the few faults in Lake County with a relatively shallow dip, about 40° to 65° NE. It strikes west-northwest in a region of predominantly north-striking, steeply dipping faults. On East Ball Mountain, the upper plate of the fault consists of Proterozoic rocks overlain by Paleozoic sedimentary rocks. On West Dyer Mountain, the lower plate of the fault consists of Cambrian Sawatch Quartzite.

Homestake Shear Zone

The Homestake shear zone was defined by Tweto and Sims (1963) and mapped in the Holy Cross quadrangle (Tweto, 1974b). The Homestake shear zone cuts through a small part of northern Lake County, near Homestake Peak (pl. 1). In most of the Sawatch Range, the Proterozoic gneiss has a shallowly dipping foliation. In and close to the Homestake shear zone, the foliation trends northeast and is vertical. The rocks

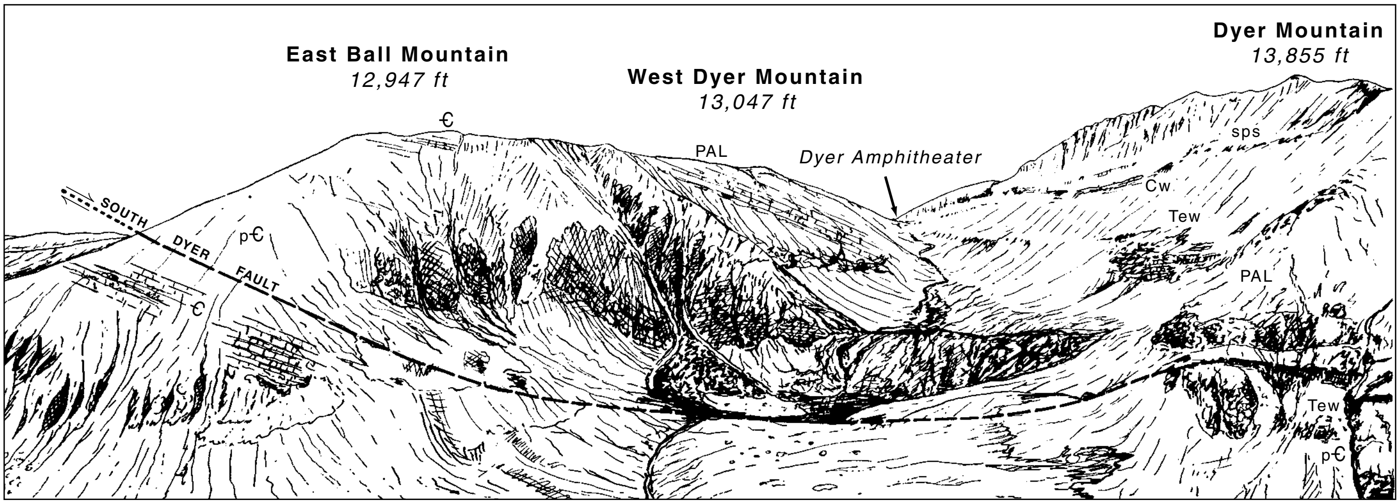


Figure 15. South Dyer Fault, Dyer Ampitheater. Explanation: Precambrian (pЄ); Cambrian (Є); pre-Minturn Paleozoic sediments (PAL); Weber Formation (Cw), sill of Sacramento porphyry (sps); White porphyry (Tew). (From Behre, 1953, p. 68).

within the Homestake shear zone range from gouge and breccia through mylonite to recrystallized and refoliated gneiss. The Homestake shear zone was active during the metamorphic event that formed the gneiss at about 1,800 to 1,700 Ma. Evidence from the west side of the Sawatch Range indicates that the Homestake shear zone was active during deposition of the lower to middle Paleozoic sedimentary rocks (Tweto and Sims, 1963). However, recent detailed stratigraphic work on the lower Paleozoic strata of this region by Myrow and others (2003) suggests that the Homestake shear zone was not a major factor controlling the sedimentation in this area.

Sawatch Uplift

The Sawatch uplift forms the Sawatch Range in Lake County; it is antiformal in shape and is composed mostly of Proterozoic metamorphic and igneous rocks. An early structure expressed in the schists and gneisses consists of tightly compressed isoclinal folds trending N. 60° E. with steeply dipping, axial planes overturned to the northwest (Stark and Barnes, 1935). Several north-trending faults have been mapped on the eastern side of the Sawatch Range. Most of these are steeply dipping normal faults along which down-to-the-east movement occurred.

The area around the Sugar Loaf and St. Kevin mining districts is broken by several faults, which have been recognized by their associated silicification. The faults in this area trend northeast and northwest. Veins associated with mineralization trend mostly north (Singewald, 1955).

Tweto (1979) suggested that the Sawatch Range was uplifted and tilted westward as evidenced by (1) the high peaks of the range facing into the Arkansas River Valley and standing in front of the Continental Divide to the west and (2) the greater depth of erosion in the molybdenum deposits on the eastern part of the range (Climax excluded).

Rio Grande Rift-Arkansas Valley Graben

The Rio Grande Rift is expressed in Lake County by a structural graben or series of grabens between the Sawatch and Mosquito Ranges. The west side of the graben is usually bounded by only one or two faults; in contrast, the eastern side is step-faulted almost to the crest of the Mosquito Range (Tweto, 1979). Late Quaternary movement on the bounding faults on the west side of the graben has been documented by Widmann and others (2002). Faults on the east side of the graben also have had major Neogene movement, as evidenced by displacements of volcanic rocks and the Dry Union Formation. Gravity measurements southwest of Leadville in the graben indicate 3,000 to 4,000 ft of fill (Tweto and Case, 1972).

Grizzly Peak Caldera-Ring Fracture Zone

Volcanic rocks and the northern part of the ring-fracture zone of the Grizzly Peak caldera have been mapped in the extreme southwestern part of Lake County. Collapse of the Grizzly Peak caldera occurred during the eruption of the Grizzly Peak Tuff along the ring-fracture zone about 34 Ma. The throw of the ring-fracture zone along the northern rim of the caldera is estimated to be 2,300 to 3,000 ft; the minimum subsidence within the ring-fracture zone is estimated to be 9,800 to 11,500 ft (Fridrich and others, 1991, fig. 11).

Lake County is the site of two of Colorado's most famous mining districts, the Leadville district and the Climax district (fig. 4). These two districts have played an important part in the establishment of mineral wealth of Colorado. The history of mining in the Leadville district began with the discovery of placer gold in California Gulch, which led to the discovery of the base-metal massive sulfide deposits that made the district famous. The Climax district was discovered as prospectors fanned out prospecting for gold deposits. They found molybdenum instead. In the twentieth century, the Climax Mine grew to become the world's most important producer of molybdenum.

Other mining districts in Lake County are of lesser importance economically but provide much of scientific value. They include the Twin Lakes district, the Sugar Loaf and St. Kevin districts, the Tennessee Pass district, the Granite district, and the Weston Pass district. **Table 3** lists all the mining districts of Lake County and their estimated production values.

CLIMAX DISTRICT

Discovery and Early History

The Climax deposit is located in northeastern Lake County at Fremont Pass, near the headwaters of the Arkansas River. The altitude around the Climax deposits ranges from 11,000 ft to 13,600 ft. State Highway 24 and the Colorado and Southern rail line are within 1,000 ft of the deposit.

In 1879, a prospector named Charles Senter was searching for gold on Bartlett Mountain (pl. 1), part of the Mosquito Range in central Colorado. He found a yellow-stained outcrop, which is usually a good sign of the presence of sulfide minerals and gold. The outcrop yielded only a gray crystalline rock laced with thin veinlets of a dark bluish-gray greasy mineral and pyrite. Senter staked three claims over this outcrop because of the presence of the pyrite. He thought the gray mineral was some sort of lead or even graphite. It took Senter an additional 14 years to get his samples analyzed. The strange gray mineral was a sulfide of molybdenum, now recognized as molybdenite.

The small settlement of Climax was established at 11,318 ft near Fremont Pass just below Bartlett Mountain in 1884. Blessed with short but spectacular summers and long hard winters, Climax remained only a couple of bunkhouses at a railroad siding on the Denver-Leadville rail route.

In the 1890s, molybdenum was just starting to be used in industrial processes for hardening steel. However, the known deposits of molybdenum were small but very rich vein deposits. Other prospectors and businessmen had heard of the strange metal on Bartlett Mountain near Climax. They staked claims around Senter's original discovery and in 1911 shipped some ore to a mill in Denver. Although metallurgical processes were improving, the low-grade ores from

Table 3. Years of operation of Lake County mining districts and their estimated value of production.
[In actual dollars not adjusted for inflation]

Mining District	Years of Operation	Estimated Value of Production
Twin Lakes	1884 – 1953	$66,053 (under reported)
Sugar Loaf - St. Kevin	1880s – 1948	$10 – 15 million
Tennessee Pass	1898 – 1936	$100,000
Weston Pass (also in Park County)	1902 – 1948	$125,000
Granite (also in Chaffee County)	1860 – 1878 – 1936	$1.3 million
Leadville	1860 – 1999	$1.8 billion
Gold		$105 million
Silver		$530 million
Lead		$470 million
Zinc		$696 million
Copper		$77 million
Climax, molybdenum	1917 – 1995	$4 billion

Climax could not compete with the small, but high-grade, vein deposits being mined in Norway.

In 1916, with World War I raging in Europe, a German company with American headquarters in New York became interested in the molybdenite deposits at Climax. Molybdenum's steel hardening properties made molybdenum alloy steel excellent for armaments. The German company's American subsidiary was called the American Metal Company. They conducted test mining and eventually gained control of the deposit. The company was nationalized in 1917 as America entered World War I against Germany, and Climax Molybdenum Company was formed. A schoolhouse, post office, and residences were established at Climax in 1918. The new Climax Mine produced about 250 tons of ore per day. The first rail cars of molybdenite concentrate were shipped from the Climax Mine in April 1918. Thus began the long history of mining and milling at Climax.

When World War I ended in November 1918, the demand for and the price of molybdenum crashed. The industry slowly recovered during the 1920s and 1930s as Climax Molybdenum Company developed new uses for molybdenum. In 1929, the Climax Mine instituted a new system of bulk underground mining-the block-caving method. The highly efficient block-caving method allowed production to climb to more than 6,000 tons of ore per day. As the depression of the 1930s ended, the Climax Mine was making its first significant profits and was supplying 90 percent of the world demand for molybdenum.

Post-World War II History

Increasing production at the Climax Mine required more miners and mill workers. However, the harsh conditions of long, hard winters and high altitude at Climax caused many miners to quit after only a short period. Nevertheless, a company town grew up at Climax, and families soon settled into the routine of life in the high Rockies (**Figure 16**).

World War II and the quickly ensuing Korean War fostered new uses for molybdenum in pigments, fertilizers, and high-temperature alloy steel for jet engines. Recovery circuits were installed in the mill to collect the small amounts of tin and tungsten associated with the molybdenite ore, as these metals were both important for the war effort. Production during those war years and the following Cold War years was deemed a high priority by the American government, and in 1957 production reached 35,000 tons per day, making Climax the world's largest underground mine. In 1960, the company expanded the mine and mill workings onto the site of the village of Climax. Most of the miners and other workers moved to the nearby town of Leadville, creating a boom in that venerable old mining town.

In 1964, Climax engineers designed and set off in the Climax Mine the world's largest nonnuclear explosion. They used 416,000 pounds of explosives to blast 1.5 million tons of ore, leaving behind a semicircular depression of broken rock called the Glory Hole (**Figure 17**). During the boom years of the 1970s, production increased to a spectacular 50,000 tons of ore per day. The price for molybdenum rose from $2

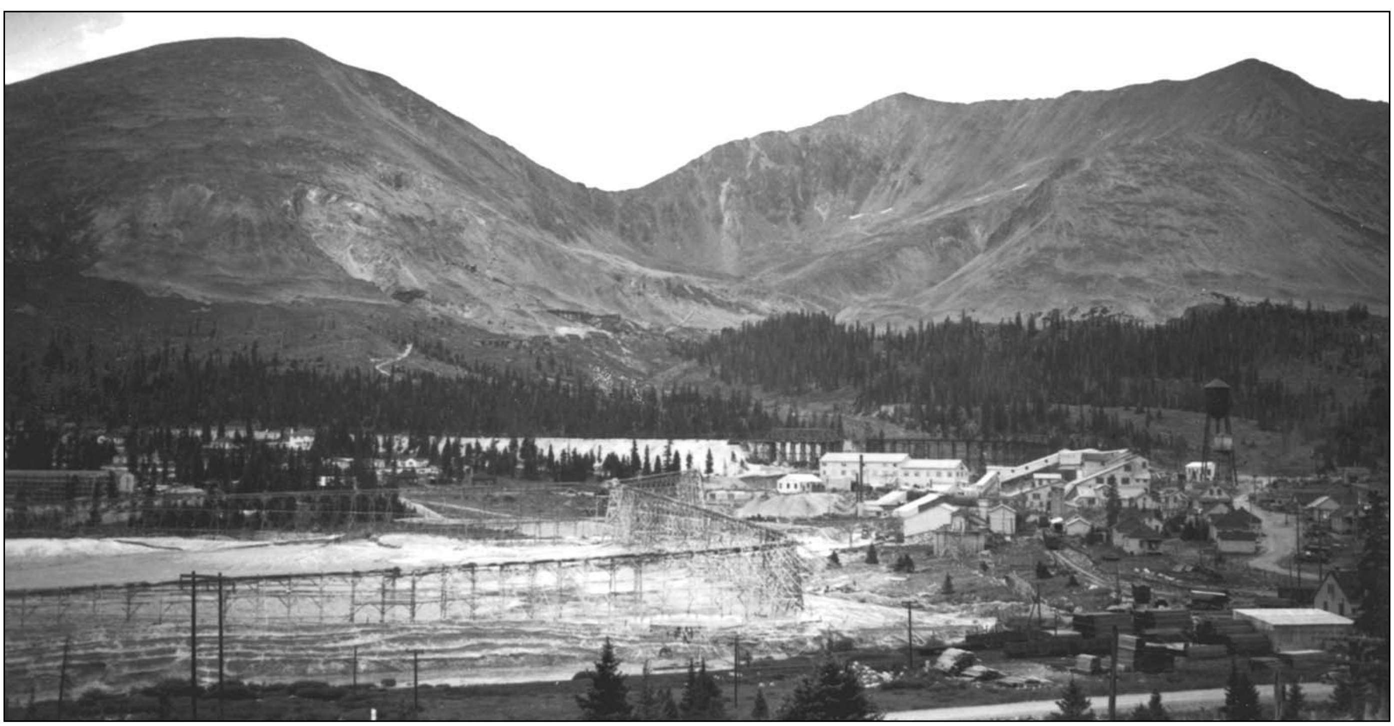


Figure 16. View of Climax mine just prior to World War II. (Photo courtesy of the Colorado Historical Society.)

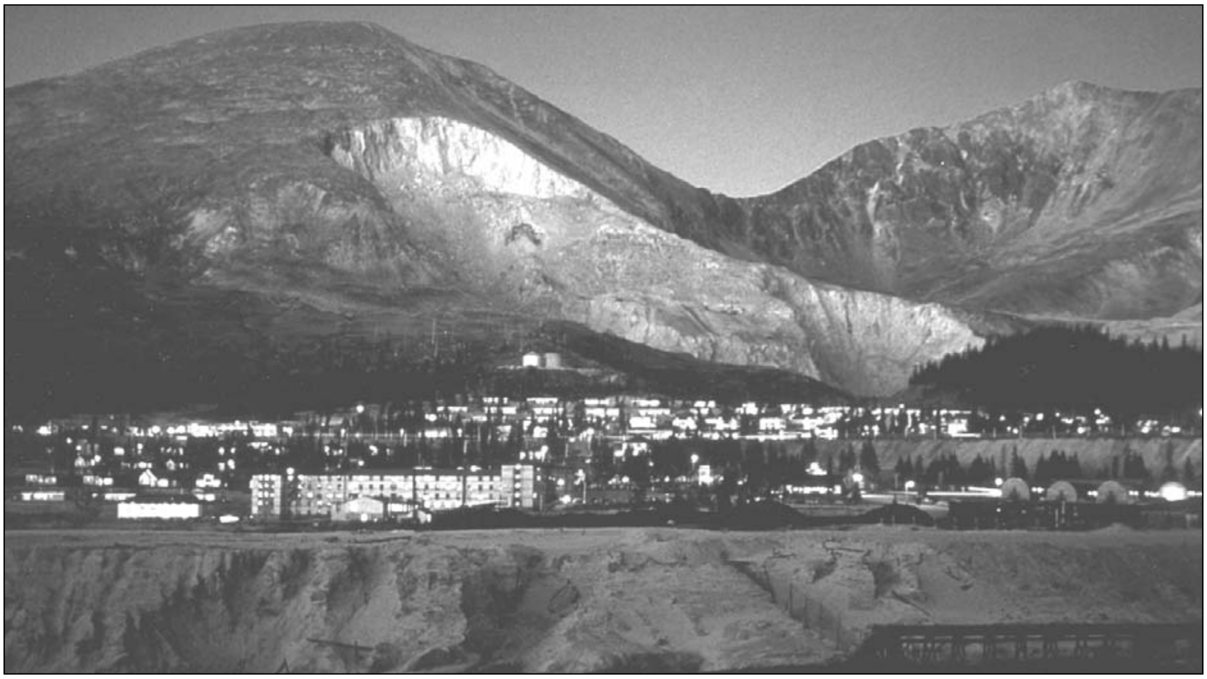


Figure 17. View of Climax Mine in the 1960s showing Glory Hole development. (Photo courtesy of the Colorado Historical Society.)

per pound to $9.50 per pound and up to $30 per pound on the spot market. An open-pit mine was constructed, and employment increased to 3,000 workers in the underground and open-pit mines and the mill. As profits increased, the company (now called American Metals Climax [AMAX] following the 1956 merger of the Climax Molybdenum Company with the American Metals Company) opened the new state-of-the-art Henderson Mine in Clear Creek County in 1976. However, the storm clouds for molybdenum were growing on the horizon (Voynick, 1996).

Because of the high price of molybdenum in the 1970s, many large porphyry copper mines in Arizona, Chile, and British Columbia installed recovery circuits in their mills to capture by-product molybdenum. With increasing molybdenum supplies and decreased demand owing to a national recession, which began in the early 1980s, the Climax Mine began a series of painful layoffs that eventually led to the suspension of mining. Despite these difficulties, mining at Climax continued on a sporadic basis through the early 1990s. The last ore shipments containing about 3 million pounds of molybdenum were completed in 1995. During 2004 and 2005, molybdenum prices rose to an all time high of $37 per pound, causing the mine owners, Phelps Dodge Corporation, to evaluate reopening the mine.

Through 1995, the Climax Mine had produced 500 million tons of ore that yielded about 1 million tons of elemental molybdenum with a "year-mined" value of $4 billion. These numbers equate to an average ore-body grade of 0.410 percent MoS_2 with a 0.2 percent cutoff (Wallace and Bookstrom, 1993). There is still ore remaining in the openpit mine: 137 million tons containing about 500,000 pounds of molybdenum. Climax is, without doubt, the largest and most productive molybdenum deposit yet to be discovered. **Figure 18** shows a graph of both Colorado molybdenum production and prices. Of note is the tremendous price increase of the late 1970s and the resultant price and production crash in the early 1980s.

Geologic Characteristics

At the Climax Mine, the oldest rocks are Paleoproterozoic (1,775 to 1,650 Ma) schist and gneiss, which have been intruded by Mesoproterozoic (1,400 Ma) granite (fig. 12). Near the Climax deposit the schist is uniform in appearance and composition, except in areas near the contact with the younger granites. The schist is medium grained and composed mainly of biotite, quartz, and plagioclase. Near the granite contact, the schist commonly contains sillimanite (Butler and Vanderwilt, 1931, p. 325).

The granite is chiefly gray to pinkish gray, medium to coarse grained, and massive. Coarse-grained granite near Bartlett Mountain displays a conspicuous alignment of tabular feldspars. Study with a petrographic microscope reveals microcline, quartz, orthoclase, oligoclase, biotite, muscovite, apatite, magnetite, titanite, and garnet, in order of decreasing abundance. Microcline forms tabular crystals and is very abundant. Quartz is present as interstitial grains and inclusions in

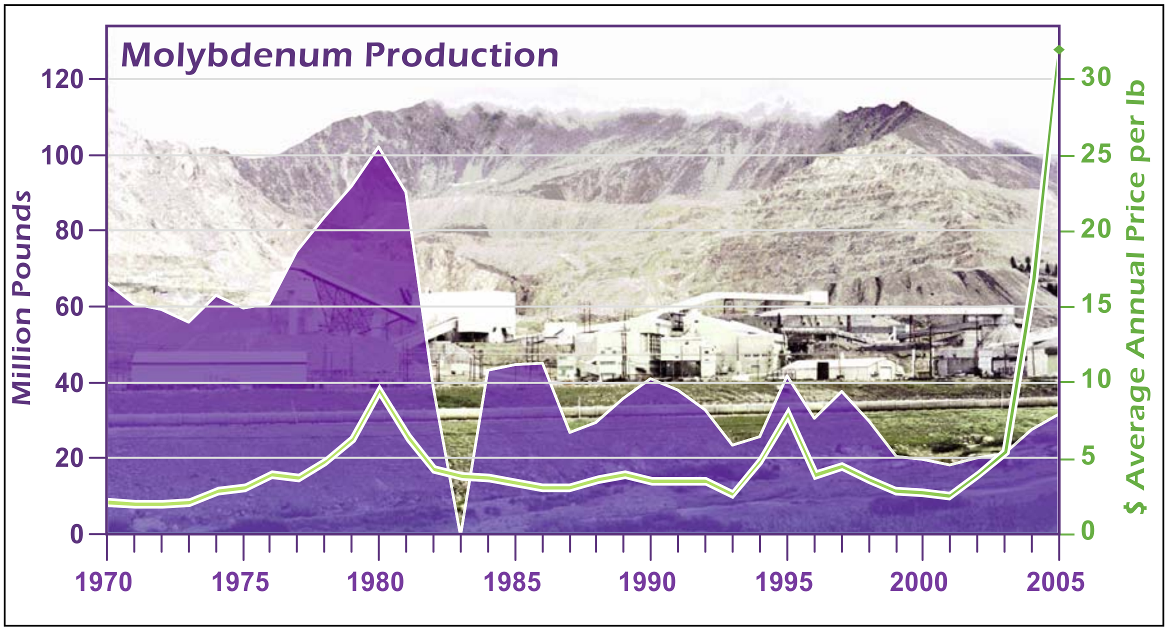


Figure 18. Colorado molybdenum production, 1970 to 2005.

feldspar. All the oligoclase shows some alteration to sericite. The mica minerals may be separate from each other or intergrown and generally constitute less than 15 percent of the rock. The biotite is commonly altered to an aggregate of magnetite and chlorite (Butler and Vanderwilt, 1931, p. 326).

The Cambrian Sawatch Quartzite overlies Proterozoic granite on the east side of the Mosquito fault. The Pennsylvanian Minturn Formation is on the west side of the Mosquito fault in contact with the ore body on the east side. Abundant quartz monzonite porphyry dikes and sills intrude the Minturn Formation (fig. 12).

Two groups of Tertiary igneous rocks have intruded the Climax area. The first group consists of "pre-ore" diorite porphyry and the just-mentioned quartz monzonite porphyry. The quartz monzonite porphyry is similar to the Lincoln Porphyry of the Leadville and Alma mining districts. The second group consists of the composite intrusive complex of the Climax Stock, which is the host rock for the Climax molybdenum deposit. The following description of igneous units and associated alteration and ore bodies is summarized from Wallace and others (1968).

Climax Stock

The Climax Stock consists of four main intrusive bodies. The intrusive bodies are similar in composition, essentially high-silica rhyolite porphyry, but each contains a particular suite of hydrothermal alteration products. In general, a zone of silicification-High-Silica Rock-lies on the upper part of each productive igneous phase. Zones of molybdenite ore cap and flank the High-Silica Rock. Zones of pyrite-tungsten mineralization lie along the upper and outer surfaces of the molybdenite ore bodies. **Table 4** lists each of the igneous and hydrothermal events of the Climax Stock and their approximate ages. Intrusion of the rhyolite porphyry stocks began about 33 Ma and may have lasted as long as 15 m.y., according to the fission-track and K-Ar dates listed in Table 4. However, dating of igneous and hydrothermal activity at the Urad-Henderson molybdenum porphyry deposit in Clear Creek County by the ^{40}Ar-^{39}Ar method reduced the time span indicated by fission-track and K-Ar methods from 10.6 m.y. to 2.95 or possibly 3.43 m.y. (Geissman and others, 1992, in Shannon and others, 2006). Therefore, Shannon and others (2006) suggested that application of high-resolution ^{40}Ar-^{39}Ar dating at Climax would probably likewise reduce the interpreted 15 m.y. span of igneous and hydrothermal activity.

Ceresco Ore Body—Alicante Stock

The Alicante stock is an elliptical body of porphyry on the southwest side of the Climax Stock (fig. 13). On the Phillipson Level, the Alicante stock is 1,800 ft by 1,100 ft. Below the Phillipson Level, it plunges northward in contact with the Bartlett stock (fig. 14). The Ceresco Ore Body lies well outside the Alicante stock, and the porphyry is not affected by the mineralization. Dikes that extend from the Alicante stock into the ore body are well mineralized.

Table 4. Climax Stock igneous and hydrothermal events and approximate ages of the events (adapted from Wallace and others, 1968; Wallace, 1995) Abbreviations: FT = fission track, zircon; K-Ar = potassium-argon.

Stage	Hydrothermal Event (Ore Body or Alteration Zone)	Igneous Event (Phase of Climax Stock)	Age(Ma), Method	Age Reference
1	Ceresco Ore Body	Alicante stock and irregular and anastomosing dike swarm	33.2±2.1, FT	White and others (1981)
2	Upper Ore Body	Bartlett stock and related arcuate dikes and sheets	30.6±0.4, K-Ar 29.8±0.4, K-Ar	Bookstrom and others (1988) White and others (1981)
3	Lower Ore Body	Wallace stock and Intra-mineral Porphyry Dikes Chalk Mountain rhyolite porphyry	26.1±1.2, FT 27.7±1.9	White and others(1981) Bookstrom and others (1988)
4a	Late Barren Stage of mineralization	Late rhyolite porphyry dikes	25.1, FT 25.5±1.2	Smith (1979) White and others (1981)
4b	Late Barren Stage of mineralization	Traver stock	18.2±0.9, FT 25.3±0.3, K-Ar	White and others (1981) White and others (1981)

Upper Ore Body—Bartlett Stock

The Upper Ore Body lies above and outside the Bartlett stock. However, mineralization extends into the porphyry in some places (fig. 14).

Lower Ore Body-Wallace Stock and Intra-Mineral Porphyry Dikes

The Lower Ore Body lies just above the upper contact with the Wallace stock, but some molybdenite mineralization is also present in the upper and outer parts of that phase. The Intra-mineral Porphyry dikes cut cleanly across the Upper Ore Body; the dikes commonly contain fragments of the Upper Ore Body. In the Lower Ore Body, the Intra-mineral Porphyry dikes commonly contain significant molybdenite mineralization (fig. 14).

"Barren" Stage-Traver Stock and Late Rhyolite Porphyry Dikes

Most Late Rhyolite Porphyry dikes have pegmatitic borders with coarse quartz, potassium feldspar, fluorite, and rhodochrosite. Pyrite, chalcopyrite, sphalerite, and molybdenite are common constituents of the pegmatitic phase.

Structure

There are three main faults that cut the Climax Stock: the East fault, the South fault, and the Mosquito fault. The East fault is a normal fault that dips about 45°–50° E. (fig. 13). It branches into a splayed fault system in its southern segment. Along it, both the Upper Ore Body and the Lower Ore Body are displaced by approximately 330 ft. The fault contains crushed rock, fine-grained quartz, and lesser amounts of coarse fluorite, rhodochrosite, pyrite, and fine-grained sphalerite, chalcopyrite, and galena. These minerals are typical of Late "Barren" Stage mineralization; therefore, the fault predates that stage. The fault is probably related to the intrusion of the Porphyritic Granite Phase.

The South fault is located in the southern part of the stock and is a normal fault with about 200 to 300 ft of slip. The fault dips about 30° NE.; however, at places the dip steepens to 50°–60° NE. The fault commonly is filled with light- to dark-gray chalcedony and fluorite. The South fault probably formed late in the sequence of intrusive and hydrothermal events at Climax.

The Mosquito fault is a major structure in the Climax area and throughout the entire Mosquito Range of Lake County. At Climax, the fault strikes about N. 10° E. and dips 70° W. The fault has more than 9,000 ft of normal separation. The hanging wall has apparently moved about 1,500 ft in a left-lateral sense. In the Climax Mine, the Mosquito fault is a zone of fractured and broken rock that is several hundred feet wide. Crushed-rock zones are as wide as 25 to 50 ft. Deep drill holes have intercepted molybdenite deposits along the Mosquito fault, probably related to the Ceresco Ore Body. Most of the observed movement along the fault is post-ore deposition.

Ore Deposits

Three main ore bodies were formed by the multiple intrusions of the Climax Stock: the Upper Ore Body, the Lower Ore Body, and the Ceresco Ore Body. The Ceresco Ore Body is related to the emplacement of the Alicante stock, the earliest porphyry intrusion. Figure 14 shows the remains of the Ceresco Ore Body and its projected position prior to erosion removing most of the ore body. The Upper and Lower Ore Bodies are related to the intrusion of the Bartlett stock and Wallace stock, respectively. The Upper Ore Body has produced most of the ore from the Climax Mine.

Upper Ore Body

The Upper Ore Body occupies a position directly above the Bartlett stock of the Climax Stock. Its shape is that of a tilted, inverted bowl. The tilt to the west (fig. 14) is a result of tilting of the Climax Stock caused by the intrusion of the Wallace stock and the Traver stock into the Bartlett stock. The Upper Ore Body has random and oriented fractures. The oriented fractures are moderately to steeply dipping and are arranged in a radial fashion about the Bartlett stock. Flat or gently dipping fractures are mostly random and less common. Potassic alteration is common in the Upper Ore Body. In some places, the parent texture of the Proterozoic schist is preserved. At other areas, the original texture and minerals of the schist have been converted to an aggregate of pinkish orthoclase and minor quartz. Quartz-molybdenite veinlets cut across the potassic alteration and indicate that alteration preceded mineralization. In addition, some of the quartz-molybdenite veinlets contain potassium feldspar, which suggests that mineralization and alteration occurred simultaneously. Orthoclase and adularia are also constituents of the quartz-pyrite-tungsten veinlets.

Almost all of the ore in the Upper Ore Body is contained in quartz-molybdenite veinlets. Quartz is the most abundant mineral, and orthoclase and fluorite are present in lesser amounts. The molybdenite forms tiny hexagonal plates embedded in quartz, commonly along the veinlet walls.

High-Silica Rock associated with the Upper Ore Body is finely crystalline, white to light-gray, hydrothermal quartz. It underlies the Upper Ore Body and forms a zone 1,500 ft in diameter and 300 to 600 ft thick (fig. 19). The silicification of the parent rock and the potassic altered rock in this zone is almost complete. The Upper Ore Body has been altered in places by the High-Silica Rock related to later intrusive bodies of the Climax Stock. In these areas, the molybdenite in the veinlets has been dispersed in the High-Silica Rock.

Pyrite and tungsten minerals were deposited in a distinct zone above and peripheral to the molybdenum ore zones (**Figure 19**). Pyrite-quartz-sericite veinlets contain tungsten in the oxide form as huebnerite and wolframite. Other minerals in the Upper Ore Body include cassiterite, brannerite, and ilmenorutile.

Pyrite and tungsten minerals occur in a distinct zone above and peripheral to the molybdenum ore zones (fig. 19). Tungsten occurs in the oxide form as huebnerite and wolframite in pyrite-quartz-sericite veinlets. Other minerals that occur in the Upper Ore Body include cassiterite, brannerite, and ilmenorutile.

Ceresco Ore Body

The Ceresco Ore Body was largely stripped away by erosion. The remaining part of the ore body is exposed in a small area on the northeast side of the Climax Stock and on the southwest side of the stock on the Phillipson Level of the Climax Mine (fig. 14). Most of the mineralization in the Ceresco Ore Body is similar to that in the Upper Ore Body. What remains of the Ceresco Ore Body is much less fractured than the Upper Ore Body; therefore, mineralization is generally more erratic and lower grade.

Lower Ore Body

The Lower Ore Body, which lies about 100 to 200 ft above the Wallace stock, is smaller and lower grade than the Upper Ore Body (fig. 14). The Upper and Lower Ore Bodies merge in the eastern part of the Phillipson Level. The Lower Ore Body is not as tilted to the west as the Upper Ore Body. The general pattern of mineralized fractures is similar to that observed in the Upper Ore Body. Potassic alteration is widespread in the Lower Ore Body. In some places, the alteration has overprinted High-Silica Rock of the Upper Ore Body. Mineralization styles of the Upper and Lower Ore Bodies are very similar. The main difference between the Upper and Lower Ore Bodies is the thickness of the zone of tungsten minerals. Like the Upper Ore Body, tungsten minerals were deposited above and outward from the molybdenum ore zone; however, in the Lower Ore Body, tungsten minerals also are found well within the main zone and into the footwall of the Lower Ore Body. The tungsten zone is about 700 ft thick and consists of quartz-pyrite-tungsten veinlets as in the Upper Ore Body. Most of the tungsten produced at the Climax Mine came from this ore body.

Late “Barren” Stage

The Late "Barren" Stage of mineralization is thought to have been associated with the final intrusive stage of the Climax Stock-the Traver stock and Late Rhyolite Porphyry dikes. The ore minerals form stockwork veinlets, stringers, disseminations in pegmatitic pods, segregations in silicified zones, and irregular veins that fill the South and East faults. Quartz-molybdenite veinlets of the Late Barren Stage cut across the High-Silica Rock of the Lower Ore Body.

Even though the Climax Mine has not operated since 1995, it still holds the title as the world's greatest single producer of molybdenum. The recognition of the cyclic nature of the intrusions and ore-body development at Climax was one of the great advances in the study of economic geology and igneous rocks during the last half of the twentieth century.

LEADVILLE DISTRICT

Discovery and Early History

Mining in the district began with the discovery of placer gold in California Gulch in early 1860. A gold rush soon followed. News reports such as the following capture the excitement of those days:

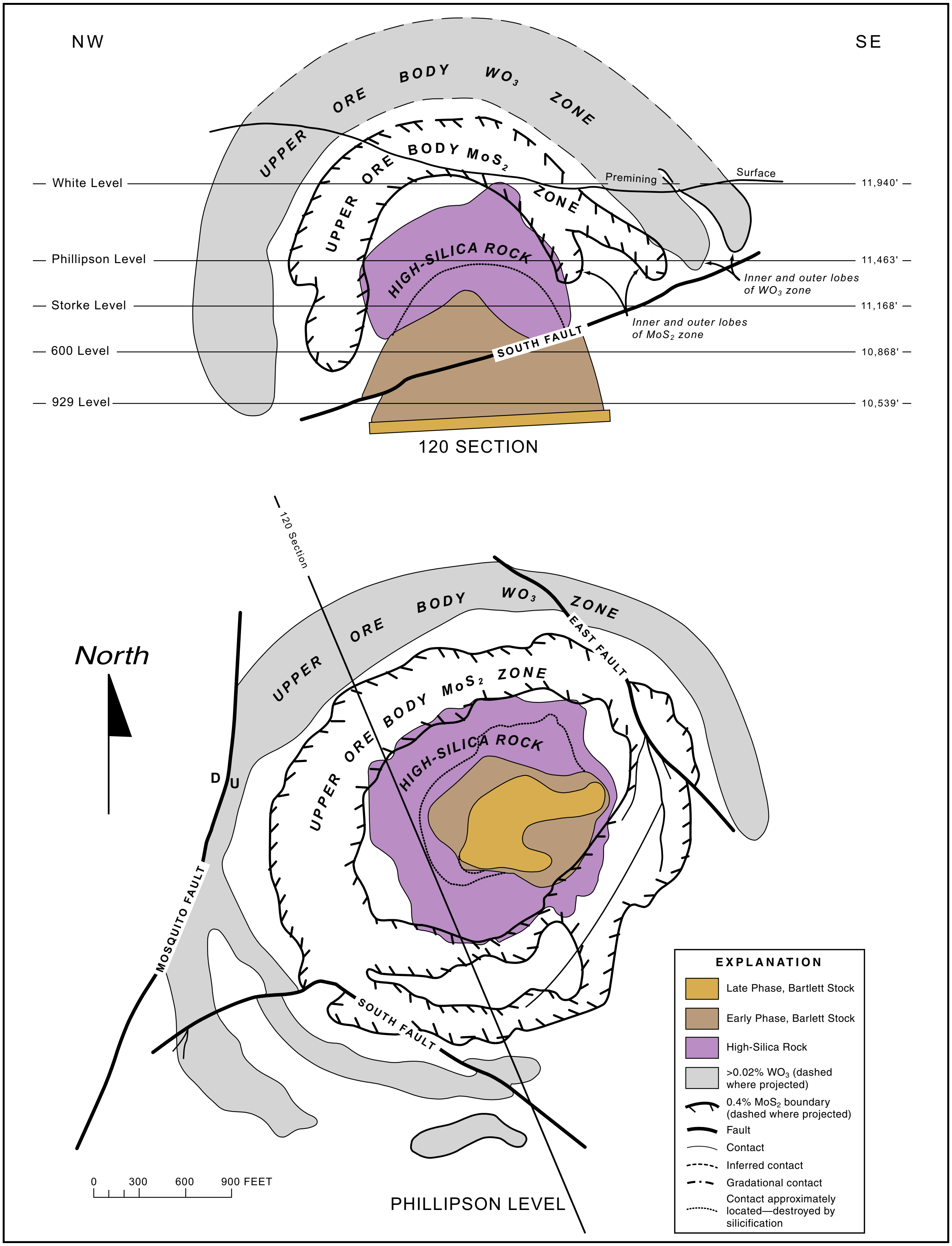


Figure 19: Generalized geology and ore zones, showing dual nature of the Climax Upper Ore Body. (adapted from Wallace and others, 1968).

> "On Wednesday eve of last week two rough looking individuals, sunburned and shaggy, entered the office of Pikes Peak Express Co., bearing sacks upon their shoulders which they deposited upon the counter like bags of corn…. Then causing door to be closed, they opened their pouches and emptied them of $27,000 in gulch gold [worth approximately $425,000 at 2002 prices]…. The shining dust, whose luster had never been dimmed by any retorting process, glittered with peculiar brilliancy and abounded in nuggets, largest of which were twice the size of silver dollars…. Owners of the treasure are two miners just in from California Gulch…. Their names were J.M. Rafferty from Ohio and George Stevens from Philadelphia" (The Mountaineer, September 26, 1860, quoted in Shannon and Shannon, 1985).

A tent city, originally called "Boughtown" and then later officially named "Oro City," was soon established. Other nearby gulches were intensely prospected for placer gold, but these had been scoured by Pleistocene glaciation that removed the gold placers; only California Gulch had significant quantities of alluvial gold (Thompson and Arehart, 1990). Peak placer activity lasted from 1860 to 1863; by then the richest ground had been worked, and majority of miners had drifted away to other camps. Placer mining continued on an ever-decreasing basis until about 1875, yielding about 344,000 oz (Thompson and Arehart, 1990). The discovery of veins with large masses of free gold at the Printer Boy Mine in 1868 helped extend the life of the camp, but did not reverse the trend of declining production.

From the early days of the development of the district, large amounts of heavy blue-black sands interfered with the placer operations; these were recognized by at least some of the miners as lead carbonate. However, economics of the day precluded processing of lead minerals unless they were excessively rich in silver, owing to the great distances to then-existing smelters. In 1874, the first outcropping lode of silver-bearing lead carbonate was located at the Rock Mine. Although rich in lead, this ore proved to be low in silver. Even so, shipments still made some profit despite the high transport charges to a St. Louis smelter. In 1876, several other lode claims were discovered, and some extremely rich assays (600 to 800 oz per ton silver) were obtained (Emmons and others, 1927). By this time, there was a lead-silver smelter at Georgetown, and several new smelters were being constructed in the vicinity. In 1877, the fabulous ore bodies at Fryer Hill were discovered, and the rush-considered the largest in the State of Colorado-was on (Henderson, 1926). Leadville, located 7 mi to the north of the site of Oro City, had an estimated population of 200 people in the spring of 1877. Within two years, Leadville was the second largest city in the State and had a population of more than 15,000. By 1880, there were 12 smelters in operation, and annual production had risen to more than 10 million ounces of silver and 66 million pounds of lead (Tweto, 1968) (**Figure 20**).

This was a bonanza period of phenomenal wealth, at least for some individuals. One of the best known is H.A.W. Tabor. Tabor was a frontier grocer who grub-staked two prospectors who sunk a shaft on Fryer Hill into what turned out to be the Little Pittsburgh Mine, a property whose production exceeded $10 million (in the dollar value at the time of production). Tabor was a man of immense luck, both good and bad. Emmons and others (1927) described how Tabor, acting as a buyer for a syndicate of wholesalers, purchased a claim for $40,000 from a disreputable character named Chicken Bill. It seems Chicken Bill did not complete his shaft on the claim to bedrock, but rather had salted the bottom with ore from a nearby mine. After the transaction with Tabor, Chicken Bill could not resist relaying to his cronies his role in the affair, word of which reached the ears of the syndicate Tabor was representing. They declined to complete the transaction, and Tabor was stuck with the property. Tabor then completed the shaft, which encountered the Chrysolite ore body. All told, the Chrysolite yielded $1.5 million in profits to Tabor, who later sold it for a similar amount. Tabor acquired phenomenal wealth from Leadville, became a U.S. Senator, divorced his wife, married (with President Chester Arthur attending) a much younger woman nicknamed Baby Doe, and then proceeded to lose his entire fortune in the Silver Crash of 1893. Tabor and Baby Doe both died penniless; Baby Doe froze to death in the shack built on one of Tabor's last holdings, the Matchless Mine (**Figure 21**).

A happier story deals with Meyer Guggenheim, a Philadelphia lace merchant. In 1881, he purchased for $5,000 a half interest in two lackluster claims in California Gulch, the A.Y. and Minnie. He then proceeded to spend $70,000 in dewatering, shaft sinking, and underground development before he hit a major strike at the A.Y. By 1888, the two mines were yielding him $750,000 a year and totaled more than $15 million prior to their exhaustion in 1902. The proceeds from these two properties allowed the Guggenheims to build a mining empire. Three major twentieth-century mining corporations arose from the humble beginnings in California Gulch: The American Smelting and Refinery Company (later known as Asarco Inc.), Guggenheim Brothers (discovers of Chuquicamata, El Salvador, and other important deposits), and the Kennecott Copper Corporation (Smith, 1988).

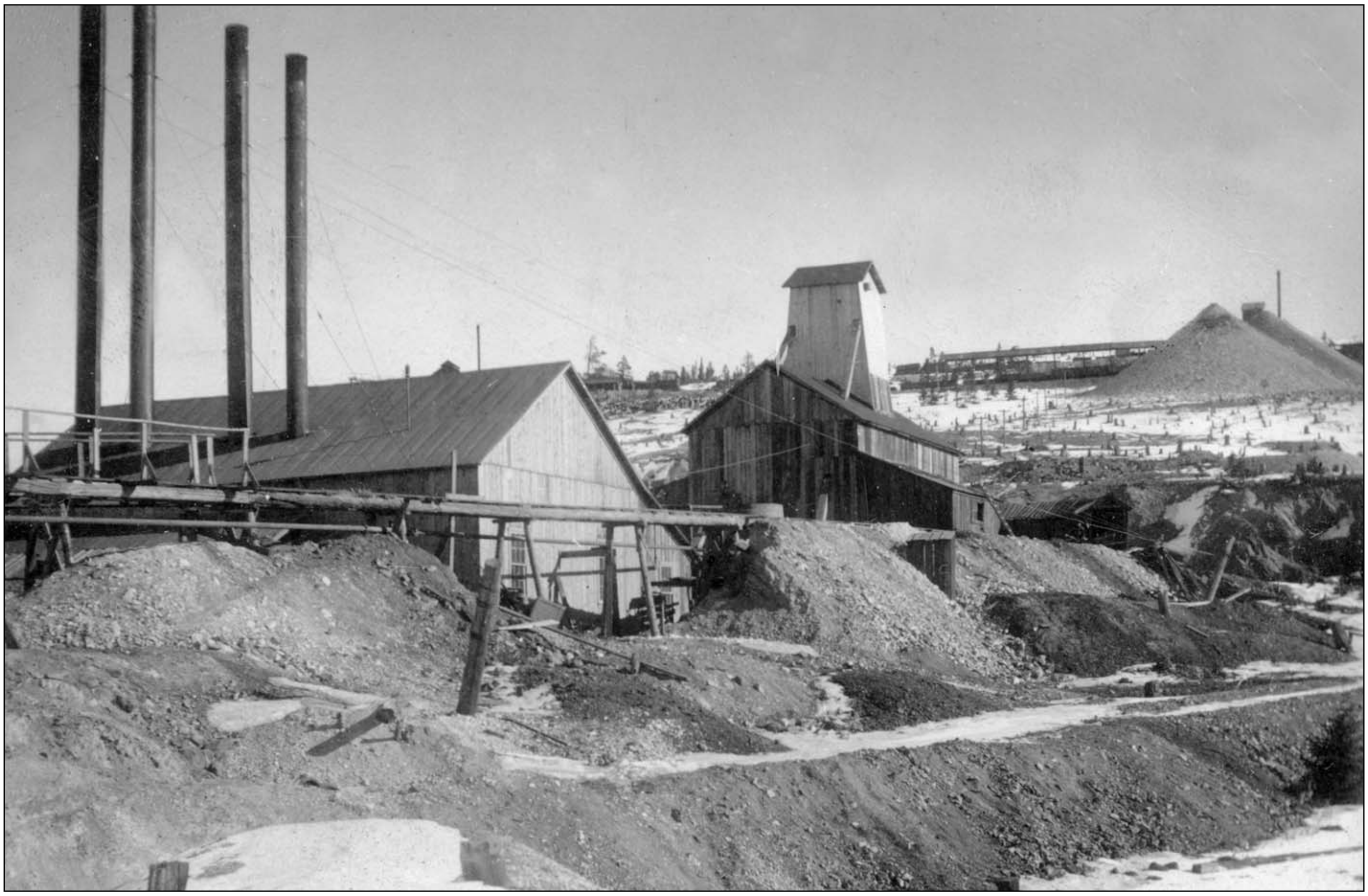


Figure 20. Penn Mine on Breece Hill, view of buildings, shafthouse, smokestake tailings and tramway, 1890–1910. (Photo courtesy of Western History Section, Denver Public Library)

Mining in the bonanza period was of carbonate ore, which was the oxidized residue of massive sulfides that had replaced dolomite. Mining typically was restricted to depths of less than 500 ft. By the late 1880s, many of the mines had reached sulfide minerals. The decreased silver-lead grades coupled with then-undesirable zinc caused a significant decline in production. In 1893, gold-rich lodes were discovered in the Breece Hill area; these sustained the district following the Silver Crash of that year. Lode gold ore, together with growing recovery of zinc sulfide from 1899 onward, maintained the district until the depression of 1907 when metal prices decreased and output fell significantly. In 1909, zinc carbonate was found peripheral to and beneath many of the old stopes. A zinc carbonate boom then followed and lasted until about 1925. The district then entered a period of continuing, but declining sulfide ore production from carbonate replacement bodies. In 1938, the Resurrection Mining Company (formed from a merger of Newmont Mining Corporation and Hecla Mining Company properties within the district) discovered gold-rich vein ores beneath some of the carbonate replacement stopes and for the next 19 years produced a substantial output (Smith, 1988).

Post–World War II History

Following World War II, there were discoveries of ore in the deeply down faulted "Down Dropped Block;" this area entered into production in the early 1950s. A fire in 1956 destroyed most of the surface facilities of the Resurrection property, and this, combined with increasing underground costs and low metal prices, led to the cessation of their operations in 1957. The district was now dormant for the first time in 97 years.

However, exploration continued. The reopening of the Irene shaft and 2,300 ft of exploration drifting in 1965 by a joint venture of Resurrection and Asarco led to the discovery of sulfide manto deposits within the "Down-Dropped Block." [Manto deposits are defined as flat, bedded, and sheetlike mineral deposits. The term is from the Spanish word for mantle or cloak (Guilbert and Park, 1986).] These were put into production in 1971. The mine, known as the Black Cloud, started life with 10 years' worth of reserves (2.1 million tons). The Black Cloud operation lasted until 1999, more than doubling the then-known reserves and shutting down with resources remaining. During the Black Cloud's 28 years of production, the mine yielded

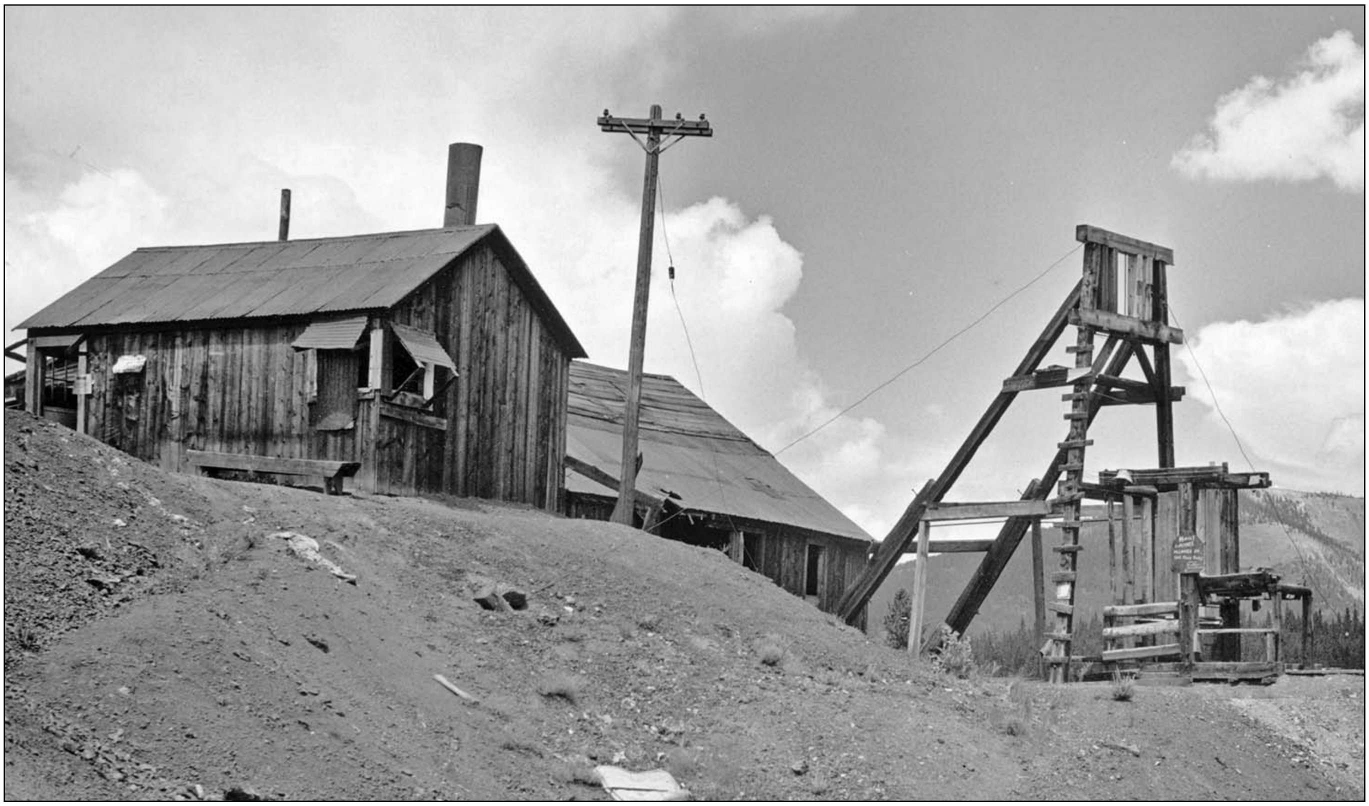


Figure 21. Matchless Mine, view of head frame and buildings, 1941. (Photo courtesy of Western History Section, Denver Public Library.)

a total of 5,637,000 tons averaging 0.063 oz per ton gold, 2.09 oz per ton silver, 3.53 percent lead, 8.18 percent zinc, and 0.13 percent copper (Asarco, unpublished data).

Remaining resources at the Black Cloud Mine are listed as 308,000 tons averaging 0.03 oz per ton gold, 1.6 oz per ton silver, 2.4 percent lead, 8.5 percent zinc, and 0.1 percent copper (S. McGeorge, 2000, personal communication); these were uneconomic at 1999 metal prices. In addition to low metal prices, operating costs were high (and increasing) owing to multiple handling of ore and increased distances from the production shaft. Ultimately, a new production shaft would have to be sunk if production in the district were to continue; then-current resources could not justify the expense of a new shaft. Therefore, the pumps were turned off and the workings allowed to flood. The district is now dormant save for some ongoing exploration (in 2001) by Leadville Mining and Milling Company in the ground directly north of the Black Cloud workings.

The Yak Tunnel and Its Remediation

Water was a particular problem at Leadville and greatly hindered operations. In 1889, work was started on a tunnel, now known as the Yak tunnel, which would serve to drain the main part of the district (Shannon and Shannon, 1985). The mouth of the tunnel was located in the lower part of California Gulch, about half way between Leadville and the site of Oro City. The tunnel then proceeded in an east-northeast fashion toward Breece Hill, turning to the northeast just past the Ibex Mine, and eventually reaching the Resurrection shafts at the far northeastern end of the district (Tweto, 1968, fig. 1). The 4-mi tunnel was completed in 1912. Local mines were charged for dewatering and for hauling of ore through the tunnel. Development activity in the Yak tunnel decreased significantly following World War I, but continued at a low rate through the Depression. In 1940, the Resurrection Mining Company purchased the Yak tunnel for $50,000; it then proceeded to build a mill at the portal where it processed ore from its White Cap and Fortune mines (Smith, 1988). The Resurrection properties closed in 1957. Track to the portal of the Yak was pulled in 1963, following closure of the Asarco smelter in 1961 (Shannon and Shannon, 1985). In 1955, Resurrection had formed a joint venture with Asarco to explore and develop the area that became the Black Cloud Mine; ownership of the Yak tunnel fell to the Resurrection-Asarco joint venture.

Unfortunately, the Yak tunnel did more than just drain water from the district's mines. Undesirable quantities of metals were concentrated in the acidic drainage water as well so that the Yak tunnel acted as a point-source discharge. In 1983, the Yak tunnel and surrounding area was declared a Superfund site. The Resurrection-Asarco joint venture was obliged to build and operate in perpetuity a water treatment plant, which it does to this day, with annual operating costs on the order of $1.2 million (R. Litle, 2000, personal communication). More than $20 million has been spent by the joint venture on reclamation and treatment associated with the Yak tunnel-an amount that has far exceeded the total profits generated by the tunnel.

Potential liability associated with Superfund has served to preclude outsider interest in the district. Further, district-scale exploration by the Resurrection-Asarco joint venture, for all intents and purposes, ceased in the mid-1980s. This world-class mining district, with abundant perceived exploration potential, has essentially lain fallow since 1985 because of potential legal liabilities.

Production Totals

Leadville is one of the great metal producing districts of the world. Through 1999, Leadville has yielded approximately 28.9 mil tons of ore with 3.3 mil oz of gold, 265 mil oz of silver, 2,354 mil pounds of lead, 1,936 mil lbs of zinc, and 110 mil pounds of copper (Thompson and Arehart, 1990, ASARCO unpublished data). In addition, there has also been significant (nearly 6 mil tons) production of manganese ores with grades up to 45 percent manganese, as well as limited bismuth production (from ore grading 5–16 percent bismuth), and sulfuric acid from pyrite ores (Tweto, 1968).

Regional Geology

The Leadville district has been a focus of detailed geologic study since Emmons's (1886) extensive monograph, which was one of the first detailed scientific studies of an existing mining district. The summary that follows is based on this work (Emmons, 1886) as well as that of Emmons and Irving (1907), Emmons and others (1927), Behre (1953), Tweto (1968), and Thompson and Arehart (1990). Readers are advised to refer to these works for additional information. However, despite the intensive study by Emmons and others (1927), much of the details of the geology of the district remain unknown. This is because of extensive surficial deposits and vast dumps that preclude surface observations. As well, the weak ground at Leadville has led to caving and virtual obliteration of the workings.

The Leadville district is located in the center of the Colorado Mineral Belt, which is a northeast-trending string of Tertiary intrusive rocks with a high concentration of economic mineral deposits (fig. 3). In particular, the Colorado Mineral Belt is noted for carbonate replacement deposits such as those at Leadville, Aspen, and Gilman; porphyry molybdenum deposits such as Climax and Henderson; gold-silver-base-metal vein deposits such as those at Breckenridge, Central City, Creede, and in the La Plata district; and the gold-silver telluride and tungsten deposits of Boulder County.

The Leadville district lies on the western flank of the Mosquito Range (fig. 4). A 2,660-ft-thick section of Paleozoic marine sedimentary rocks overlies Mesoproterozoic St. Kevin Granite and hosts, along with the Tertiary rocks, the district's ore deposits. At Leadville, the northeast trend of the Colorado Mineral Belt is intersected by the postmineralization, north-trending Rio Grande Rift. In general, sedimentary rocks in the district have an eastward dip off the Sawatch uplift, but are normally faulted, step-wise, into the graben valley to the west of the district. A critical exception to this pattern is a north-trending graben in the eastern part of the district, known informally as the Down-Dropped Block. The formation of the Down-Dropped Block lowered the ore-hosting sedimentary section in this part of the district and is the locale for recent mining at the Black Cloud Mine.

Stratigraphy

Sedimentary rocks in the Leadville district consist of about 500 ft of Cambrian through Mississippian quartzites and dolomites and more than 2,000 ft of Pennsylvanian black shale, quartzite, and arkose. Virtually all of these units host ore in the district. The principal ore hosts are the three carbonate units: the Leadville Dolostone, the Dyer Formation, and the Manitou Formation. The Mississippian Leadville Dolostone is by far the predominant host for carbonate replacement ore, containing approximately 80 percent of the total. A karst surface and associated karst-fill deposits (Molas Formation) mark the top of the Leadville Dolostone and have served to localize ore in some places.

The stratigraphic section is rarely found intact within the district. Rather it is extensively intruded by a series of igneous dikes, sills, and plugs that can inflate the Paleozoic stratigraphy to two or three times its normal thickness or segment it into islands or isolated blocks within a sea of porphyry.

Igneous Rocks

Excluding the Proterozoic granite basement, there are six different igneous intrusive rocks ranging in age from Late Cretaceous (72 Ma) to early Tertiary (38.5 Ma) that crop out in the district. Leadville was clearly a long-lived center of igneous activity. Mineralization occurred toward the end of the igneous cycle at 39.6±1.7 Ma (Thompson and Arehart, 1990, p.153). The early pre-ore intrusions range in composition from quartz latite to quartz monzonite. All but one were porphyritic. The most important of these-the Johnson Gulch Porphyry (43.1 Ma)-formed the Breece Hill "stock" on which mineralization appears centered, on the basis of metal ratios and zoning (**Figure 22**). This is not a true stock in the conventional sense, but rather a composite of different igneous sills fused together into a Christmas-tree-like laccolith. Although clearly pre-ore, the Breece Hill igneous center acted as a focal point for later ore-forming fluids.

The only significant postore igneous rock is the "Late Rhyolite Porphyry," dated at 38.5 Ma. This rock and its accompanying hydrothermal breccia, known locally as "Fragmental Porphyry" (**Figure 23**) (Hazlitt and Thompson, 1990), crop out around the margins of the Breece Hill complex. Intrusion of the Fragmental Porphyry postdated main-stage mineralization, as sulfide clasts (in cases as much as a hundred tons) are found contained within the Fragmental Porphyry. In turn, pyrite-base-metal veinlets and/or late golden barite locally cut the Fragmental Porphyry. It appears that the Late Rhyolite Porphyry and the Fragmental Porphyry are late extensions of the same magmatic and hydrothermal system that formed the ore deposits at Leadville.

In terms of composition and age, the rhyolite porphyry is earlier and less chemically evolved than the high-silica rhyolite porphyries responsible for molybdenum mineralization at Climax (33 to 25 Ma) and Henderson (27.8 to 23.1 Ma) (White and others, 1981). The Leadville mining district is characterized by polymetallic base- and precious-metal sulfide and oxide mantos hosted by Mississippian, Devonian, and Ordovician carbonate rocks. Exploration is complicated by a series of steeply dipping, north-striking faults with recurrent movement. The faults provided a conduit for the intrusions and hydrothermal solutions. Intrusions both displaced and obliterated the stratigraphic sequence. Alteration halos associated with mineral emplacement are typically small.

The primary method of exploration in later years of the district was by underground core and percussion drilling. Targets were selected on the basis of stratigraphy, structure, and proximity of intrusive rocks (especially the Fragmental Porphyry). These techniques were sufficient to nearly triple the effective life of the last mine, the Black Cloud. The Black Cloud Mine area, the Down-Dropped Block (**Figure 24**), and the district as a whole contain a number of identified targets that have not been tested; exploration potential is perceived as excellent. District-scale exploration by Asarco (operator of the Resurrection-Asarco joint venture) has been virtually nonexistent since 1982 and minimal for five years preceding that. What exploration was done was focused exclusively on the vicinity of the mine area. Certainly there appears room for additional discoveries using modern exploration techniques.

Structure

Structures in the Leadville mining district are extremely complex. Repeated faulting evidently followed the intrusion of each igneous rock. There was significant postore faulting as well that chopped the district into a series of blocks. Generally these faults strike north to northeast and dip steeply (more than 70°). Recurrent slip on faults produced fault zones as wide as 35 ft. Faults within the Down-Dropped Block stair-step down from west to east to the center of the graben and stair-step up to the eastern edge. Outcrops of Fragmental Porphyry found along the periphery of the Down-Dropped Block suggest the possibility that this graben formed as the result of magmatic devolatilization, possibly in a subvolcanic setting. Although structures served as conduits for the hydrothermal solutions, not every structure carried every mineralizing solution, and many faults are not mineralized.

Ore Deposits

The Leadville mining district is noted for six types of mineral deposits (**Table 5**). By far, base- and precious-metal mantos form the dominant type of deposit. Orebody sizes ranged from 39,000 to 1.2 million tons (or larger-early records about ore-body size are unclear). A typical ore body at the Black Cloud Mine was 500,000 to 800,000 tons.

Descriptions of the ore minerals and the mines of the greater Leadville district from Emmons and others (1927) and Behre (1953) are included in Appendix 1.

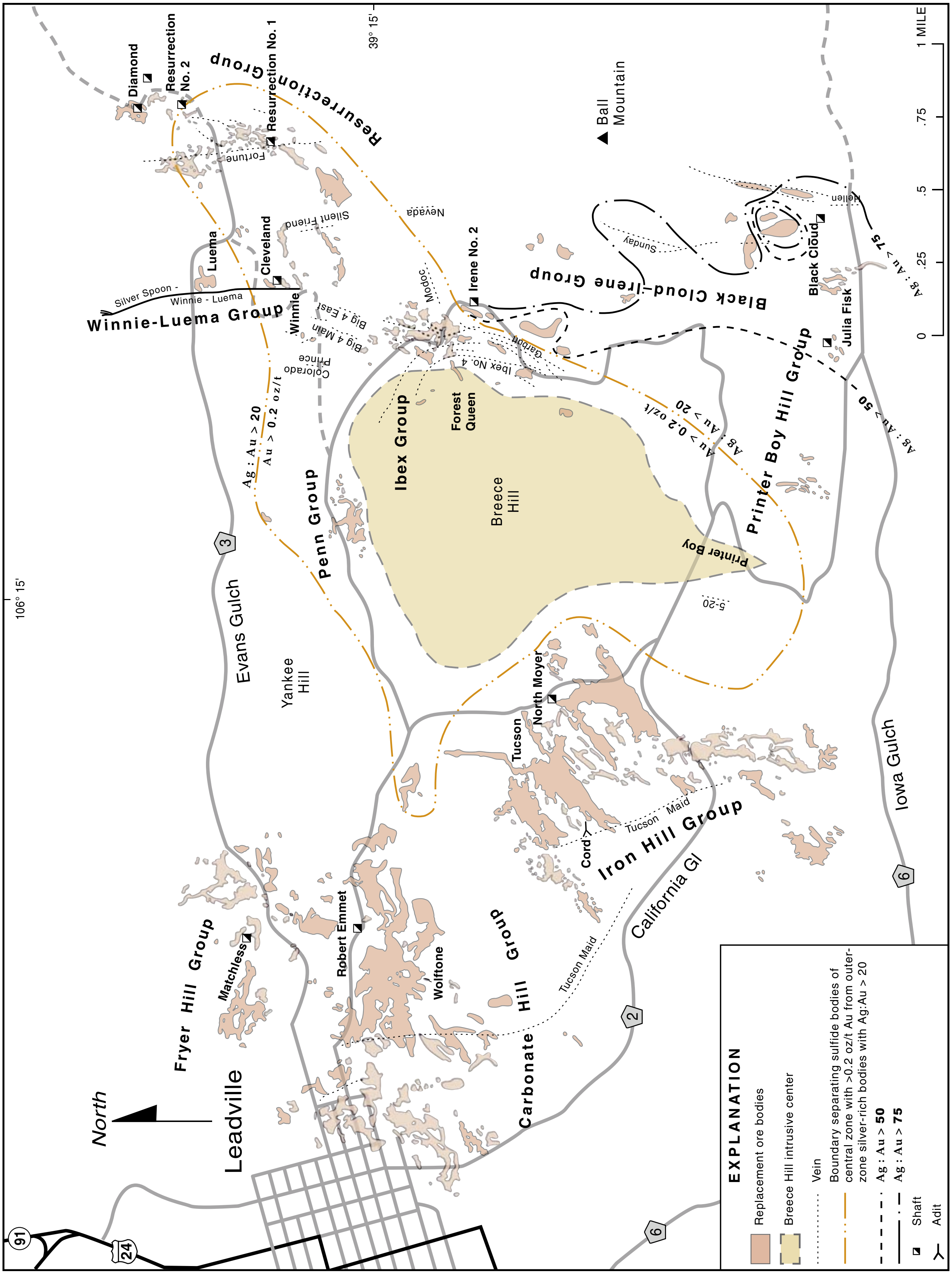


Figure 22. Map of Leadville district showing replacement ore bodies.

Figure 23. Location of Fragmental Porphyry pipes, Late Rhyolite Porphyry and projected ore bodies in the Leadville district.

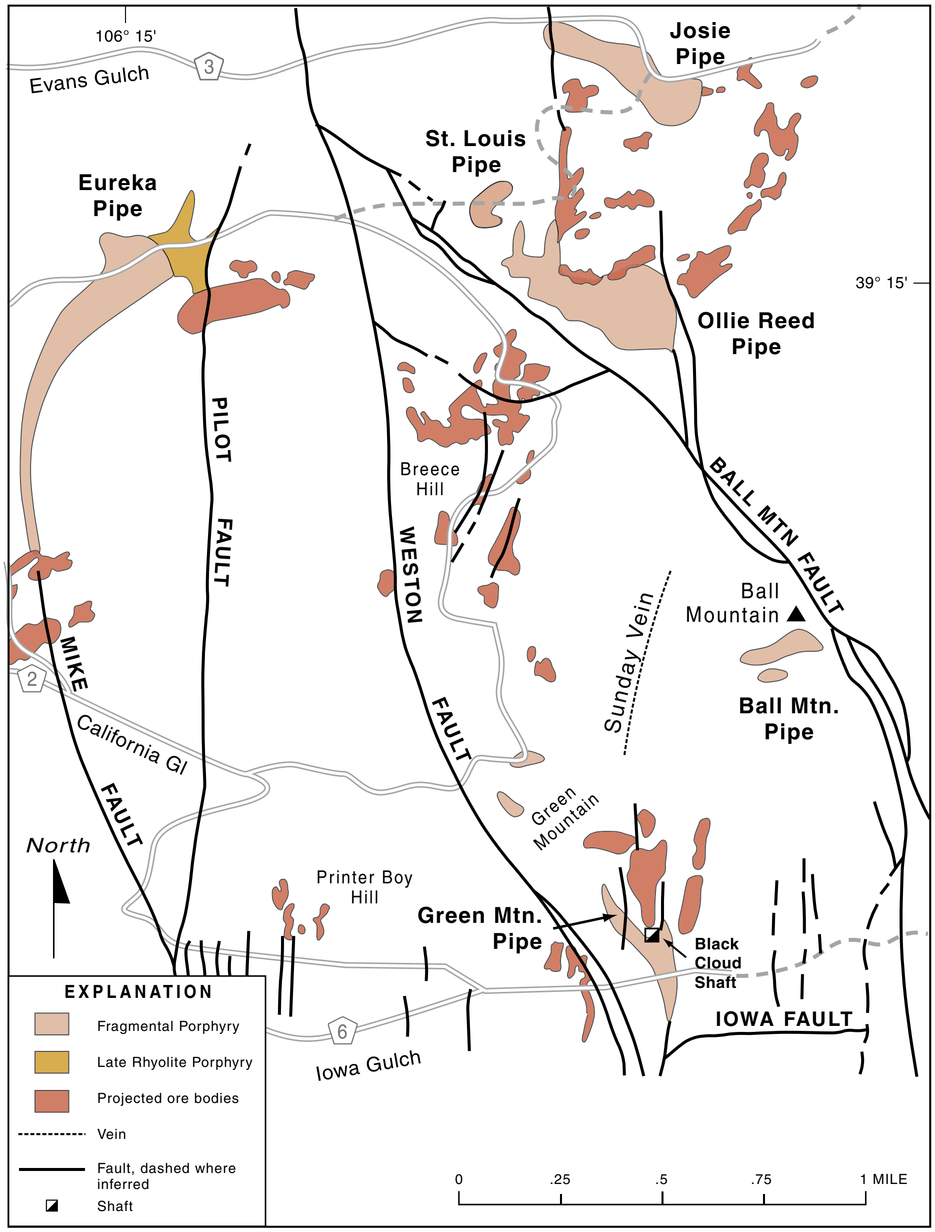


Table 5. Types of mineral deposits of the Leadville mining district.

Type of deposit	Gold (oz/ton)	Silver (oz/ton)	Lead (%)	Zinc (%)	Copper (%)
Zinc-lead-silver-gold mantos (and their oxidized equivalents)[1]	0.05–0.2*	2–6* 10–2,000†	3–8* 20–50†	6–30* 15–40†	0.1–0.3* –
Quartz-base-metal veins[2]	0.1–0.5	2–13	5–15	4–10	–
Magnetite-serpentine-gold replacement bodies[3]	0.06–0.17	2–4	–	–	Some
Quartz-pyrite-gold-silver veins[3]	0.5	30–40	–	–	–
Disseminated pyrite-gold in porphyry[4]	0.15–0.9	–	–	–	–

[1]Typical grades. The grades marked with an asterisk (*) are for hypogene deposits; the grades marked with a dagger (†) are for supergene deposits. [2]Typical grades. [3]Average grades. [4]Historic grades.

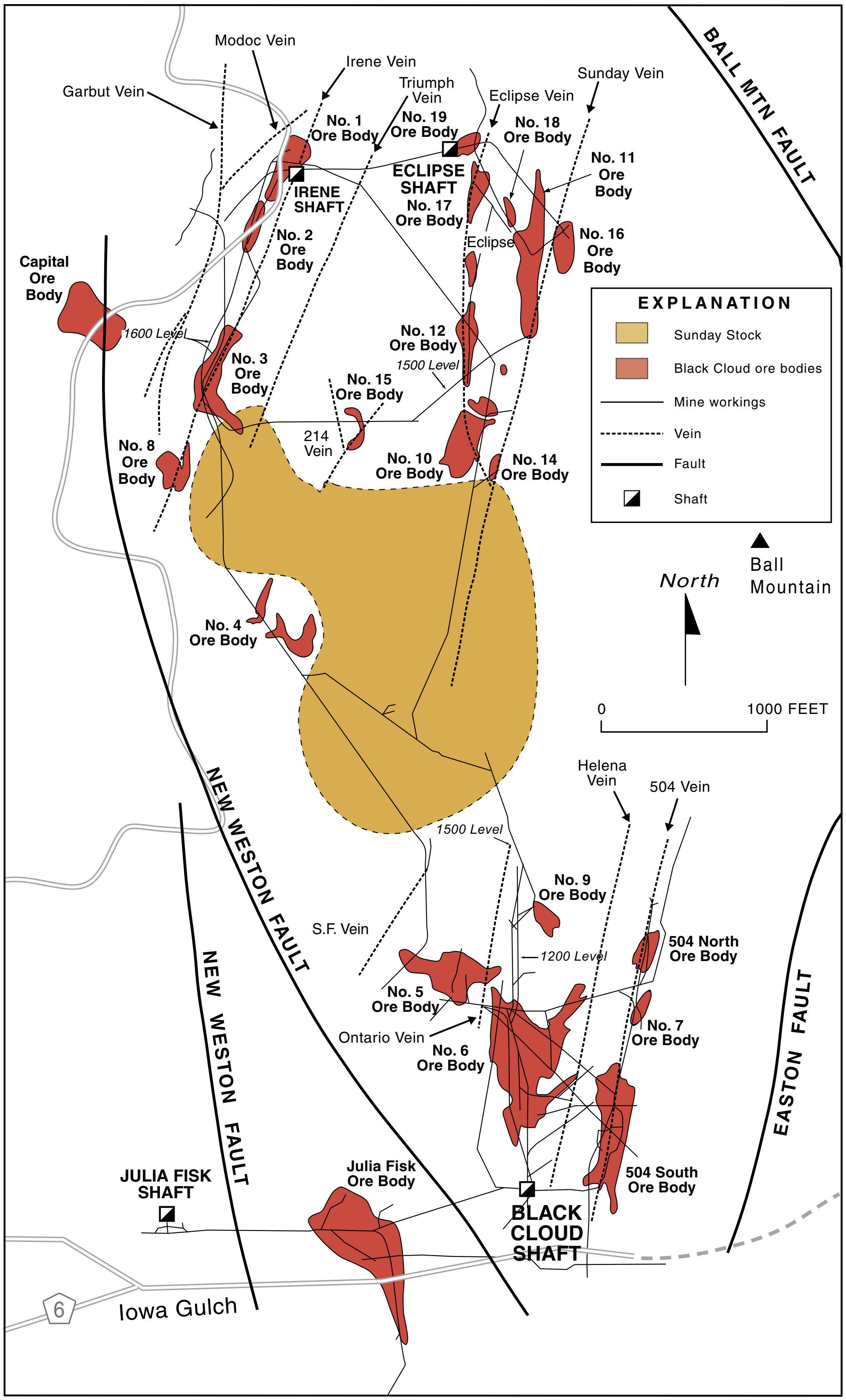


Figure 24. Generalized location map of ore bodies around the Black Cloud Mine in the Leadville district.

Supergene Deposits

Supergene deposits formed the backbone of the bonanza production days. Supergene ore was primarily oxide ore, though locally significant quantities of enriched sulfide ore were mined. Lead was originally deposited in the hypogene environment as galena, which later was typically oxidized to anglesite and cerussite without much apparent migration. The cerussite was accompanied by considerable quantities of silver chloride minerals, particularly close to the surface. Native silver and argentite, if present, tended to form deeper (in the enriched sulfide zone) and directly precipitated on the sulfides (Loughlin and Behre, 1947). Zinc was originally deposited in the mineral sphalerite in the hypogene environment; the sphalerite was completely dissolved, and the zinc was carried downward and reprecipitated as smithsonite, hemimorphite, or calamine. The zinc phases tended to replace manganosiderite or dolomite at favorable locations beneath or lateral to the original ore bodies. Loughlin and Behre (1947) stated that large bodies of high-grade zinc oxide formed where manganosiderite had been the only original gangue mineral around the primary ore bodies, which in turn graded out into the dolomite country rock. If jasperoid, quartzite, or porphyry underlay the original ore body, then the descending zinc solutions became scattered in passing through these rocks, and only small bodies of low-grade ore resulted.

Copper was leached from the oxide zone and redeposited as chalcocite coatings on chalcopyrite and pyrite and as covellite coatings on sphalerite. Sphalerite, particularly if coated with covellite, is said by Loughlin and Behre (1947) to have been particularly effective in precipitating gold; some of the richest gold shoots were of this type.

Oxidation of manganosiderite, which tends to form an outer halo about zinc-lead ore bodies in the western part of the district (Emmons and others, 1927), yielded black manganese-iron ore and locally high-grade manganese oxide. Manganese oxide was used for furnace flux or steel manufacture. The value of this material as flux was significantly increased by its associated lead and silver content.

Ore Controls

In the Leadville mining district, mantos are commonly found at the upper Leadville Dolostone contact beneath porphyry sills, which may have acted as aquitards. The uppermost contact of the Leadville Dolostone is usually the most productive. This contact was known to old miners as the "first contact" (if a porphyry sill was present). The second contact was commonly between the Redcliff and Castle Butte Members of the Leadville Dolostone (again if the contact was occupied by a porphyry sill), and the third contact was typically the basal contact between the Leadville Dolostone and the dolomitic Dyer Formation. In most cases, the first contact had the best manto ore bodies.

Structural controls are common. Ore bodies are adjacent to or strongly associated with major faults in the district; mineralizing fluids used the faults, both reverse and normal, as conduits. Many ore bodies are located at the intersection of dikes and sills, particularly on the downdip side of dikes, and have vein roots or branches away from a central vein. In many cases, these veins did not continue upward to the surface.

The presence of karst appears to have controlled some of the mineralization, although the significance of karst features has been debated in the Black Cloud Mine. The upper contact of the Leadville Dolostone is a karst surface, and cave channels have been reported from the western part of the Leadville district. Increased permeability due to the formation of karst may well be the reason that the upper contact of the Leadville Dolostone is such a favorable ore host. Not all karst features were mineralized, but mineralization included and preserved some bedding features.

Ore bodies in the Black Cloud Mine have a strong spatial association with the Fragmental Porphyry (fig. 23). The fact that the emplacement of the Fragmental Porphyry was approximately contemporaneous with the timing of mineralization suggests that a genetic relationship exists as well.

Exploration at the Black Cloud Mine for carbonate replacement ore bodies, however, dominantly focused on veins. Where veins were intercepted in workings, drifts were then driven along them to their intersection with favorable carbonate stratigraphy. Other factors (paleokarst, Fragmental Porphyry) were of secondary importance; the primary criterion was a favorable (mineralized) structure that intersected dolomite.

Ore Genesis

The genesis and chemical parameters of ore deposition are summarized in Thompson and Beaty (1990). Hydrothermal solutions were generally hot (350° to 420°C), acidic, and ascending. Metals and sulfur were deposited in the carbonates as a result of pH changes, cooling, and decreases in pressure. Alteration halos (weak argillic to sericitic) extend a few meters into intrusive rocks adjacent to ore bodies. (There is also widespread sericitic to argillic plus or minus pyrite alteration of intrusive rocks unrelated to specific ore bodies, particularly in the Breece Hill area.) Within carbonate in the Black Cloud Mine, a knife-sharp contact was typical between massive sulfide mineralization and apparently unaltered dolomite. Ore bodies in the western part of the district, however, typically had a manganosiderite halo. The most peripheral ore bodies in the western side of the district commonly were bordered by jasperoid (Emmons and others, 1927; Thompson and Arehart, 1990, fig. 16).

Five to seven episodes of mineralization occurred, and not every ore body was affected by every episode. The first stage of mineralization was the formation of magnetite-serpentine skarn brought about by the intrusion of the Breece Hill stock at about 43 Ma (Thompson and Beaty, 1990). The first sulfide mineralization deposited pyrite, which in some sites replaced magnetite. The main base-metal mineralization deposited varying amounts of lead, zinc, cadmium, copper, iron, and minor amounts of silver. This process may have been caused by the intrusion of a large stock under the Breece Hill stock at 39.6 Ma (Thompson and Beaty, 1990). The precious-metal mineralization overprinted gold and silver on the existing base metals or magnetite. Later episodes of mineralization include late-stage vein quartz, late-stage vug dolomite, and finally vug-filling golden barite. Zoning within a hypogene ore body consists of a base-metal core (as much as 40 percent combined lead and zinc, but deficient in precious metals) surrounded by a pyritic precious-metal halo. Both were mined at the Black Cloud Mine.

MINERALS AND ORE TEXTURES

Primary sulfide minerals of the Leadville mining district are marmatitic sphalerite, galena (some of which was argentiferous), pyrite, and chalcopyrite. Precious-metal minerals varied by ore body, but typically consisted of tetrahedrite-tennantite, electrum, and gold-silver-bismuth tellurides (Gray and Titley, 1990). More than 100 minerals have been reported from the district (Emmons and others, 1927). A variety of ore textures, such as sulfide banding, rod texture, bird's eye texture, and zebra rock have been described within the district (Emmons and others, 1927; Behre, 1953; Thompson and Arehart, 1990).

METAL RATIOS, FLUID INCLUSIONS, ISOTOPES

Metal ratios based on production statistics show a pronounced bulls-eye centered on the Breece Hill igneous complex (fig. 22). This bulls-eye is elongated to the northeast and captures the Resurrection ore bodies within the Ag/Au > 20 contour. A small local area of low Ag/Au ratios also appears centered on the Black Cloud ore bodies. Contouring of district fluid-inclusion values (Thompson and Beaty, 1990, fig. 2) confirms the metal-ratio pattern. The overall hottest part of the district-having average ore-formation temperatures greater than 350°C -centered on the Breece Hill intrusive complex and decreased away to cooler temperatures of less than 250°C at the district margins. An oxygen isotope distribution diagram (Thompson and Beaty, 1990, fig. 14) shows a similar pattern. Thompson and Beaty (1990) interpreted the available metal ratio, isotopic, and fluid-inclusion data to indicate magmatic derivation of water, sulfur, and lead from an igneous source centered on the Breece Hill magmatic center. Other workers, such as DeVoto (1983) and Smith (1996) postulated that basinal brines may have had a significant role in the formation of these ore bodies. However, the isotopic evidence presented by Thompson and Beaty (1990, p. 174) offers convincing evidence of the magmatic origin of these ore deposits. The exploration ramifications of these models have not been fully addressed in the Leadville district and await future discoveries by future workers.

WESTON PASS DISTRICT

Introduction

The Weston Pass district is located in southern Lake County along the Weston Pass Road at 11,900 ft near Weston Pass; it is partly in Lake County and in Park County (**Figure 25**). The Weston Pass district was discovered around 1890, but little work took place until the Ruby Mine was developed in 1902. The Ruby Mine was the most important mine in the district (Behre, 1932). The district is small; only nine mines are shown on Behre's (1932) map.

Stratigraphy

The full Proterozoic-Paleozoic stratigraphic sequence exists at Weston Pass. The main ore bodies are located along a well-defined stratigraphic zone in the Leadville Dolostone. In this area, the Leadville Dolostone is about 370 ft thick, much thicker than the approximately 140 ft in the Leadville district to the north. Two small sills of Pando Porphyry, which in this district has the composition of muscovite granite with a porphyritic texture, intrude the Leadville Dolostone.

Structure

The structure of the district is simple; Paleozoic sedimentary rocks strike northwest and dip about 25° NE. Near the west side of the Weston fault, the strata flatten and change strike to east and northeast. Closer to the Weston fault the strata are slightly overturned (not shown on simplified map in fig. 25). The change in attitude indicates that the block on the east side of the fault moved upward and to the north. On the north side of the district, the west-trending Weston fault juxtaposes Proterozoic rocks against the Pennsylvanian Minturn Formation. The minimum throw on this fault is about 1,200 ft (Behre, 1932).

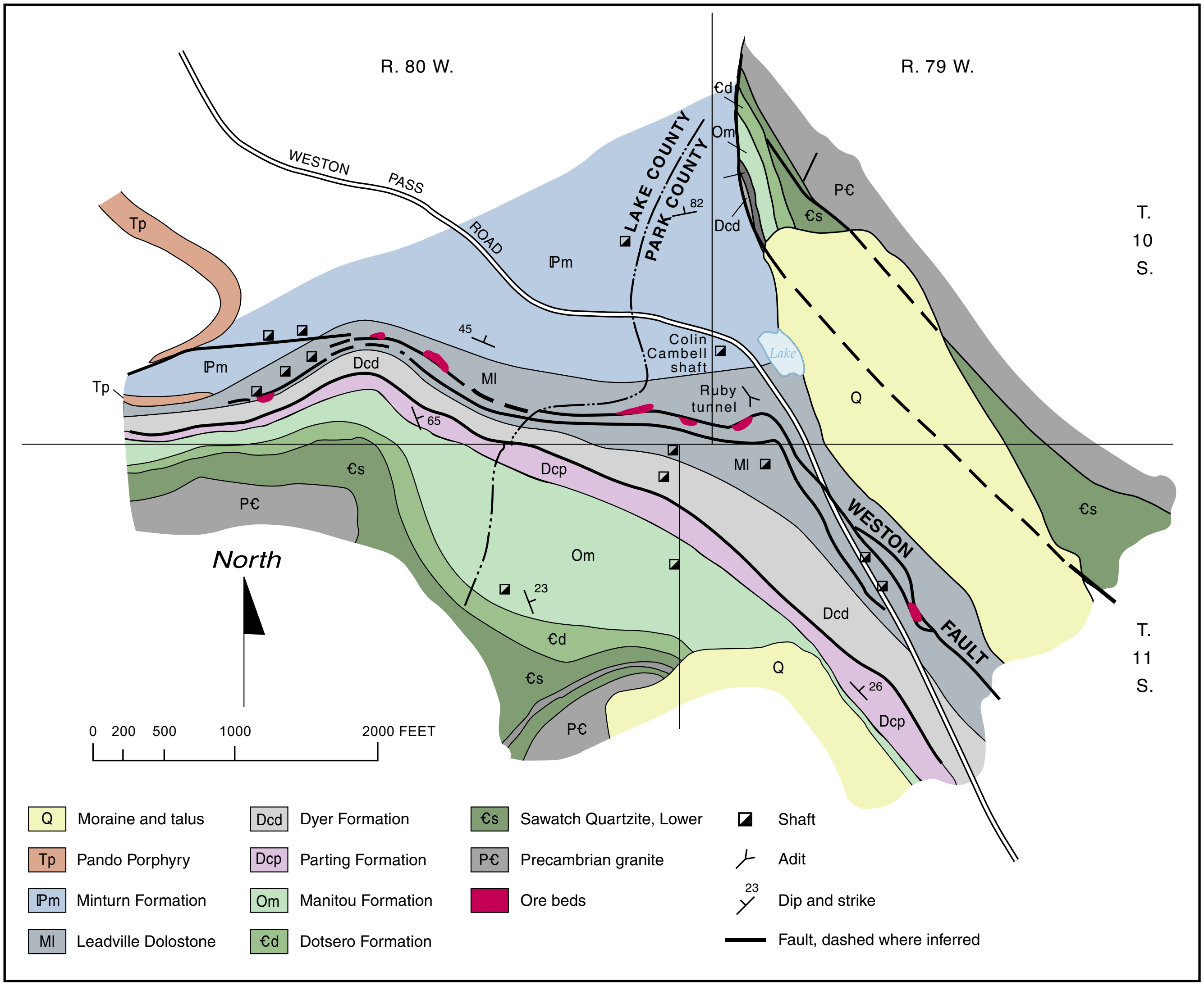


Figure 25. Geologic map of the Weston Pass district. (Adapted from Behre, 1932).

The most striking structural feature is a silicified breccia zone in the Leadville Dolostone, which extends laterally for about 7,200 ft. The breccia zone maintains a constant stratigraphic position about 90 ft above the base of the formation throughout its length. The breccia zone is about 20 ft thick and consists of light-gray, highly silicified, dense jasperoid. The jasperoid is broken into angular fragments and recemented by iron-stained silica. Behre (1932, p. 64) suggested that the silicified zone is a thrust fault, which could account for the thickening of the Leadville Dolostone in this district.

Ore Deposits

The most common ore mineral is galena. Rarely sphalerite and pyrite are present. Oxide minerals are cerusite, anglesite, calamine, smithsonite, iron oxide (limonite?), and chalcedony. Dolomite is the most abundant gangue mineral often forming “zebra rock”; a characteristic banded black-white texture in dolomite of the Leadville district.

Ore bodies are associated with an “ore bed” in the Leadville Dolomite; this zone is stratigraphically 75 ft higher than the silicified jasperoid breccia previously described. Ore minerals are disseminated in vuggy cavity zones, which generally have a thickness of less than 10 ft.

The ore grades are the Ruby Mine were reported to be higher than other mines of the district. Lead grades varied from 15 to 46 percent, zinc from 4 to 28 percent, silver 4.8 oz per ton, and gold from the Colin Campbell Claim at 0.10 oz per ton (Behre, 1932, p. 68).

GRANITE AND TWO BITS DISTRICTS

Introduction

The Granite and Two Bits districts (and the Lost Canyon Placer district) are in southernmost Lake County and northern Chaffee County along and to the east of the Arkansas River (**Figures 26 and 27**). The average elevation of these two districts is 9,000 to 9,500 ft. Placer gold was discovered in 1859 near the present town of Granite in Chaffee County. Prospecting in the early 1860s lead to the discovery of gold-bearing quartz veins of Yankee Blade Hill (Figure 26). The two largest mines of the district were the Belle of Granite and the Yankee Blade Mines, which together produced about 47,000 oz of gold. Most of the district production came the period 1862–1878. In 1908, the Granite Tunnel was driven to test the deep vein potential of the Yankee Blade district. By 1936 some 6,000 ft of tunnel and drift had been completed (Gese and Scott, 1993). Vanderwilt (1947, p. 47) reports production of 3,628 oz of gold from 1932 to 1945 from the Granite and Lost Canyon Placer districts (mostly in Chaffee County).

American Gold Resources carried out a mineral exploration program on Yankee Blade Hill of the Granite district from 1985 to 1989. In 1988 four drill holes were completed to depths of 581 to 684 ft. Selected parts of the core were analyzed; the highest concentration of gold was 0.097 oz per ton (Gese and Scott, 1993, p. 60).

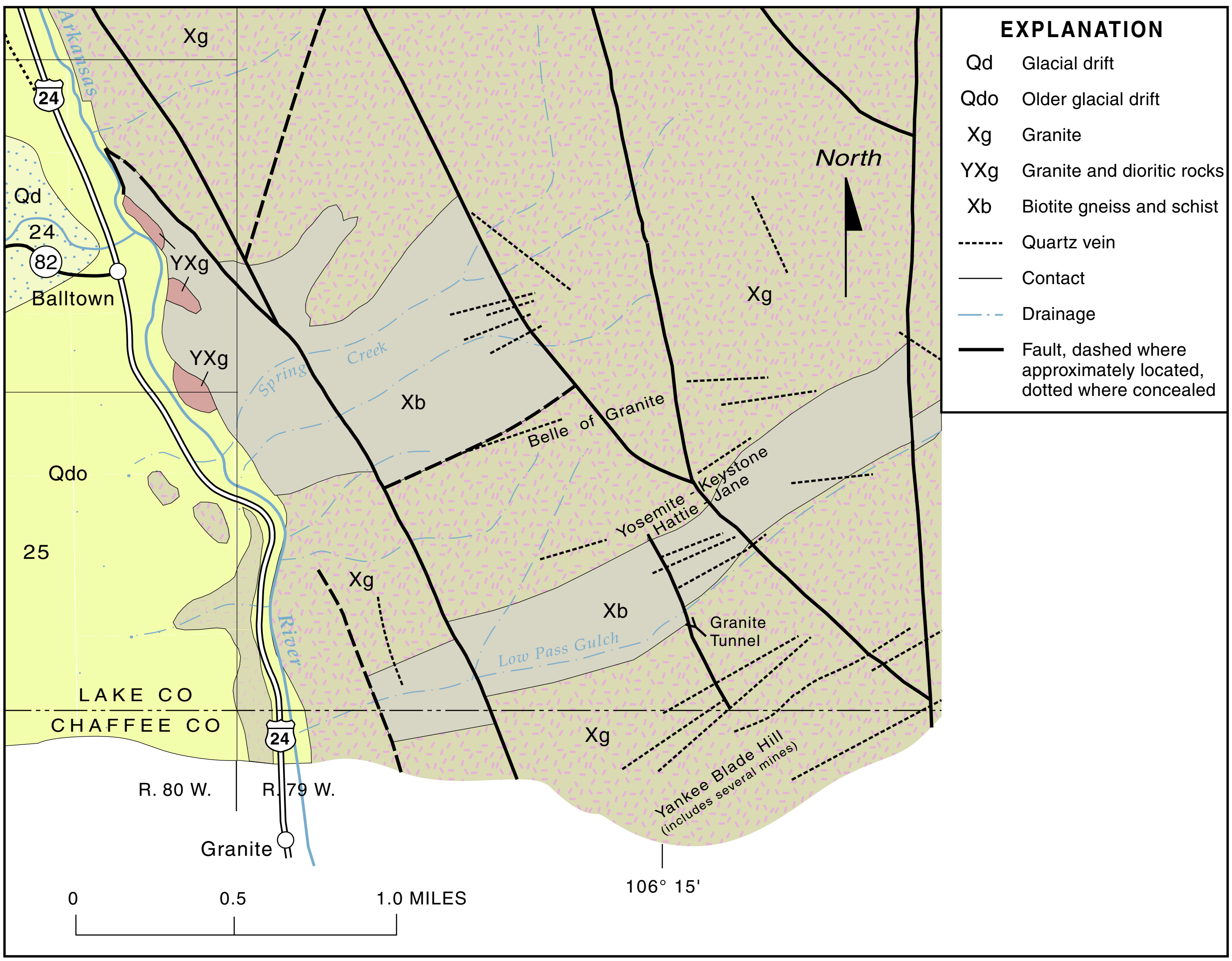


Figure 26. Geologic map of the Granite district. (Adapted from Gese and Scott, 1993).

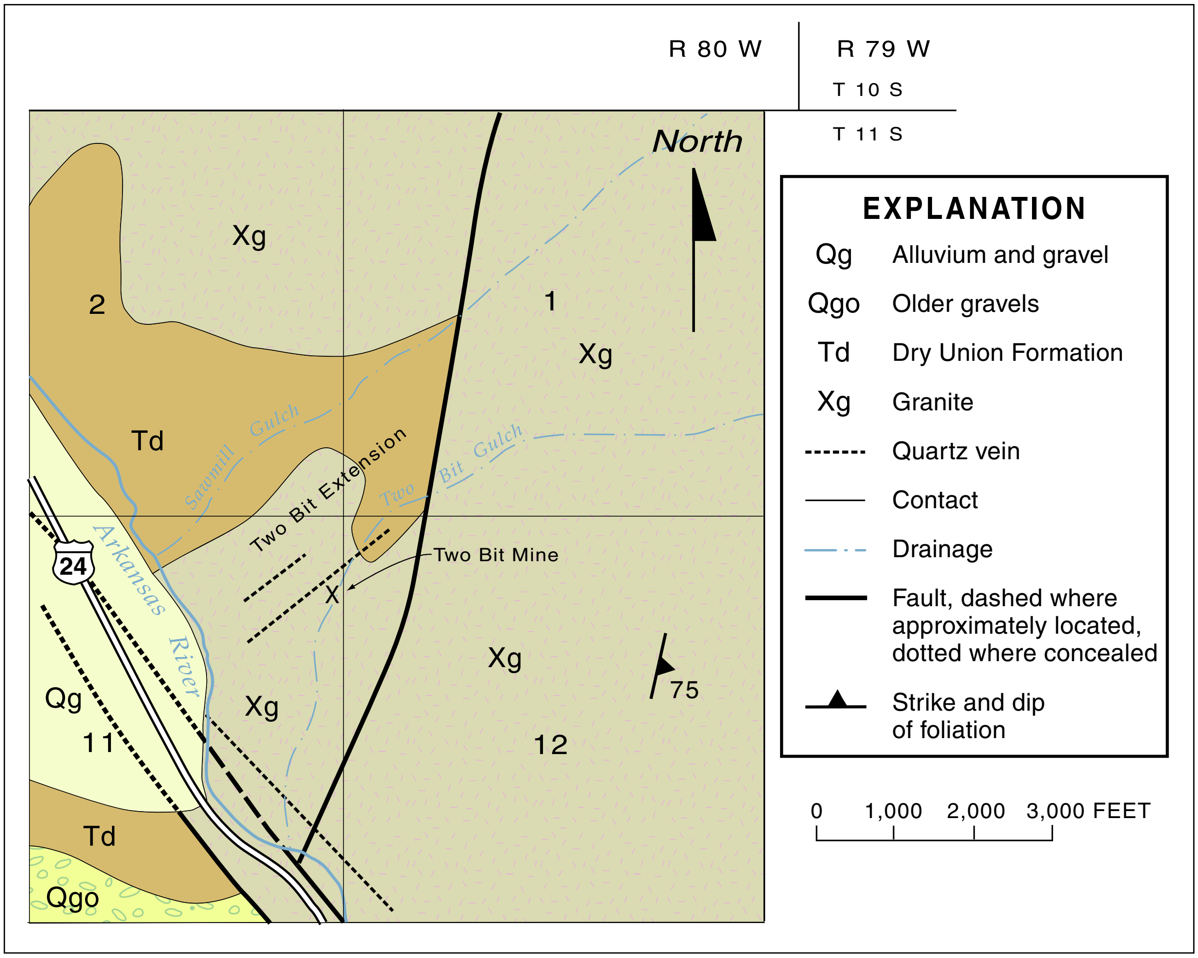


Figure 27. Geologic map of the Two Bits district. (Adapted from Gese and Scott, 1993).

Stratigraphy and Lithology

The host rock for the district is Proterozoic biotite gneiss and migmatitic gneiss, which has been intruded by a synkinematic adamellite and two-feldspar granite. The biotite gneiss is highly foliated and locally migmatized; it contains as much as 50 percent quartz, 25 to 30 percent biotite, and 5 to 10 percent fibrous sillimanite. Stretched quartz pebbles are present locally and indicate the sedimentary origin of the gneiss (Anonymous, 1982). There are a few east-northeast-striking rhyolite-andesite dikes of Laramide age in the district. Some of the dikes are associated with the gold-bearing fissure veins of the district. R.F. Marvin, in Hedlund and others (1983), reported a potassium-argon age of 65.3±2.4 Ma for a rhyolite dike in the district.

Structure

The metamorphic gneisses have been deformed into a dismembered syncline about 2.8 mi across with an axial plane that strikes northeast. The granitic rocks intrude the keel of the fold. The fissure veins are steeply dipping and are hosted by the gneiss except for the two veins in the Two Bit district. The veins there preferentially follow the north-northeast foliation of the gneiss (Anonymous, 1982).

Ore Deposits

The ore deposits of the Granite and Two Bit districts are quartz-pyrite-gold fissure veins (figs. 26 and 27). The veins form swarms on Yankee Blade Hill; as many as 19 veins have been observed in a 2,054-ft interval. The veins are as long as 3,000 ft, as wide as 1 to 3 ft, and discontinuous along strike. The veins have a relatively simple mineral inventory-chiefly early pyrite and gold as well as minor amounts of chalcopyrite, galena, and sphalerite. The veins are oxidized to depths of about 200 ft, and in the oxidized zone the gold is coarser grained than in the sulfide ore. Alteration of wall rock around the veins is primarily silicification near the vein and chlorite and sericite farther from the vein.

Grades range from 0.005 to 10 oz per ton gold. Some veins in the Yankee Blade Hill area have grades of approximately 0.7 oz per ton gold. Silver grades are low, 0.7 to 0.64 oz per ton. Boron geochemical anomalies are associated with most of the veins. The boron is probably related to the presence of tourmaline; however, tourmaline is not described as a gangue mineral in any available literature (Hedlund and others, 1983). **Table 6** shows the estimated production of each of the mines from the Granite and Two Bit districts.

Table 6. Estimated gold production from the Granite and Two Bit districts. (From Hedlund and others, 1983)

Mine	Gold produced (troy oz)
The Belle of Granite	24,000
Yankee Blade	23,000
Magenta	9,600
Robert George	4,800
New Year	3,800
Bunker Hill	3,300
Washington	2,800
D.C.C.	1,200
Gopher	960
B and B	400
California	380
Yosemite-Keystone	350
Hattie Jane	46
Two Bits and Two Bits Extension	Unknown

Yankee Blade Hill

Ten of the veins (fig. 26) on Yankee Blade Hill have been productive; however, most gold production came from two veins. One of these was developed by the Yankee Blade, Gopher, and Bunker Hill mines; the other was developed by the Robert George and Magenta mines.

The Granite tunnel was dug at the 9,330 ft level to intercept the lower levels of the veins on Yankee Blade Hill. Only 3 of the 19 intercepted quartz-pyrite-gold fissure veins contained economic gold concentrations. Over 4,000 ft of drifting was accomplished on these veins. Gold concentrations were correlated with high concentrations of galena and chalcopyrite. A total of 429 oz of gold was produced from the tunnel from 1930 to 1936 (Gese and Scott, 1993).

Belle of Granite Mine

The Belle of Granite Mine (fig. 26) was developed on a 1 to 5 ft wide quartz-pyrite-gold fissure vein that follows the footwall of a Laramide age andesite porphyry dike in sheared and altered schist. The mine included a 450 ft deep shaft with six levels and more than 3,000 ft of workings. Higher-grade ore was located along northwest-trending fractures (Gese and Scott, 1993).

Two Bits and Two Bits Extension Mines

The Two Bit and Two Bit Extension (fig. 27) are located north of the main Granite district. These mines were mainly silver producers; however, the amount of production is unknown. Veins bearing silver, chalcopyrite, galena, and sphalerite strike north-northeast. The granite wall rock is chloritized. The presence of 300 parts per million antimony in dump samples may indicate the presence of silver sulfosalts (Hedlund and others, 1983, p. 11).

TWIN LAKES (GORDON) DISTRICT

Introduction

The Twin Lakes mining district is located 16 mi southwest of the city of Leadville and approximately 2 mi northwest of the village of Twin Lakes on the steep eastern slopes of Parry Peak at elevations above 11,800 ft. The early history of the district is poorly known. The principal mine, the Gordon, was worked starting in 1884 and by 1919 had development on four levels (Howell, 1919). There are at least eight veins in the area (**Figure 28**), all of which shipped gold- (silver) ore to a mill in Twin Lakes by way of a gravity tram. Early production records are not available. Incomplete records from the American Smelting and Refinery Company smelter at Leadville from 1937 to 1942 indicate that 163 tons of crude ore averaging 1.6 oz per ton gold, 4.8 oz per ton silver, 9.7 percent lead, 2.1 percent zinc, and 0.7 percent copper were shipped from the Gordon Mine. Production at the Gordon Mine was apparently stopped by Federal order during World War II; there is no evidence that it reopened after the war.

In general, the district consists of a series of northeast-trending, shallow-dipping, fault veins cutting the Tertiary Twin Lakes Granite and Paleoproterozoic schist. Mineral deposits are spatially associated with a set of northwest-trending quartz monzonite porphyry dikes. The surface geology of the district is poorly exposed. In 1991, there was access to more than 2,100 ft of underground workings district-wide; these provided exposures revealing the nature of the geology and mineral deposits. The workings were mapped and sampled in detail by one of the authors, Paul J. Bartos, and Cindy L. Williams as part of an exploration project for Asarco. Parts of the following were summarized from Ms. Williams' report.

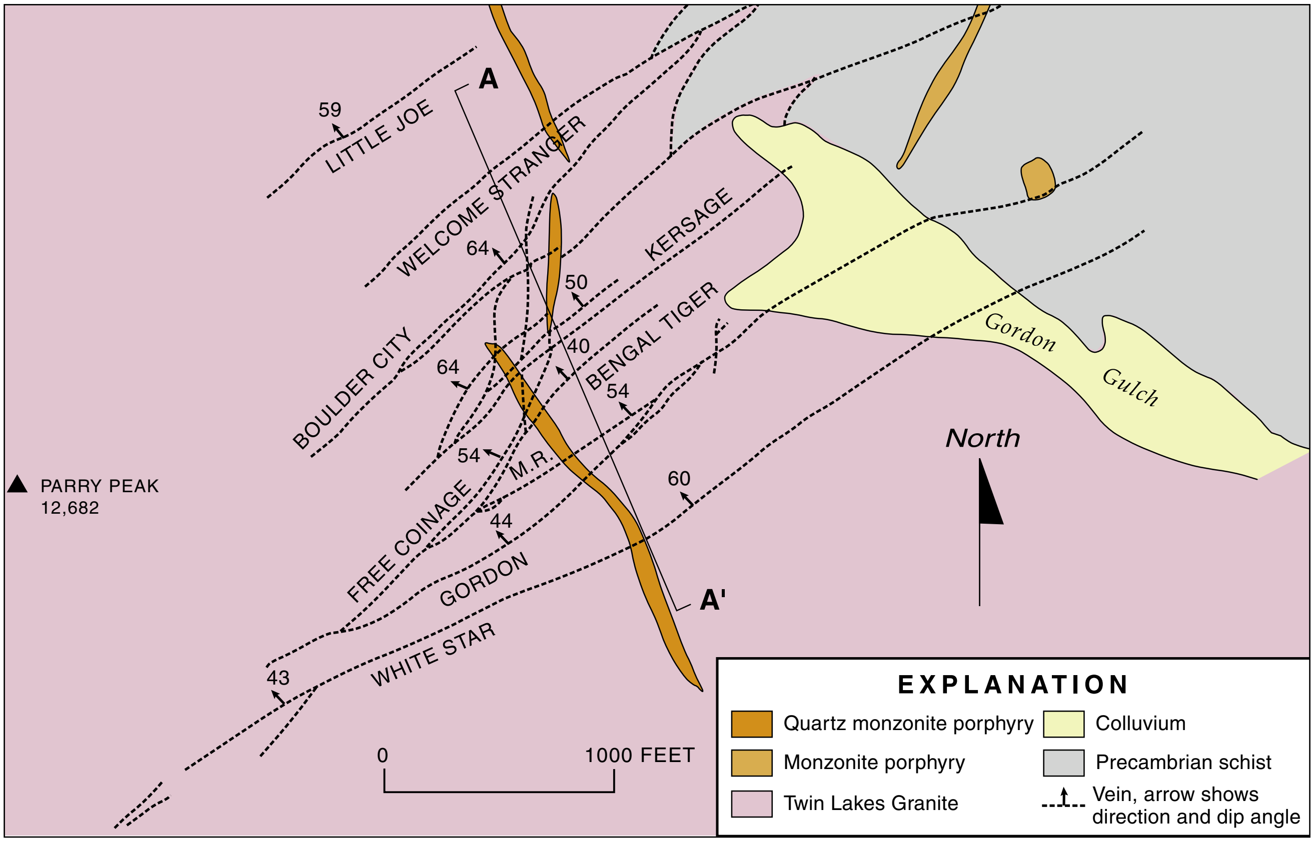


Figure 28. Generalized geologic map of the Gordon Mine area, Twin Lakes district.

Lithology

The oldest rock in the area is a dark-gray to black, fine-grained, quartz, biotite±sillimanite schist of Paleoproterozoic age. This rock constitutes the wall rock for the eastern, less productive, part of the district. The Twin Lakes Granite, host rock for most of the district's mines, is one of the phases of the Twin Lakes batholith, a large composite intrusion whose outcrop covers more than 45 sq mi (Wilshire, 1969; Cruson, 1973). In the district, the Twin Lakes Granite is typically light gray to pink, and relatively coarse-grained; it has phenocrysts 0.5 to 1.5 cm in length and a distinct porphyritic texture. The local miner's term for this rock was "corn granite" (Howell, 1919). Potassium feldspar phenocrysts as long as 6 cm are visible at some places. Quartz and potassium feldspar are the dominant phenocrysts, and approximately 5 percent biotite phenocrysts are also present. Chemically, the composition of the Twin Lakes batholith ranges from granodiorite to quartz monzonite (Wilshire, 1969); the granite appears to be a slightly more silicic local phase. Cunningham and others (1977) reported an age of 64 Ma for the Twin Lakes batholith.

The quartz monzonite porphyry dikes are typically gray to green; the porphyry contains minor phenocrysts of potassium feldspar, embayed quartz, and biotite in a fine-grained matrix. Howell (1919) termed these dikes "quartz porphyry" and considered them of rhyolitic composition; the presence of minor but persistent small plagioclase phenocryst laths suggest that a quartz monzonite to quartz latite composition is more likely. Several small monzonite porphyry dikes of similar appearance, but with distinctly fewer quartz phenocrysts, have been mapped in the eastern part of the district. Most likely, these dikes are cogenetic with the quartz monzonite porphyry dikes; younger veins cut both types of dikes, although sericitic and local silicic alteration and metal ratios are clearly centered on the quartz monzonite porphyry dikes. These dikes have been included by Fridrich and others (1991, fig. 1B) as part of the extra-caldera dike swarm that marked the onset of Grizzly Peak caldera volcanism. If so, then these dikes are at least older than 34 Ma (age of eruption of the Grizzly Peak Tuff). Cunningham and others (1977) reported an alteration age of 46 to 43 Ma for the Twin Lakes batholith, which may reflect the age of quartz monzonite porphyry dike emplacement.

Structure

Structurally, the Twin Lakes district is dominated by a series of subparallel stacked reverse faults that generally strike N. 60°–80° E. and dip 35°–70° NW. (**Figure 29**). Estimated offsets on these faults are on the order of several hundred feet, and slickensides suggest a large component of strike-slip. A second group of faults strikes N. 20° W. to N. 20° E.; these faults are particularly prominent in the Gordon Mine where their intersection with the main Gordon reverse fault yielded zones of intensely fractured and mineralized rock more than 60 ft in width. The north-trending faults both cut and are offset by the northeast-trending reverse faults and appear to have limited offsets, on the order of 1 ft to tens of feet.

Ore Deposits

Veins at Twin Lakes are dominated by quartz and disseminated fine-grained pyrite, galena, sphalerite, and chalcopyrite. Principal economic values were gold, which was commonly free and coarse, typically filling small cracks in the quartz or interstices in the sulfides. Vein widths range from inches to 8 ft, and gouge is strongly developed on both walls. Typically, veins are observed in the shear zones associated with the northeast-trending reverse faults; wider pods of mineral deposits were typical at the intersections of the reverse faults with the north-trending fractures. Argillically altered rock surrounds mineralized veins and forms zones as much as 125 ft wide, which typically contain significantly anomalous concentrations of gold.

Alteration is more intense and pervasive around the Gordon vein and adjacent veins than elsewhere in the district. Mineralogic and metal ratio zoning is also centered directly on the Gordon Mine. The Gordon and adjacent veins are characterized by sheared rock with only minor quartz, pyrite, and cerussite (after galena), whereas peripheral veins to the north and south contain significantly more quartz (increasing outward), galena, sphalerite, and pyrite. Beyond these base-metal veins, the dominant vein filling is barite with minor amounts of quartz and pyrite. Silver concentrations in the far-peripheral veins can be considerably higher (up to 14 oz per ton silver) than in veins near the Gordon Mine. Contours of Ag/Au ratios are centered on the Gordon Mine with a 350- by 150-ft core zone of Ag/Au ratios less than or equal to 2, surrounded by a 900- by 2,000-ft area of Ag/Au ratios approximately equal to 10, and then peripheral areas with Ag/Au ratios of 75 to 100 and higher (**Figure 30**).

Excluding the mapping and sampling just described, no modern exploration or any drilling appears to have occurred in the district.

SUGAR LOAF–ST. KEVIN DISTRICT

Introduction

The Sugar Loaf district is located approximately 6 mi west of Leadville, directly south of Turquoise Lake. The St. Kevin district, on the north shore of Turquoise

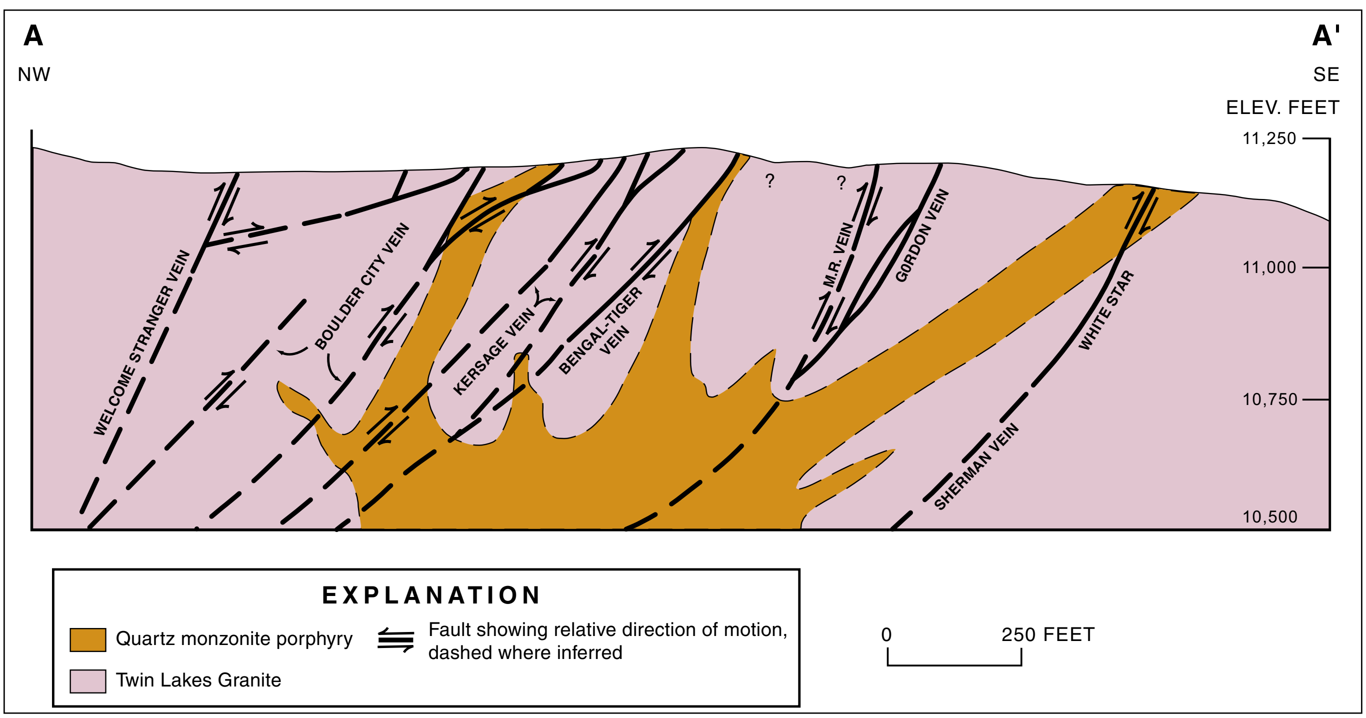


Figure 29. Geologic cross section of the Gordon Mine area (section line A–A′ on Figure 28).

Lake, is essentially contiguous to Sugar Loaf. The history of both districts is similar. Nearly all the veins were discovered in the 1880s, supposedly by one man, Tom Welsh (Singewald, 1955). Peak production was from the 1880s until the Silver Crash in 1893. Some mines continued production until World War I, and one mine, the Dinero, continued producing into the 1920s. Reliable production records from this area are not available from before 1914; Singewald (1955) estimated the total value of production from both districts as $10 to $15 million. Metals from the district were dominantly silver and subordinate gold.

There are four main vein zones in the Sugar Loaf district: Dinero, Tiger, Venture, and Bartlett; smaller veins were emplaced on the periphery of the district (**Figure 31**). The Dinero Mine is estimated to have yielded $1 to $2 million; the Venture, Tiger and Silvers mines each yielded between $500,000 and $1.5 million; and the T.L. Welsh, Red Hook, and Nellie C. Mines each yielded $100,000 to $500,000. Production records from the Dinero Mine from 1914 to 1928 indicated an output of 9,259 tons, of which 939 tons were manganese ore and the rest silver ore. The manganese ore averaged 12 percent manganese; the silver ore averaged 62.7 oz per ton silver, 0.155 oz per ton gold, 0.12 percent copper, 1.88 percent lead, and unknown zinc (Singewald, 1955). An anonymous compilation of records from the Dinero and adjacent mines from 1891 to 1923 reported by Singewald (1955) suggested that shipment grades were 11 to 140 oz per ton silver, 0.04 to 0.5 oz per ton gold, 0 to 14 percent zinc, and less than 1 percent lead. Average grades from the more than 25,000 tons shipped (worth approximately $800,000 at the time) were 63 oz per ton silver, 0.17 oz per ton gold, and 4.3 percent zinc. Zinc grades increased with depth of the workings; average shipment grades started at 0.3 percent and finished at 5.2 percent. This change in the zinc concentration reflected near-surface leaching of sphalerite. In contrast, silver grades were relatively constant over the depth of the workings.

Lithology

The area is characterized by poor exposures in dense forest with a glacial drift cover 10 to 15 ft thick. Dumps constitute the principal exposure. The bedrock

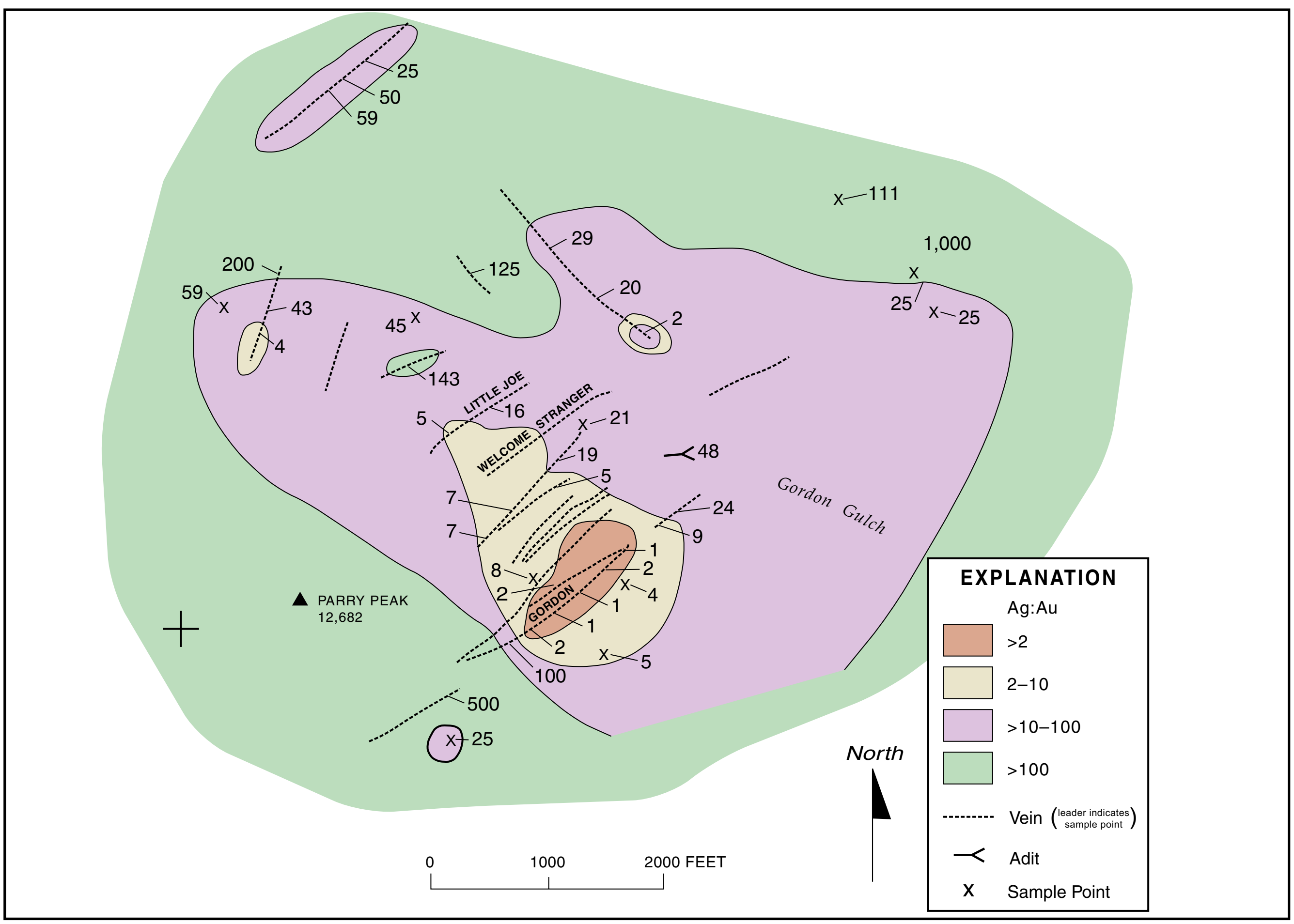
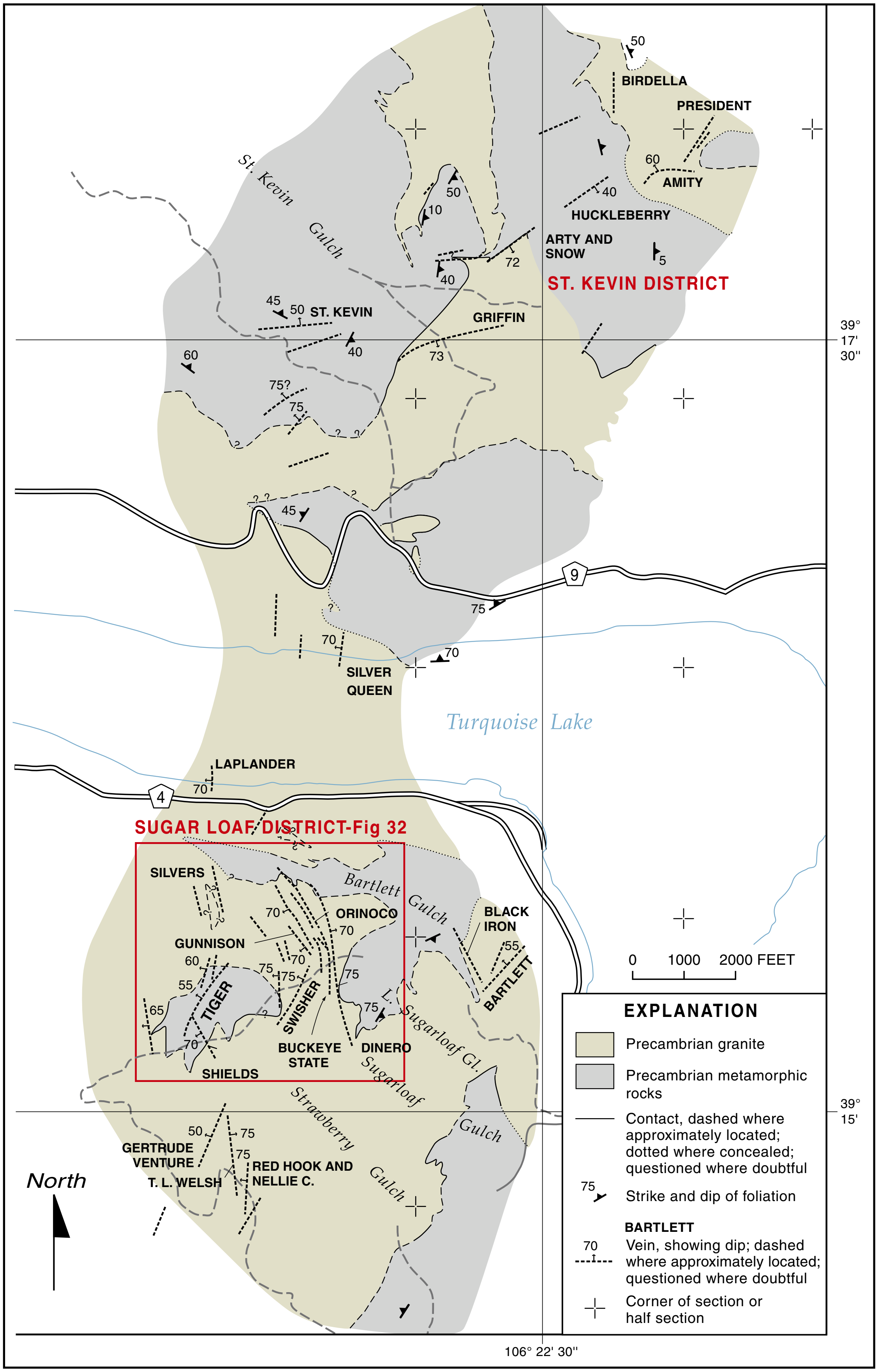


Figure 30. Gold-silver zoning map of the Twin Lakes district.

Figure 31. Vein pattern in Sugar Loaf and St. Kevin districts.



is dominantly Mesoproterozoic granite with islands of Paleoproterozoic gneiss and schist (**Figure 32**). These rocks are cut by Tertiary porphyry dikes and mineralized veins. The granite was originally correlated to the Silver Plume Granite by Stark and Barnes (1935); Tweto (1987) considered it a separate Proterozoic intrusion, termed the St. Kevin Granite. The granite is typically medium grained and gray; it has small flakes of biotite and subordinate muscovite scattered among larger grains of feldspar and quartz. The granite is locally foliated. Chemically, it appears more akin to quartz monzonite than to true granite (Singewald, 1955); for historical purposes, the granite nomenclature is retained. The biotite schist, quartz-mica gneiss, and migmatite are all medium grained; mica grains are commonly larger than the quartz or feldspar grains. Dikes and pods of granite and pegmatite cut the schist and gneiss; outcrops are insufficient to resolve completely these field relationships.

A series of east-trending Tertiary porphyry dikes cut the Proterozoic rocks. These are typically gray-white and have rare phenocrysts of quartz, muscovite, and potassium feldspar in a fine-grained groundmass. The overall composition appears to be that of a quartz latite. These dikes have been tentatively correlated to the Pando Porphyry (Early White Porphyry) by Singewald (1955), which has been dated in the Leadville mining district at 72 Ma (Pearson and others, 1962).

Structure

Veins at Sugar Loaf strike due north (±25°), whereas the porphyry dikes tend to be oriented east-west. Other dikes trend northeast and northwest. In contrast, the dominant vein orientation at St. Kevin is N. 70° E. Most, but not all, veins at Sugar Loaf are contained within granite, and a preferred rock type with respect to vein width, vein concentration, or alteration style, was not observed. Veins appear to cut the porphyry dikes, although field relationships are insufficient to state whether offset occurred or not.

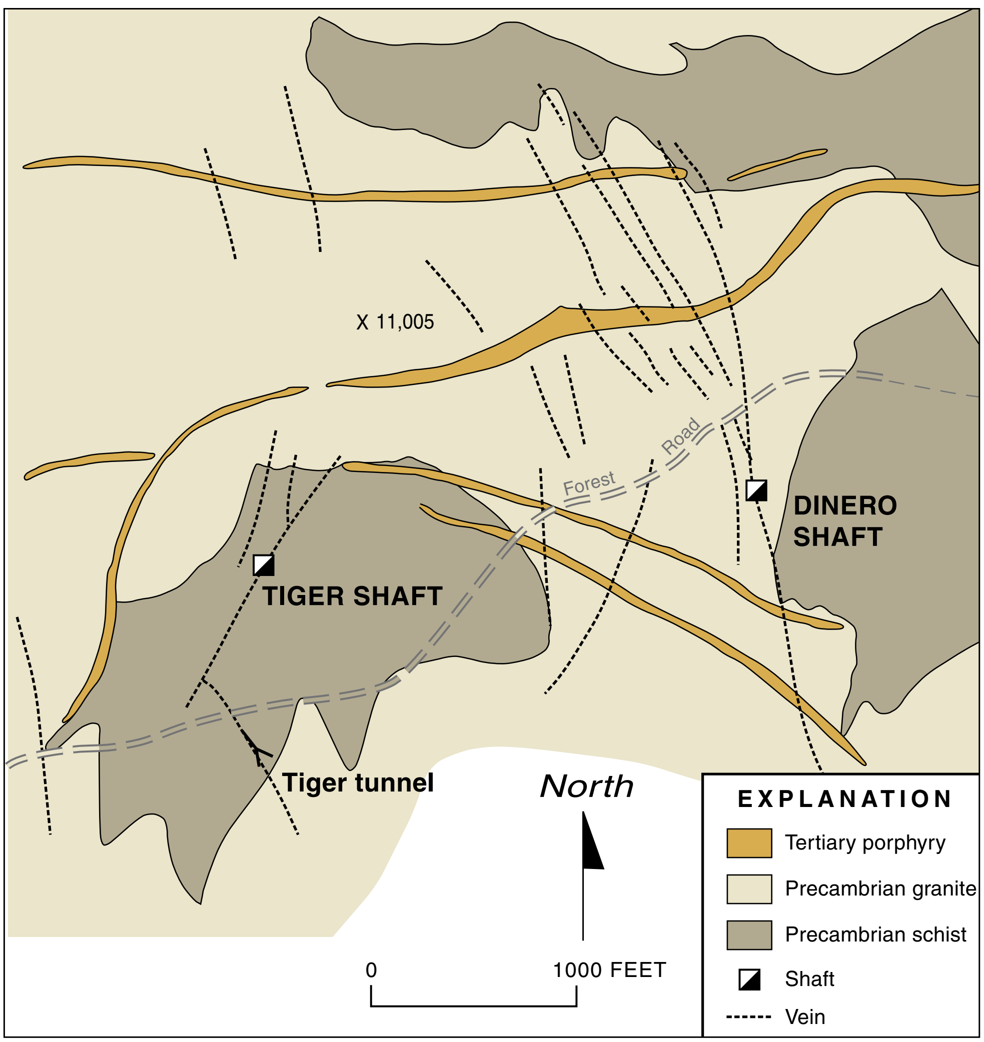


Figure 32. Generalized geologic map of the Sugar Loaf district.

Ore Deposits

The veins are not true veins in the sense of having well-defined walls; rather they are broad, steeply dipping (57° to 78°) shear zones containing broken rock, gouge, and sulfide minerals. Multiple high-grade fissures and fractures within a given shear zone are common. Compared to the country rock, these shear zones are low in silica so they typically do not crop out, but form topographic depressions. The country rock is typically intensely altered to aggregates of sericite, pyrite, and clay and contains stringers and lenses of sulfides with or without fine-grained chert-like quartz. Alteration halos are broad, with measured widths of 200 to 800 ft. Total amount of sulfide in the alteration zones is on the order of several percent. Pyrite is the dominant sulfide, followed by sphalerite, and to a much lesser degree, galena. Minor amounts of chalcopyrite, tetrahedrite, and argentite are also found in the alteration zones (Sandberg, 1935). In addition to fine-grained silica (chert), rhodochrosite and manganocalcite gangue are present in some deposits (Singewald, 1955). Native silver appears to have been the principal ore mineral during early production; tetrahedrite and argentite have also been reported (Sandberg, 1935). Ore shoots typically bottomed within 100 to 200 ft of the surface (Singewald, 1955). Both Sandberg (1935) and Singewald (1955) thought that this limited vertical distribution of the ore bodies in part represented the hypogene distribution of silver. Some ore minerals are laterally zoned: sphalerite and galena seem restricted to the northern part of the Sugar Loaf district, and the concentration of pyrite in the Tiger-Shields vein set distinctly diminishes away from the main Tiger shear (K. Friehauf in unpublished Asarco report, 1990).

In addition to the sericitic alteration associated with the vein zones, Singewald (1955) described "chert zones" (fine-grained silicification) associated with the porphyry dikes. One of these chert zones forms Sugarloaf Mountain, where the chert zone is as wide as 100 ft thick and nearly 1 mi long. (The "Sugarloaf" in Sugarloaf Mountain is spelled as one word, whereas the "Sugar Loaf" district as named by Singewald (1955) is spelled as two words.) Overwhelmingly, the chert zones are associated-spatially and probably genetically-with the porphyry dikes and not with the mineralized shear zones. The granite in the chert zones is so thoroughly silicified by local silica veinlets and high-density chert stockworks that only remnant original texture can be seen. Typically, this silicification is not associated with sulfides, and the chert zones have a dominant east-west orientation, whereas sulfide "veins" tend to be oriented north-south. The chert-like quartz is present in an early, light-colored variety and a later dark-gray variety, which has associated sulfides. The indicated paragenetic sequence of mineralization is (1) emplacement of porphyry dikes; (2) silicification by fine-grained, light-colored chert followed by a change in the orientation of fracture filling; (3) silicification by dark chert; and (4) sulfide deposition (typically early pyrite followed by sphalerite, galena, and silver). Samples of sericitic granite cut by light-colored chert veinlets suggest that sericitic alteration preceded (or at least was broadly contemporaneous with) silica deposition (Singewald, 1955).

Sulfides formed zones of high-grade mineralization within much larger sericitic alteration halos. Extensive sampling (avoiding obvious high-grade material) of the Dinero and Tiger-Shields area dumps averaged 0.025 oz per ton gold, 4.7 oz per ton silver (98 samples) and 0.014 oz per ton gold, 2.4 oz per ton silver (66 samples), respectively (K. Friehauf in unpublished Asarco report, 1990). These dumps, which included crosscut material, were thought to represent the entire shear zone and not just the high-grade "fracture-veins" within them.

Asarco completed an induced polarization (IP) and resistivity survey to delineate the veins of the Sugar Loaf district and conducted a reverse-circulation drilling program in 1990. This exploration effort produced 15 drill holes having inclinations of 45° and 61° and depths ranging from 125 to 505 ft (5,540 ft total) (**Figure 33**; drill-hole locations are proprietary). These drill holes typically encountered intervals of 10 to 40 ft (not true thicknesses as the drill holes cut the steeply dipping shear zones at angles less than perpendicular); assays of the drill samples ranged from 0.01 to 0.025 oz per ton gold, 0.5 to 3 oz per ton silver. The sericitic alteration halos were broad; widths measured 200 to 800 ft. The drilling served to confirm the dump sampling (and thus the overall grades of the shear zones), but did not establish sufficient bulk tonnage material to justify additional exploration. As far as is known, the district has been dormant since Asarco's drilling.

TENNESSEE PASS DISTRICT

Introduction

The Tennessee Pass mining district straddles the Lake County-Eagle County line at Tennessee Pass (**Figure 34**). The district is at an elevation of about 10,500 ft. Little is written on the early history of the district. The most prominent mine, the Jennie June, is reported to have produced about $100,000 of gold ore within a few years of its discovery in about 1898. The mine was last worked in 1936. It consisted of a shaft with two levels at 80 and 150 ft (Tweto, 1956). There are two other significant mines in the Lake County part of the district, the Lucy L. and the Golden Gate; however, there are no production records from these mines, and their locations are not given on commonly available maps of the district.

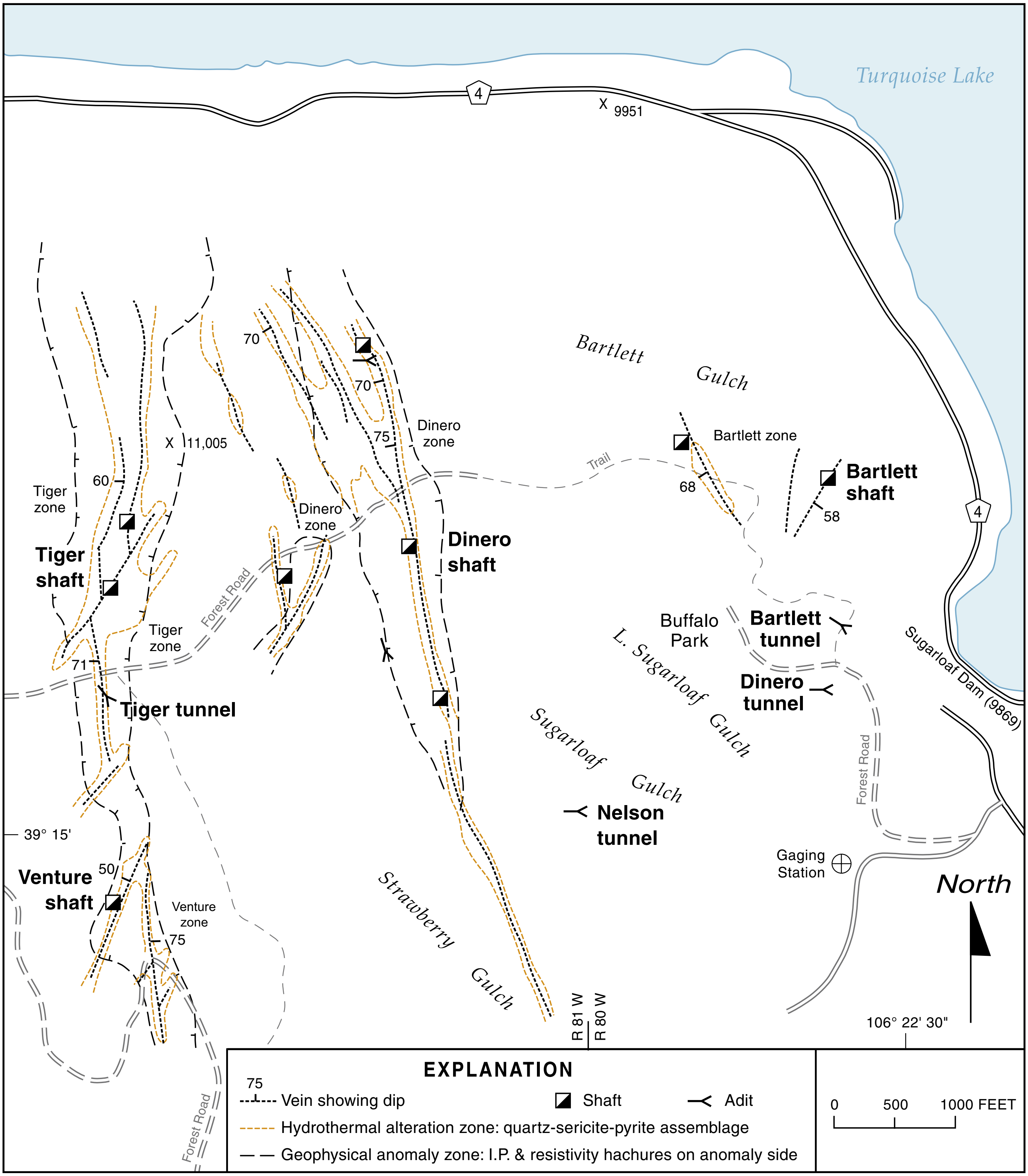


Figure 33. Vein and mine map of the Sugar Loaf district.

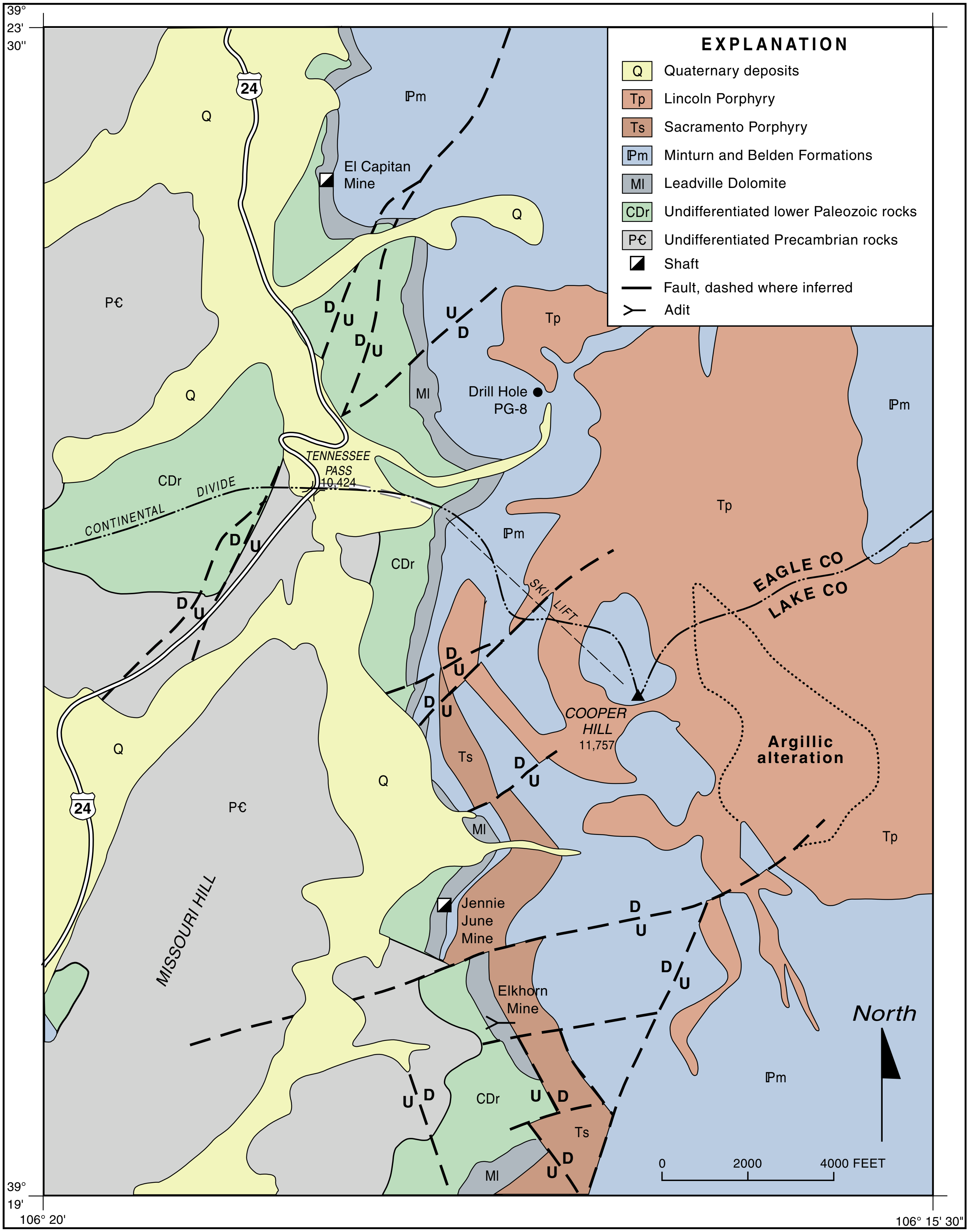


Figure 34. Geologic map of the Tennessee Pass district.

Noranda Exploration Inc. and Tenneco Minerals conducted exploration in the district in the 1980s. Exploration drilling was completed about 1.5 mi southeast of Cooper Hill in an area known as "Buckeye Gulch alteration zone" (Pohl and Beaty, 1990). Zones of Leadville Dolomite, which were replaced by a pyrite-rich mixture of sulfide, sulfosalt, and telluride minerals were intercepted by at least two of the drill holes. Gold concentrations in the sulfide replacement zone varied from 1.7 ppm (parts per million) over 5 ft, to 2.3 ppm over 5 ft, to 96 ppm over 2 ft (Pohl and Beaty, 1990, Table 1).

Stratigraphy

The Tennessee Pass area consists of Proterozoic gneiss and schist overlain by approximately 400 ft of lower Paleozoic sedimentary rocks. These strata are overlain by the Lower Pennsylvanian Molas Formation, an unconformity-related red clay deposit. The Molas Formation is overlain by 125 ft of Middle Pennsylvanian Belden Shale and an undetermined thickness of the Minturn Formation. The Pando Porphyry intrudes the Belden Shale near Cooper Hill. The Lincoln Porphyry and the Sacramento Porphyry form large quartz monzonite sills in the Minturn Formation.

Structure

The strata of the Tennessee Pass mining district have been deformed into an east-dipping homoclinal sequence. Measured dips are on the order of 7° to 10° (Tweto, 1956). Several east-northeast-trending normal faults have been mapped in the area (fig. 34).

Ore Deposits

The ore host rock in the major mines of the Tennessee Pass district is the Mississippian Leadville Dolostone. Gold and sulfide minerals were produced from three stratigraphic levels in the Leadville Dolostone (**Figure 35**) (Beaty and others, 1987). Mineral deposits also have been found in some of the strata underlying the Leadville Dolostone. There are two types of gold deposits found in the district, jasperoid and dolomite breccia. The jasperoid consists of light-gray, very fine grained quartz with calcite pseudomorphs after pyrite. The dolomite breccia found at the Jennie June Mine consists of fine-grained dolostone and chert clasts in a dolomite sand matrix. The breccias are locally iron stained and contain abundant pyrite (Beaty and others, 1987). The grade of gold mineralization is about 0.3 to 0.4 oz per ton (Gese and Scott, 1993).

OTHER METAL DEPOSITS

Homestake Mine

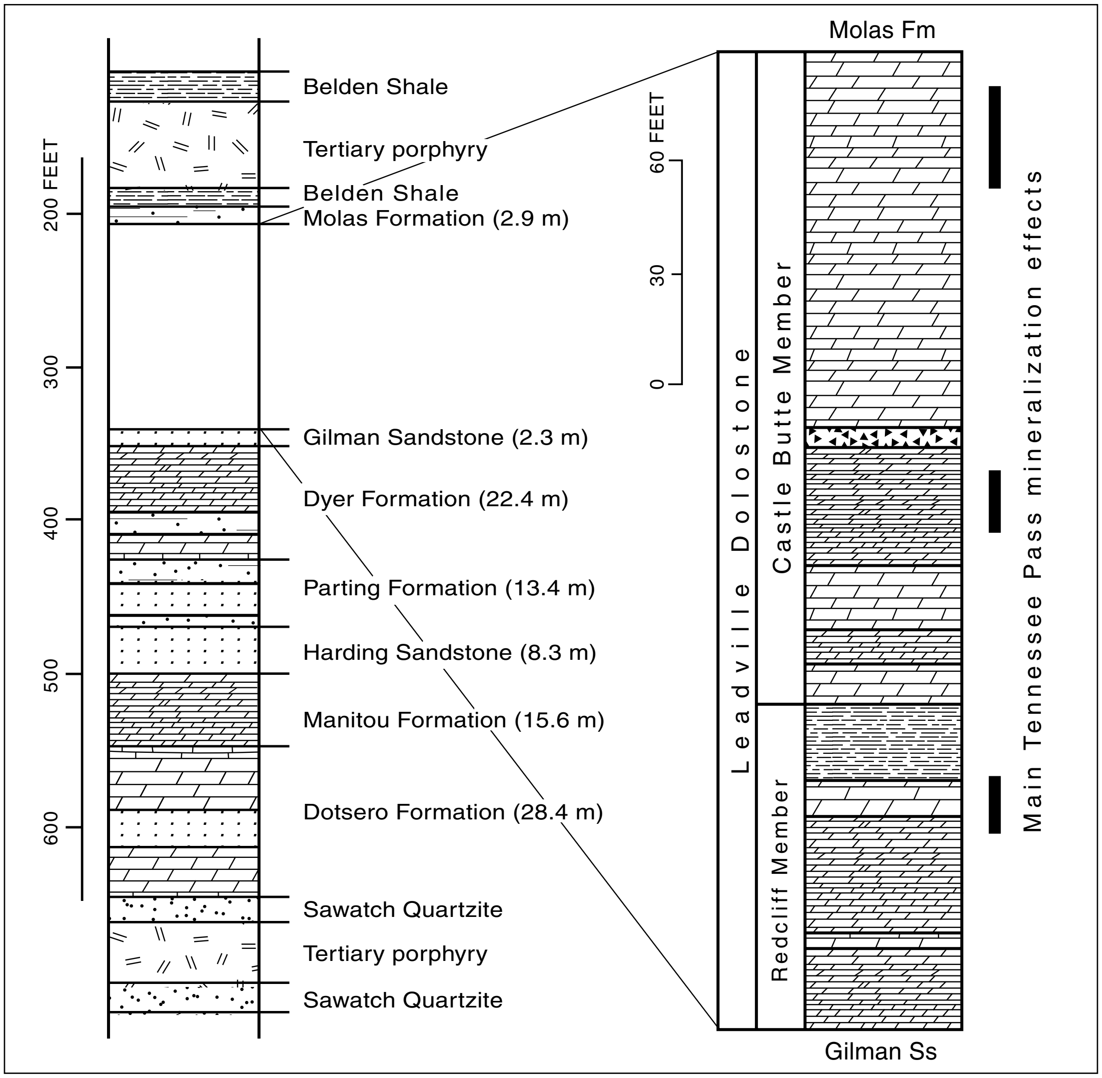
The Homestake Mine is located in northwest Lake County about 2 mi south of Homestake Peak (pl. 1). The host rock for the Homestake Mine is Proterozoic gneiss and schist. Gold and silver mineralization in quartz veinlets 2 to 4 in. wide is associated with east- to northeast-trending quartz veins.

The main vein is a pyritic, silicified, limonitic shear zone that extends for 3,900 ft and attains a width of 20 ft. Precious metals along with galena, chalcopyrite, sphalerite, bornite, siderite, calcite, and barite were produced. Workings at the Homestake Mine consist of five shafts and eight adits. Selected rock samples collected by the U.S. Bureau of Mines (Lundby and Brown, 1987) show concentrations from nil to 0.42 oz per ton gold and from 5.1 to 87.3 oz per ton silver. However, most of the samples collected contained no economic metal concentrations.

Champion Mine and Iron Mike Mines

There are a number of small mines and vein prospects in the general vicinity of Lackawanna Gulch (pl. 1), located approximately 14 mi southwest of Leadville. By far the largest of these was the Mount Champion Mine, situated on the south side of Mount Champion, close to the summit. The property was discovered in 1881, but was not developed until 1907 when the Mount Champion Mining Company purchased the property and started construction of a 50-ton/day mill and a 6,100-ft-long tramline. Significant production started in 1912 and continued until 1918. U.S. Bureau of Mines records indicate that 4,759 tons of direct shipping ore were produced at a grade of 3.23 oz per ton gold and 2.6 oz per ton silver. In addition, 40,259 tons of milling ore assaying 0.374 oz per ton gold and 0.28 oz per ton silver were mined. This ore also had minor amounts of lead (1 percent) and, locally, copper (0.3 to 1 percent). During this period, the Mount Champion Mine generated 26,500 oz of gold and a total estimated metal value of $550,000 to $600,000. The Mount Champion Mine was dormant from 1919 to 1936. From 1937 to 1940, the property was leased, and there was small-scale mining; incomplete records suggest that 17.5 tons averaging 2 oz per ton gold and 2 oz per ton silver were mined (G.L. Fairchild, unpublished report, 1974). There is no record of mining activity past 1941. In the late 1970s through the early 1980s, the property was further explored with five drill holes, totaling 400 ft.

Figure 35. Stratigraphic section of Paleozoic rocks in the Tennessee Pass area.



During this period, a small firm (Minerals, Inc.) claimed a resource at Mount Champion of 93,000 tons averaging 0.4 oz per ton gold; the basis for this resource estimate is unknown, and no record exists of any subsequent mining.

The Mt. Champion Mine is developed on a single quartz vein-fault striking N55E, with dips ranging between 20 and 60° to the southeast, averaging 45°. Total known vein length is 1,400 ft. Post-mineral faults truncate the vein and create a complicated structure. This vein was developed on four levels for 1,000 ft along strike and 320 ft down dip. Mineral-ization consists of quartz, pyrite, galena, and gold in pods and dilation zones in the fault, which is interpreted as a reverse fault (G.L. Fairchild, private report, 1974). Typical pod dimensions are 20 to 160 ft along strike and 30 to 120 ft along dip. Widths are on the order of 1 to 10 ft. These mineralized pods, in an otherwise continuous, but narrow vein tend to occur in the flatter portion of the vein and near horizontal breaks in the hanging wall or footwall. The mineralization consisted of white quartz with occasional (up to 5 percent) pyrite, galena, chalcopyrite, sphalerite, and gold. Approximately half of the gold was free, and typically not visible. The rest of the gold was commonly associ-ated with pyrite (Howell, 1919). There was no apparent lateral or vertical zonation. Alteration consisted of silicification and argillization next to the vein and continuing up to two ft away, with more distal propylitization.

The rock in the area is typically black biotite or hornblende schist. This schist contains local injections of gneiss and granitoids. The wall rock for the Mt Champion Mine is the Proterozoic Mt. Champion quartz monzonite, which forms a sill-like body. This is a light-gray, medium-grained rock, with quartz evenly distributed throughout and feldspar grains up to 5 mm. The quartz monzonite contains some coarse biotite, and minor amounts of apatite and magnetite. The best portion of the vein is in the quartz monzonite; where the vein crosses into schist, it becomes thinner, and quickly turns into a series of thin stringers, with more lower metal grades, such that it couldn't be mined (Howell, 1919). In addition to the schist and quartz monzonite, thin dikes of fine-grained, gray, alaskite porphyry occur in the area.

Within the general Lackawanna Gulch area, Howell (1919) reported an additional five veins. These are respectively; the Eureka, Independence, Mauser No. 1 and No. 2, and D.M. Elder veins. Typically, these are quartz, pyrite, gold, plus or minus galena veins of limited strike length and thickness (typical vein widths of 0.5 to 1.5 ft). The Eureka vein, located near the mouth of Mountain Boy Gulch, is the exception, with a strike length of 500 ft and widths up to 10 ft (averaging 3 to 5 ft). It had some limited production (estimated at perhaps as much as 5,000 tons). Production from other veins in the area is believed trivial.

The Iron Mike Mine is located up South Half Moon Creek about two miles west of Mount Elbert. The host rock is Proterozoic granite. There is no published literature that discusses the geology, mineralogy, and production amounts of the Iron Mike Mine.

Placer Deposits

The junction of the Arkansas River and California Gulch, about 2 mi west-southwest of present-day Leadville, was the site of the first gold discovery in Lake County in late 1859. Prospectors returned to this site in early spring of 1860 and by following the California Gulch upstream discovered rich gold placers in the alluvium and terrace deposits of the gulch. A gold rush ensued, which led to the establishment of Oro City, the first settlement with a post office in the upper Arkansas River Valley. The gold rush was over within a few years; however, placer operations continued through the 1930s (Parker, 1974, p. 17–19). Henderson (1926, p. 176) estimated the value of gold placer production from 1859 to 1867, mostly from California Gulch, as $5.272 million (approximately 164,000 oz of gold at an average price of $32 per ounce during the Civil War years).

Placer gold was mined in California Gulch from modern alluvium and high-level terrace gravels. The irregular gold flakes and nuggets came mostly from the prolific lode deposits of Printer Boy Hill, as the gulch gravels do not contain placer gold upstream of Printer Boy Hill. Cerussite ($PbCO_3$) occurred in the placer deposits of upper California Gulch, and it interfered with gold recovery from the sluice boxes. When it was finally identified, it guided prospectors to the rich lead-zinc-silver lode deposits of the Leadville district (Parker, 1974).

The placers of the Twin Lakes district are in Lake and Chaffee Counties and were worked continuously from 1860 to 1918. They produced gold worth about $3 million. The Derry Ranch placer is located on Box, Herrington, and Corske Creeks about 1.5 mi north of Twin Lakes. Mining on these placer deposits commenced in 1915 with the construction of a 6-cu-ft dredge for the Empire Dredging Company. The Empire Dredging Company stated that the gravels were 35 ft thick and had a value of $0.20 per cu yd (at a gold price of $20.67 per ounce) (Parker, 1974). The dredge worked these gravels until 1932 when it was dismantled. Other companies worked these Derry Ranch placers until 1951. The estimated total production was more than $1.3 million. The placer deposits are primarily in modern stream alluvium except for those parts of Corske Creek that are in glacial moraine. The produced gold had a fineness of 765 and was fine grained, about the size of a pinhead, but a few 0.5-in. nuggets were found as well (Parker, 1974, p. 50–61). Some minor placer deposits were worked at the confluence of Lake Creek and the Arkansas River. Between 1860 and 1867, these produced gold with a value of about $55,000 (Parker, 1974).

Placer workings are located in Buckeye Gulch, a tributary of the East Fork of the Arkansas River in secs. 29 and 32, T. 8 S., R. 79 W. Buckeye Gulch is a narrow valley with glacial drift deposits in the upper part and alluvial-fan deposits in the lower part near its confluence with the East Fork of the Arkansas River. The placer workings are in boulder gravel composed of porphyry and Minturn Formation clasts. Gold was derived from pyrite-quartz veins at the head of the gulch (Parker, 1974, p. 34).

Small placer deposits were mined in East Tennessee Creek and Thayer Gulch in T. 8 S., R. 80 W. Source rocks in these two streams are mostly lower Paleozoic strata and Paleoproterozoic metamorphic rocks of the Tennessee Pass district. In 1938, the placers on East Tennessee Creek produced 471 oz of gold at a fineness of 888.5 (Parker, 1974, p. 38).

Other small placer deposits were found in Colorado and Frying Pan Gulches in the Sugar Loaf district. Source rocks of the gold in this area are quartz veins in weathered and saprolitized Mesoproterozoic granite. No reliable information on gold production from these placers exists (Parker, 1974, p. 38–42).

Several other small placer deposits in Lake County produced minor amounts of gold. These are located in Flume Gulch south of Twin Lakes, Two Bit Gulch about 2 mi north of Twin Lakes, and along the Arkansas River (Parker, 1974).

Consrtuction Material Deposits

An abundance of high-quality Quaternary gravel (Qg on pl. 1) deposits line the Arkansas River Valley of Lake County. These deposits have been and are currently being exploited for construction material. The Colorado Division of Minerals and Geology lists four active sand and gravel operations in Lake County for 2006. One of these is used by the Climax Mine for the purposes of their mine and tailings pond reclamation and one is operated by Lake County. The remaining two operations are commercial sand and gravel quarries.

Older gravel deposits and older glacial drift deposits (Qgo and Qdo on pl. 1) are composed of angular to subangular boulder clasts, some of which are many feet in diameter, that are coated with mineral matter and more weathered than the Arkansas River Valley gravels. Hence the gravels of these older deposits will be less durable in any commercial use. The matrix is pebble to granule size material and clay (Capps, 1909). Glacial drift deposits (both Qd and Qdo on pl. 1) tend to include finer-grained material along with sand and gravel and may be less suitable for easily processed construction material.

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107°
106° 45'
106° 30'
106° 15'
106°
105° 45'
39° 30'
39° 15'
39°
38° 45'
EAGLE
SUMMIT
CLEAR CREEK
PITKIN
LAKE
PARK
CHAFFEE
GUNNISON
WHITE RIVER NATIONAL FOREST
PIKE NATIONAL FOREST
GUNNISON NATIONAL FOREST
SAN ISABEL NATIONAL FOREST
Eagle (6600)
Gypsum
Edwards
Avon
Minturn
Vail
West Vail
Silverthorne
Dillon
Frisco
Keystone
Montezuma
Breckenridge (9603)
Leadville (10,152)
Aspen (7907)
Snowmass Village
Woody Creek
Fairplay (9850)
Alma
Jefferson
Como
Garo
Hartsel
Granite
Twin Lakes
Balltown
Buena Vista (7955)
Johnson Village
Crested Butte (8909)
Mount Crested Butte
Gothic
Tincup
Redcliff
Gilman
Climax Mine
Malta
Stringtown
Thomasville
Norrie
Nast
Lenado
Ruby
Ashcroft
Vicksburg
Winfield
Pieplant
Fulford
Holy Cross City
Camp Hale (site)
Mount of the Holy Cross 14,005
Mount Massive 14,421
Mount Elbert 14,433 (Highest point in Colorado)
La Plata Peak 14,336
Mount Oxford 14,073
Mount Belford 14,073
Missouri Mt. 14,067
Huron Peak 14,003
Mount Harvard 14,420
Mount Columbia 14,073
Mount Yale 14,194
Mount Princeton 14,197
Mt Democrat 14,148
Mt Lincoln 14,286
Mt Cameron 14,238
Mt Bross 14,172
Quandary Peak 14,264
Mount Sherman 14,036
Torreys Peak 14,267
Grays Peak 14,270
North Maroon Peak 14,014
Pyramid Peak 14,018
Maroon Peak 14,156
Castle Peak 14,265
Maroon Bells
Elk Mountains
Sawatch Range
Mosquito Range
Tenmile Range
Gore Range
Holy Cross Wilderness
Hunter-Fryingpan Wilderness
Mount Massive Wilderness
Collegiate Peaks Wilderness
Buffalo Peaks Wilderness
Eagles Nest Wilderness
Snowmass Wilderness
Turquoise Lake (9869)
Twin Lakes
Antero Reservoir (8940)
Taylor Park Res (9330)
Dillon Reservoir
Independence Pass (12,093)
Hagerman Pass (11,925)
Tennessee Pass (10,424)
Fremont Pass (11,250)
Hoosier Pass (11,539)
Mosquito Pass (13,186)
Weston Pass (11,921)
Vail Pass (10,610)
Loveland Pass (11,990)
Cottonwood Pass (12,126)
Trout Creek Pass (9487)
South Park
CONTINENTAL DIVIDE
5 MILES
N
Map Explanation
County seat
County roads (paved)
County or forest road (unpaved)
Major ski area
Mining areas of Lake County
Historic mining town site
County line
Continental Divide
National Forest lands
BLM lands
Cartography by Larry M. Scott, Colorado Geological Survey, 2007.

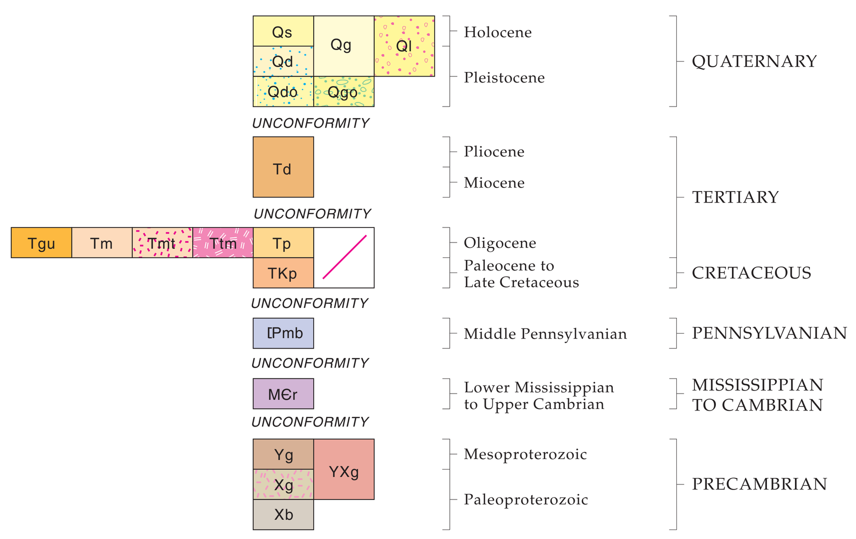
COLORADO GEOLOGICAL SURVEY
DIVISION OF MINERALS AND GEOLOGY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

Geologic Map of Lake County, Colorado

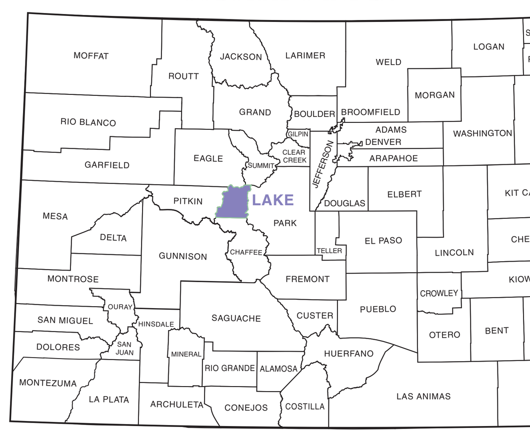
Compiled by James A. Cappa and Larry M. Scott

RESOURCE SERIES 42
GEOLOGIC MAP OF LAKE COUNTY
PLATE 1 OF 1
2007

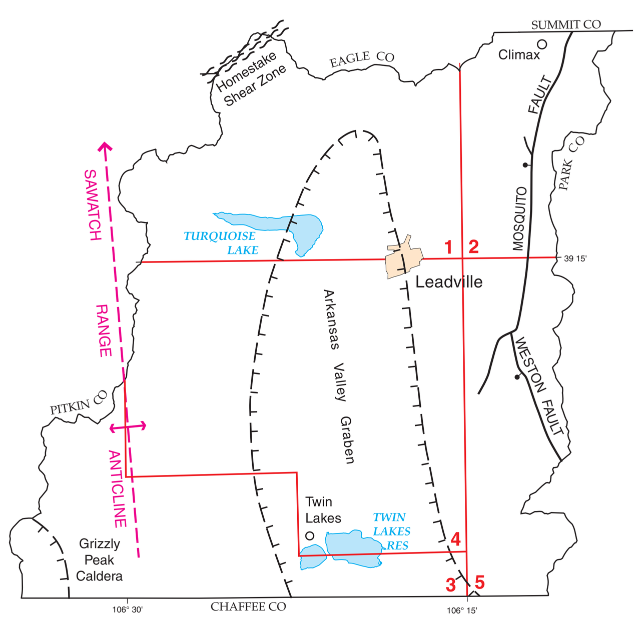
CORRELATION OF MAP UNITS



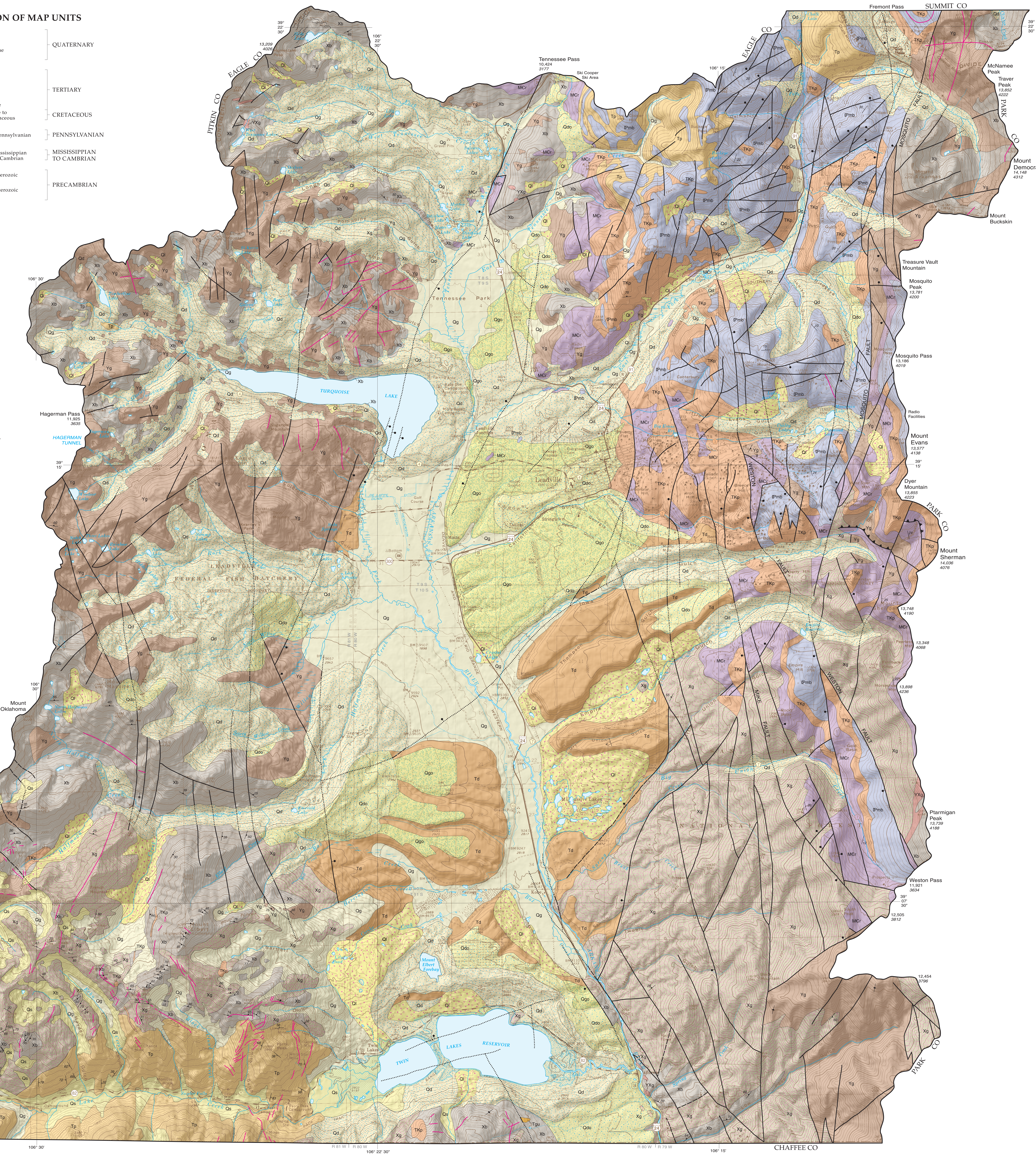
COLORADO INDEX



MAJOR GEOLOGIC FEATURES AND SOURCE MAPS OF GEOLOGIC DATA



1. Holy Cross 15-minute quadrangle, Tweto, 1974
2. Mount Lincoln 15-minute quadrangle, Tweto, 1974
3. Geologic map of the Collegiate Peaks Wilderness area and the Grizzly Peak Caldera, Sawatch Range, Colorado, Fridrich and others, 1998
4. Mount Elbert 15-minute quadrangle, Tweto and Reed, 1973
5. Geologic 15-minute quadrangle of 7.5-minute quadrangles—Fairplay West, Mount Sherman, South Peak, Jones Hill, Tweto, 1974



SCALE 1:50 000

1 .5 0 1 2 3 4 MILES

3000 0 3000 6000 9000 12000 15000 18000 21000 FEET

1 .5 0 1 2 3 4 5 KILOMETERS

CONTOUR INTERVAL 100 FEET

DESCRIPTION OF MAP UNITS

UNCONSOLIDATED DEPOSITS (HOLOCENE AND PLEISTOCENE)

Qs — **Surficial deposits**—Alluvium, alluvial fan deposits, talus, landslide deposits, colluvium, solifluction deposits, rock glaciers, and rock avalanches.

Ql — **Landslide debris**—Landslide, mass movement, talus, rock streams, and coarse fan deposits; glacial and post-glacial in age.

Qg — **Alluvium and gravel**—Holocene and Pleistocene alluvium in stream valleys and fans, terrace and glacial lake gravels. Locally grades into Ql.

Qd — **Glacial drift**—Deposits of Bull Lake age typically form prominent high lateral moraines and massive terminal moraines, some of which are extensively dissected. Moraines of first Pinedale glacial advance generally are nearly coextensive with Bull Lake moraines but smaller in volume; small moraines of the two later Pinedale advances are in canyon bottoms upstream from the older terminal moraines.

UNCONSOLIDATED DEPOSITS (PLEISTOCENE)

Qdo — **Older glacial drift**—Blanket-like bodies without morainal form; the upper surface is weathered to gumbo to as much as 50 ft at Leadville. Younger pre-Bull Lake till is mainly in nearly blanketlike remnants on canyon sides above the Bull Lake lateral moraines and the remnants have few or no boulders exposed at surface.

Qgo — **Older gravels and alluvium**—Terrace, outwash, and pediment gravels of pre-Bull Lake age.

BEDROCK UNITS

Td — **Dry Union Formation (Pliocene and Miocene)**—Predominatly brown, sandy and pebbly silt but contains lenses of gray to white sand, greenish-and pinkish-gray clay, brownish-gray gravels, and thin beds of light-colored volcanic ash. Silt is not cemented and incoherent enough to fracture into angular blocks; sand and gravel are somewhat cemented and gravel may be cemented to hard conglomerate. Thickness near Leadville is less than 1,000 ft but may be more than 3,000 ft south of Malta.

Tgu — **Grizzly Peak Tuff–upper rhyolite subunit (Oligocene)**—Phenocryst rich (20–40%), lithic lapilli, ash-flow tuff. Compositionally, a rhyolite tuff containing numerous wedges, sheets, and tongues of megabreccia. Equivalent units to the south of the map area have a potassium-argon age on biotite of 33.3 ± 1.0 Ma.

Tm — **Grizzly Peak Tuff–caldera collapse breccia–megabreccia (Oligocene)**—Extremely coarse, rock avalanche breccia with little or no matrix composed primarily of clasts of Proterozoic igneous and metamorphic rocks. Clast size is commonly several 10s of feet long.

Tmt — **Grizzly Peak Tuff–caldera collapse breccia–clast supported tuff megabreccia (Oligocene]**—Extremely coarse, rock avalanche breccia with clast sizes less than about 30 ft. Large masses of nonwelded to poorly welded tuff matrix surround the breccia clasts.

Ttm — **Grizzly Peak Tuff–caldera collapse breccia–matrix supported tuff megabreccia (Oligocene)**—Extremely coarse, rock avalanche breccia with clast sizes less than about 30 ft. Clasts are well rounded and matrix supported. Matrix is poorly welded, lithic rich, low silica rhyolite of the Grizzly Peak Tuff.

Tp — **Middle Tertiary intrusive rocks (Eocene to Oligocene; 26–44 Ma)**—Intrusive porphyries, mainly quartz latite to rhyolite, granodiorite and quartz monzonite in stocks, dikes, and sills.

TKp — **Laramide intrusive rocks (Lower Tertiary and Upper Cretaceous)**—Intrusive porphyries-mainly granodiorite, quartz monzonite, and quartz diorite in stocks, dikes, and sills.

IPmb — **Minturn and Belden Formations (Middle Pennsylvanian)**—The Minturn Formation includes eight or nine members and is composed of arkosic grit, conglomerate, shale and sandstone in lenticular bodies, and interclated beds and reefs of dolomite and limestone; predominantly gray but maroon near base and brick red in middle. Thickness to 1,000 ft north of Leadville, but thickens to more than 5,000 ft north of Lake County. The Belden Formation is black shale with thin-bedded dark limestone and sandstone; it lies on an erosional karst surface of the Leadville Dolomite where it may be as much as 50 ft thick.

MЄr — **Leadville Dolostone (Lower Mississippian); Chaffee Group with Dyer Formation, Parting Formation, and Gilman Sandstone (Upper Devonian); Manitou Formation (Ordovician); Dotsero Formation (Upper Cambrian); and Sawatch Quartzite (Upper Cambrian)**—Aggregate thickness may be as much as 700 ft. The Leadville Dolostone is typified by karstic erosion and it is the principal host rock of ore deposits at Leadville and neighboring lead-zinc-silver districts. The Dyer Formation of the Chaffee Group is also an important host rock of ore deposits at Leadville and it along with the Leadville Dolostone are the “blue limestone” of old usage.

Yg — **St. Kevin Granite (Mesoproterozoic)**—Approximately 1,400 Ma age group [Y]- Mixtures of fine and even grained granite facies, fine-to medium-grained granodiorite, and coarse-grained, in homogeneous trachyoid-hybrid. Metalamprophyre occurs in dikes. The St. Kevin Granite forms a batholith about 25 by 12 mi in the Sawatch Range but only the northeast part of the batholith is in the west-central part of Lake County.

YXg — **Granite and dioritic rocks of Holy Cross City and unclassified granites (Paleoproterozoic to Mesoproterozoic)**—Possibly related to group (X), suite of granitic and dioritic rocks in layers generally concordant with enclosing gneisses and generally pink, textured, unclassified granite near shear zones.

Xg — **Granite of Cross Creek (Paleoproterozoic)**—Approximately 1,700 Ma age group (X), medium-to coarse-grained irregularly porphyritic slightly to strongly foliated granodiorite, quartz monzonite, and related dioritic dikes and hybrid border facies. The Rb–Sr age of granite is about 1,700 Ma.

Xb — **Biotite gneiss and schist (Paleoproterozoic)**—Approximately 1,700 Ma age group (X), biotite-quartz-plagioclase gneiss and schist; sillimanite, garnet, and cordierite is present locally. The gneiss and schist are interpreted as largely meta-sedimentary in origin.

MAP SYMBOLS

Contact

Fault—Dashed where approximately located; dotted where concealed; ball and bar on downthrown side

Thrust fault—Dotted where concealed; sawteeth on upper plate

9 **Strike and dip of inclined beds**—Angle of dip shown in degrees

Strike and dip of tectonic foliation

7 **Inclined**—Angle of dip shown in degrees

Vertical

Strike and dip of igneous foliation

22 **Inclined**—Angle of dip shown in degrees

Tertiary dike or sill

Precambrian shear zone

Bill Ritter Jr., Governor,
State of Colorado

COLORADO DEPARTMENT OF NATURAL RESOURCES

Harris D. Sherman, Executive Director,
Department of Natural Resources

COLORADO GEOLOGICAL SURVEY

Vince Matthews, State Geologist
and Division Director

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Geology and Ore Deposits of the Leadville Mining District, Colorado (Emmons, Irving, and Loughlin, 1927)

CHAPTER 8

IRON MINERALS

In the Sulphide Zone

MAGNETITE

Magnetite (Fe_3O_4) occurs mostly in large, irregular masses as much as 300 feet in length and 80 feet in both width and thickness. [(See plate 68 (Chapter 13) and sections on plate 28 (extra figures and plates)] These masses are dark gray to black and fine to medium grained. Single grains are 0.1 to 1 millimeter in diameter. The massive magnetite in places is spotted with manganosiderite, and where this mineral has been dissolved out, the resulting cavities are lined with magnetite crystals. The crystals of magnetite are best developed where the manganosiderite is relatively abundant. Many of the crystals inclose one or more zones of manganosiderite near their margins (**Figure 46**).

Around the margins of the large masses, magnetite is found as fine bluish-black streaks along bedding planes and as disseminated grains, particularly in shaly limestone (**Plate 47, *C*,** and **Figure 47**). A specimen of massive magnetite tested by W.F. Hillebrand in the chemical laboratory of the United States Geological Survey was found to be entirely free from titanium, chromium, aluminum, magnesium, phosphorus, and zinc; but considerable phosphorus is recorded in the analysis on page 2, Chapter 9.

Microscopic magnetite has also been found in the Tucson mine partly replacing manganosiderite, whose color is correspondingly darkened. This magnetite is developed along the cleavage planes of manganosiderite grains. Whether this association is to be interpreted as indicating an approach to contact-metamorphic conditions or as a later alteration of manganosiderite is uncertain.

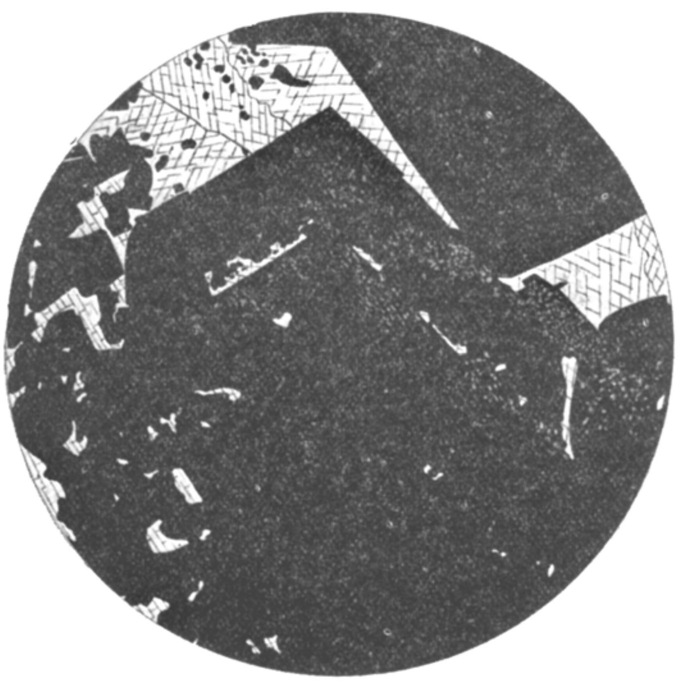

Figure 46. Thin section of magnetite with interstitial manganosiderite and zonal inclusions of the same mineral. Zonal aggregates of pyrite are also present . Magnified about 50 diameters.

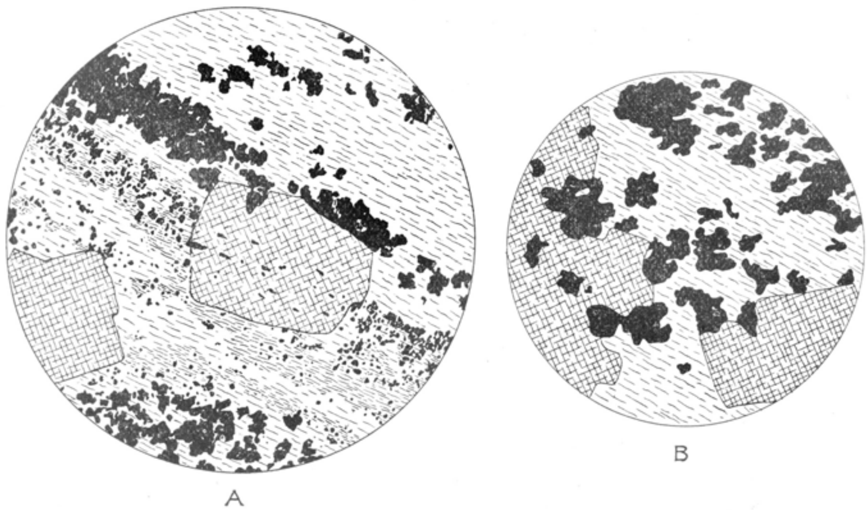

Figure 47. Photomicrographs of thin sections of lean magnetite ore from seventh level of Ibex mine.

SPECULARITE (HEMATITE)

Although hematite (Fe_2O_3) occurs abundantly in all the ores of the Leadville district, it is much less abundant that the hydrated oxides. In the high-temperature ores, the dark-gray crystalline variety, specularite is occasionally found, although it is subordinate in quantity to the magnetite. Specularite is found in the contact-metamorphic ores of the Ibex mine, but it is not usually present in those portions of the ore, which contain appreciable amounts of magnetite. In the siliceous jasperoid, which is closely associated with the magnetite ore and which has usually a characteristic vuggy or cavernous appearance, numerous minute scales of specularite set at all angles to one another are observable. As this mineral is so characteristic of high-temperature deposits in general, the fact that so little of it occurs in the Ibex, Breece Iron, and Comstock mines is somewhat surprising. Specularite replacing dolomite or manganosiderite (?) has been found in the Wolftone mine. (**Plate 46, *B***)

Besides the variety specularite, of hypogene origin, hematite is present in red earthy to compact masses of supergene origin. The red variety is found in great quantity, however, in the outcrops of iron ore at the Breece Iron mine, where it forms a dull, dark-red, compact, tough material, which has evidently resulted from the oxidation of magnetite.

PYRITE

Pyrite (FeS_2) is the most abundant of the primary ore minerals in the Leadville district. It is locally prominent in contact-metamorphic deposits and is abundant in the veins and blanket ore bodies. It also impregnates nearly all the porphyry masses and other country rocks. In most of the ores it is the predominating mineral, and in some portions of the blanket ore bodies and veins it is the only sulphide present. More commonly, however, it is mingled with the other sulphides – sphalerite, galena, and chalcopyrite – and may be totally absent from shoots of high-grade zinc blende and also from local masses of practically pure galena. In the porphyries it is generally associated with sericite, which forms microscopic fringes around pyrite grains. In all these modes of occurrence and throughout the district, the pyrite is characteristically associated with quartz.

Pyrite occurs in large masses of grains without crystal outline, but isolated grains and those that line cavities generally show distinct and typical crystal form. In the large masses the grains range in size from those of such extreme fineness that the mass has a velvety appearance up to grains half an inch in diameter. Cavities in these masses are lined with well-shaped pyrite crystals, which vary in size with the coarseness of grain of the mass. Some of the well-formed crystals are 12-faced (pentagonal dodecahedrons), and some are cubes. All have characteristic striated faces. The larger crystals attain sizes of 1½ inches and more, and the largest found are cubes measuring 4 to 5 inches on an edge. The large well-formed cubes are found mostly in shaly strata and in the “Weber grits’ of the Ibex mine and vicinity. The largest of all were found in the South Ibex stockwork. A striking feature of the crystals of this ore body was the presence of parallel ridges, composed of smaller and smaller superposed layers with rounded tapering ends, which resembled Gothic windows in outline. These ridges are unusually large and incompletely developed examples of the striations that are characteristic of pyrite crystals. Some well-formed pyrite crystals are surrounded by finer granular aggregates of the same mineral, formed at a later stage of deposition.

In the Wolftone mine a considerable quantity of pyrite was found with radiation structure suggestive of marcasite, but chemical tests proved it to be pyrite. The surfaces of many of these radiating pyrite crystals are coated with pyrite crystals of more ordinary form. The radiating aggregates are irregularly mingled with masses of galena and zinc blende and in places are cut by veinlets of these minerals, particularly galena.

Pyrite unrelated to ore deposition may be present as fine to microscopic crystals in the different country rocks, but none has been positively identified. The bluish color of some of the unaltered shale and limestone may be due in part to inclusions of these minute crystals within the translucent mineral grains of the rocks.

ARSENOPYRITE

Arsenopyrite ($FeAsS$ or $FeS_2.FeAs_2$) or mispickel, the silver-white arsenical pyrite, has been reported from the Moyer mine and was also discovered in the Tucson mine, where it formed a lens 5 feet long, 3 feet wide, and 1 foot thick, parallel with the pitch of the ore shoots in the Tucson fault. Well-developed crystals of it were orthorhombic prisms terminated by basal plane but with no pyramid faces. So far as known, these are the only occurrences of arsenopyrite discovered in the Leadville district.

SIDERITE AND MANGANOSIDERITE

Siderite ($FeCO_3$), though abundant at Leadville, was not recognized for a long time, although recognized in several other districts in neighboring parts of the State. It was first adequately described by Philip Argall[12] in 1914.

Two varieties of siderite accompany the sulphide ores. One is relatively pure iron carbonate, which occurs in flat rhombs or disk-like crystals of light to dark-brown color on the walls of cavities; the other with a high content of manganese, which forms large granular masses usually around the margins of sulphide ore bodies. The crystals of the first variety range from a sixteenth of an inch or less up to half an inch in diameter. The larger sizes are unusual at Leadville, though common in the similar sulphide ores at Red Cliff (Gilman), 28 miles to the north (**Plate 47, *D***). Some of the larger crystals have curved edges, and in this respect resemble dolomite crystals. The conspicuous crystals of siderite are perched on edge upon the sulphide crystals, but close inspection and microscopic study show that some of them are intergrown with galena, the latest of the sulphides to form, and that some interstitial siderite is found among the massive mixed sulphides. It evidently crystallized later than all the sulphides except galena, and continued to crystallize after the deposition of galena had ceased.

Argall showed that siderite accompanying sulphide ores (“vein siderite” in contrast to sedimentary siderite or spathic iron ore) contains considerable manganese. He cited no analyses of the cavity-coating siderite from Leadville, however, presumably because crystals large enough for analysis were difficult to obtain.

The massive variety is by far the more abundant in the Leadville district. Its content of manganese, though variable, is high enough to classify it as manganosiderite [$(Fe, Mn, Mg)\ CO_3$]. It

[12] Argall, Philip, Siderite and sulphides in Leadville ore deposits: Min. and Sci. Press, July 11 and 25, 1914.

occurs in abundance in the Downtown, Fryer Hill, Carbonate Hill, and Iron Hill areas and is present in the Ibex mine on Breece Hill and other Leadville mines, either intimately mingled with sulphides or replacing the original limestone or dolomite, forming an envelope or casing of variable width around the sulphide bodies. The replacement has usually been so complete that all the original rock structures are preserved, and the mass of manganosiderite so closely resembles the unaltered White limestone that the boundary between the two is not easily found without systematic quantitative determinations of iron and manganese.

The manganosiderite is usually light gray, but much of it shows a very slight yellowish and some a pinkish tinge. It is coarsest grained where mingled with the sulphides, and single grains there range from 1 millimeter to more than 5 millimeters in diameter. The larger grains show a marked rhombohedral cleavage and their faces are slightly curved. In the envelopes that surround ore bodies and in the isolated masses, within ore bodies, of what at first appear to be residual masses of limestone it occurs as fine-grained aggregates of irregular grains from 0.05 to 1 millimeter in size. These aggregates are interrupted by thin layers of greenish-gray shale that mark the original bedding of the limestone (**Plate 48, *D***).

Determinations of iron and manganese made by Argall are here quoted with his remarks:

In various places in the Tucson mine the beds of siderite are of such wide extent as to suggest sedimentary deposition. Observing a drift closely following the strike of the beds in such a locality, samples were taken at intervals of 20 feet along one particular bed and assayed with the following result:

Sample	From fissure (feet)	Iron (per cent)	Manganese (per cent)	CaO (per cent)	Insoluble (per cent)
A	40	24.3	16.2	1.8	16.6
B	60	5.2	3.1	19.6	25.2
C	80	3.4	1.2	24.1	13.2

A second place was chosen where ore was mined along a “flat” in the footwall country of a fissure where, on reaching the limits of the pay ore, a crosscut had been extended through the siderite into the unreplaced limestone following the bedding. Samples here gave the following results:

Sample	Feet	Iron (per cent)	Manganese (per cent)	CaO (per cent)	Insoluble (per cent)
A	10 from ore	26.6	18.9	0.6	29.6
B	20 from ore	19.4	21.0	0.7	19.2
C	30 from ore	16.7	20.1	1.2	25.0
D	40 from face of crosscut, top	4.2	3.2	19.6	20.0
E	40 from ore, floor of crosscut	3.6	2.8	23.0	18.0

These samples conclusively showed that practically complete siderite replacement of the limestone extended 30 feet beyond the termination of the zinc-lead ore [**Figure 48**], extending as a “flat” from the fissure, and then gradually faded out in 10 feet, as shown in samples D and E. In fact, the change in the crosscut is so gradual and imperceptible that no person with the unaided eye could determine in the mine the limestone from the siderite. *** Consequently the siderite has, perhaps, been mistaken for White limestone, both by the miners and by the visiting scientists.

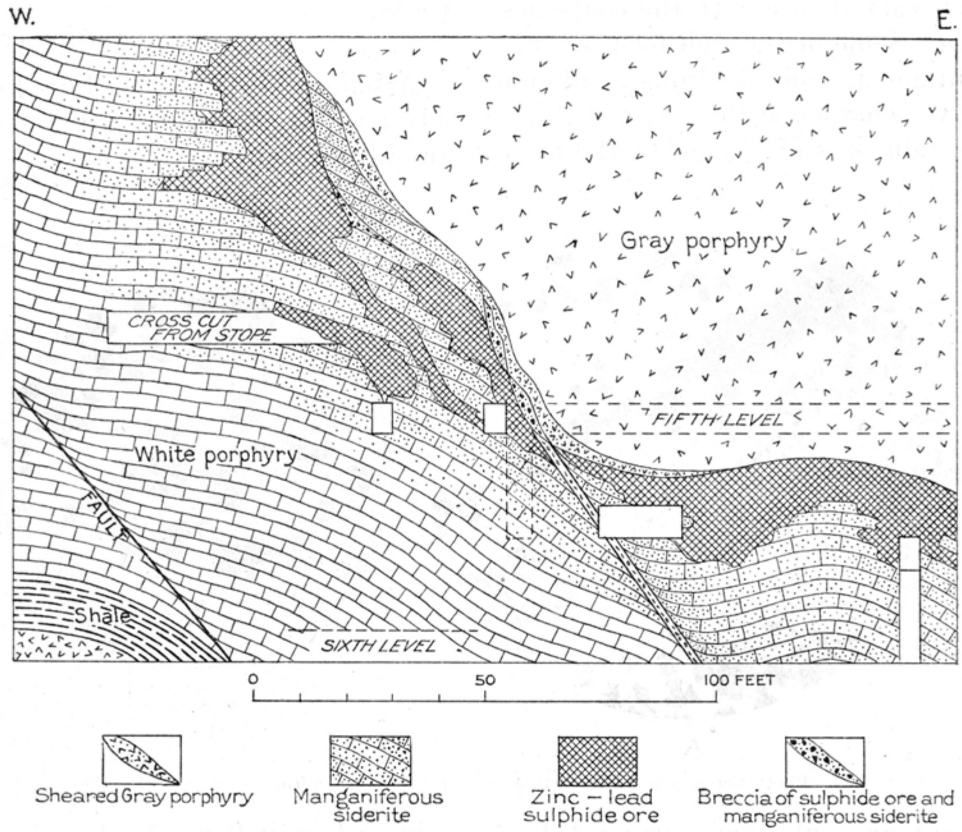

Figure 48. Cross section showing relations of manganosiderite to sulphide ore and limestone, fifth level, Tucson mine. (After Phillip Argall)

Plate 47, *A*, illustrates the massive manganosiderite. Under the microscope the mineral closely resembles dolomite in color, cleavage, and lack of distinct crystal boundaries but has stronger absorption and higher index of refraction. It is usually clear and contains no inclusions, although it is cut by many later veinlets of quartz and sericite with pyrite, sphalerite, and galena and is likewise replaced by crystals of these minerals, single or in clusters. Where vugs are present, however, they are lined with crystals of manganosiderite (**Plate 48, *A***) that grew later than the bulk of the sulphides and therefore correspond to the siderite crystals already described. It is impossible to separate these small drusy crystals sufficiently from the massive mineral to determine any difference in chemical composition, and their indices of refraction are too nearly equal to indicate such a difference. It appears on the whole that manganosiderite crystallized throughout a great part of the period of ore deposition and through a considerable range of high to moderate temperature. It apparently acted as an advance guard of the sulphides, replacing the limestone first, only to be replaced itself by the sulphides (**Plate 48, *C***) and carried into the limestone around them, where it was again deposited by replacement.

Argall[13], from his study of the manganosiderite masses in the Tucson mine, concluded that they were in part of contact-metamorphic origin and in part introduced through deep-seated fissures. The evidence in favor of contact-metamorphic origin consisted of the position of the manganosiderite along the contact of a large irregular sheet of Gray porphyry (Figure 48) and its association with comparatively small aggregates of magnetite and specularite. Argall also refers to the association of chloritic material and suggests that it may have been derived from contact-metamorphic pyroxene; but the chloritic material may represent remnants of original shaly matter in White limestone. The close association with magnetite (page 1, Figure 46) and specularite points to deposition in high temperature, but the scarcity or absence of

[13] Argall, op. Cit., p.32

associated silicates and the occurrence of masses of manganosiderite away from intrusive contacts (for example, at Red Cliff where no intrusive rocks have been found associated with the ores) indicate that its temperature of deposition may extend from the lower end of the contact-metamorphic (pyrometasomatic) range well through that of the intermediate (mesothermal) vein zone.

A complete chemical analysis of massive manganosiderite from the Tucson mine is given in the table below. Beside it is the corresponding calculated mineral composition in column 1; also the calculated mineral composition of another massive specimen from the Tucson mine and a sample of crystals from Gilman (Red Cliff), Colo. Partial analyses quoted from Philip Argall's paper are given in the second table.

Analyses and mineral composition of manganosiderite

1						
Chemical analysis		Calculated mineral composition				
	Percent		Calculated from analysis	Carbonates recalculated to 100%	2	3
SiO_2	10.08	Quartz	6.48	---	[a]4.22	0.9
Al_2O_3	3.16	Sericite:				
		Muscovite	0.80	---	---	---
		Paragonite	6.88	---	---	---
Fe_2O_3	None	$FeCO_3$	43.15	51.49	68.22	56.5
FeO	26.80	$MnCO_3$	31.97	38.15	20.53	21.3
MgO	4.04	$MgCO_3$	8.48	10.12	7.00	13.4
CaO	0.08	$CaCO_3$	0.20	0.24	0.16	0.7
Na_2O	0.57	Pyrite	0.84	---	---	0.5
K_2O	0.08	?Water+[b]	0.52	---	---	---
H_2O	0.22	Water	0.22	---	---	---
H_2O+	0.89	?P_2O_5[c]	0.47	---	---	---
TiO_2	Trace		100.01	100.00	100.13	93.3
CO_2	33.14					
P_2O_5?	0.47					
FeS_2	0.84					
MnO	19.71					
BaO	Trace					
	100.08					

a Insoluble.
b Part may be in sericite, in excess of the muscovite-aragonite formula.
c If P_2O_5 is combined with Fe, Mg, Mn, or Ca there will be a corresponding excess of CO_2.

1. Manganosiderite replacing White limestone 4 feet beneath sulphide ore body, seventh level, Tucson mine. Analyst, J.G. Fairchild, U.S. Geol. Survey.
2. Fine-grained manganosiderite from "horse" between two sulphide bodies in Blue limestone, third level, Tucson mine, 250 feet N. 10º E. from shaft. Average of two analyses. The specimen from which this was taken was intersected by many seams of sulphide, and scattered grains of sulphide were likewise abundant in it. These were all carefully removed before the analysis was made, so that practically clean material was available. Four grams of pure material was thus obtained, which was dried at 100º C for one hour. Analyst, Dr. W.M. Bradley, Sheffield Scientific School, Yale University.
3. Fresh crystals from sulphide zone at Gilman (Red Cliff), Colo., collected by J.A. Ettlinger. Mineral composition calculated from a commercial analysis by J.W. Hawthorne, chemist of the Empire Zinc Co.

Partial analyses of manganosiderite[a]

	1	2	8	9	10	11	12	13	14
Insoluble	19.60	21.20	19.60	21.20	19.20	4.40	2.00	18.10	28.40
Iron[b]	23.07	21.80	13.00	21.80	19.40	25.60	28.10	29.70	17.20
Manganese	20.70	21.10	20.70	21.10	21.00	12.60	9.90	5.40	11.70
MgO	1.40	2.40	---	---	---	---	---	---	---
CaO	0.30	0.40	0.47	0.40	0.70	---	---	---	---
Lead	1.50	0.60	---	---	---	---	---	---	---
Zinc	0.30	0.30	---	---	---	---	---	---	---
Iron carbonate[b]	47.86	45.23	47.72	45.23	40.25	53.11	58.30	61.62	45.68
Manganese carbonate	43.36	44.20	43.36	44.20	43.99	26.40	20.74	11.31	24.51
Magnesium carbonate	2.94	5.04	---	---	---	---	---	---	---
Calcium carbonate	0.54	0.71	0.84	0.71	1.25	---	---	---	---

a Quoted from Argall, Philip, Siderite and sulphides in Leadville ore deposits: Min. and Sci. Press, July 11 and 25, 1914.
b Includes a small quantity of iron present as sulphide and oxide.
Nos. 1 and 2 each contained 0.04 ounce of gold to the tone, and No. 1, 0.08 of silver.

From these analyses it appears that the iron is generally present in greatest amount and that magnesia is a persistent minor constituent. The small amount of calcite may be due wholly to infiltrated calcite or to minute quantities of unreplaced rock and need not be considered a part of the mineral. If the carbonates are regarded as isomorphous mixtures of siderite, rhodochrosite, and magnesite molecules the formulas for the two are relatively complete analysis may be written as follows:

Analysis 1. $4FeCO_3.3MnCO_3.MgCO_3$
Analysis 2. $7FeCO_3.2MnCO_3.MgCO_3$

Microscopic examination of the sample represented by analysis 1, at the top of this page, revealed quartz and a small quantity of finely divided sericite and pyrite in veinlets and irregular patches in the manganosiderite, and recalculation of the analysis agrees very closely with the microscopic evidence. The predominance of the paragonite (soda mica) molecule over the muscovite (potash mica) molecule in the sericite is particularly noteworthy and raises a question as to the relative amounts of these two molecules in sericite throughout the district. The excess water of composition (H_2O) is more likely to be in the sericite than in any other mineral. The P_2O_5 was neglected in the calculation, as no mineral of which it is a constituent could be identified.

The sulphide ores shipped from the district to smelters are very low in manganese carbonate and give no adequate idea of the large amounts of this mineral present in the masses of low-grade ore and practically barren manganosiderite that border the high-grade shoots and are occasionally found within them.

In the Oxidized Zone

MELANTERITE

The hydrous ferrous sulphate, melanterite ($FeSO_4$+$7H_2O$), is a very common mineral in the Leadville mines but has been deposited by surface waters that have been active since the development of the workings has been carried on. It incrusts the walls of drifts and also forms stalactites and stalagmites of considerable size. When fresh, the mineral is green and transparent, but on exposure to air and light, it gradually turns to a white chalky powder. It is generally found well within the sulphide zone, and in the oxidized ores its place is taken by ferric sulphates and oxides.

VIVIANITE

Vivianite ($Fe_3P_2O_8+8H_2O$) occurs in small quantity in all the oxidized ores of the district. It is not uniformly disseminated, however, but occurs as indigo-blue to bluish-green flat prismatic crystals, some small and some very large. The prism faces are generally striated. It is found most abundantly in the oxidized portions of the magnetite-pyrite ores of the contact-metamorphic class. Here it forms solid aggregates, single crystals, crystalline druses lining cavities, or masses embedded in loose infiltrated clay.

BROWN IRON OXIDE

Brown to yellowish earthy hydrous oxides, generally referred to as limonite and goethite, accompanied by the red hydrous oxide, turgite, form a large part of the oxidized ores of the district and also appear as stains and coatings on rocks and siliceous ores. They have resulted chiefly from the decomposition of pyrite and ferruginous zinc blende, to a somewhat similar degree from the decomposition of siderite, and to a slight degree from the decomposition of magnetite. They also result from the alteration of the hornblende and biotite in weathered eruptive rocks, which are correspondingly stained brown.

These iron oxides are mingled with manganese oxides in all proportions. As the proportion of manganese increases, the brown or reddish-brown color changes to a very dark brown, and finally to black. These oxides are also mingled with kaolin, producing the light-yellowish ocherous varieties, which are not readily distinguished from jarosite and other basic ferric sulphates.

One of the commoner varieties of brown iron oxide in the district is commonly known as "liver-colored rock." This is a dense flinty material of yellowish-brown color, having a conchoidal fracture and containing a large proportion of admixed silica. Much of it is sprinkled through with irregular blotches and particles of massive cerusite, and is often spoken of as low-grade hard carbonate ore. The earthy material and the "liver-colored rock" are the most abundant varieties of brown iron oxide in the district. None of the botryoidal and fibrous varieties have come to the writers' attention.

JAROSITE AND BASIC FERRIC SULPHATES

Ricketts,[14] Emmons,[15] and Hillebrand[16] have described the occurrence of abundant basic sulphates of iron in the oxidized ores. Ricketts described basic ferric sulphate as forming a bed or layer lying beneath the richer bodies of lead carbonate in Carbonate Hill. The material is an ochery yellow, rather loose and earthy substance, resembling dry clay in some places and light-colored limonite in others. It contained considerable though varying quantities of lead sulphate, evidently in the form of plumbojarosite, which had not then been recognized as a distinct mineral species.

Three analyses of this material quoted from Emmons and one quoted from Ricketts are given below:

[14] Ricketts, L.D., The ores of Leadville, p. 36
[15] Emmons, S.F., U.S. Geol. Survey Mon. 12, p.549, 1886
[16] Hillebrand, W.F., idem., p.607.

	1 Maid of Erin	2 Morning Star	3 Lower Waterloo	4
SiO_2	None	0.30	0.36	Trace
Fe_2O_3	46.70	42.98	44.40	40.22
Al_2O_3	None	0.20	0.23	1.11
CaO	0.06	0.64	None	---
MgO	0.06	None	None	---
K_2O	5.33	6.31	0.15	---
Na_2O	1.68	0.83	0.37	---
H_2O	10.54	10.12	8.99	11.20
PbO	4.27	8.27	19.50	29.98
Bi_2O_3	0.08	None	None	---
As_2O_5	0.46	0.42	0.39	---
P_2O_5	0.08	1.58	0.11	---
SO_3	30.53	27.81	25.07	18.02
Cl	0.02	0.26	0.04	0.27
Ag	0.0048	0.0036	0.075	
Au	Trace	None	None	---
	99.8148	99.7236	99.685	100.80

1-3. Emmons, S.F., U.S. Geol. Survey Mon. 12 , p. 550, 1886
4. Ricketts, L.D., The ores of Leadville, p. 36, 1883. Exact locality not specified; Waterloo, Morning Star, or Evening Star mine.

The first two analyses represent mainly mixtures of jarosite ($K_2O.3Fe_2O_3.4SO_3.6H_2O$) and a basic ferric sulphate, with minor quantities of plumbojarosite, pyromorphite, and other compounds; the third and fourth represent mainly plumbojarosite.

MANGANESE MINERALS

In the Sulphide Zone

Manganese in the ores of Leadville is present mainly as manganosiderite, described on pages 3–7. A few occurrences of rhodochrosite (manganese carbonate) and one or two doubtful occurrences of rhodonite (manganese silicate) have also been reported. The sulphide, alabandite, has not been found in the Leadville district, although reported by G.M. Butler[17] from the Alma district, on the east slope of the Mosquito Range. Before the casings of manganosiderite around the sulphide ores were recognized, the opinion had been held by several that the manganese in the extensive bodies of "black iron" or oxidized iron-manganese ore was derived in part at least from alabandite; but alabandite is rarely found in considerable quantity. The only evidence of the existence of manganese as sulphide is presented in the three chemical analyses of ferruginous zinc blende (marmatite) quoted on page 11. In these analyses, manganese isomorphous with zinc and iron ranges from 1.3 to 3.7 percent.

In the Oxidized Zone

In the oxidized ore of Leadville manganese occurs abundantly as oxides and hydrated oxides. In much of this material it is difficult if not impossible to determine the exact mineral species to which the earthy manganese oxides belong. Pyrolusite, though not seen by the writers, was detected by Emmons in his original investigation, but psilomelane and wad are doubtless the oxides present in greater abundance.

[17] Colo. Geol. Survey Bull. 3, p. 240, 1912.

The difference between the last two minerals is chiefly in the degree of hydration, and it is probable that they occur together abundantly in the oxidized manganese ores. Pyrolusite and probably manganite are also present. Away from the ore bodies black oxide of manganese commonly forms dendritic or fernlike growths on fracture surfaces. Manganese is also present in hetaerolite and chalcophanite, which are grouped among the zinc minerals of the oxidized zone.

PSILOMELANE AND WAD

Stalactitic and mammillary forms of black to dark steel-gray psilomelane (H_4MnO_5, generally impure, hence composition doubtful) are often found but are much less common than the black, impure, earthy variety of material which is commonly known as wad. This material occurs mixed in all proportions with the iron oxides. It frequently contains admixed chalcophanite where the ore carries appreciable amounts of zinc.

PYROLUSITE

The black dioxide of manganese, pyrolusite (MnO_2), occurs mixed in all proportions with the iron oxides and with the other oxidized minerals. It is so intimately mingled with the psilomelane that the two can rarely be distinguished from one another. It is very abundant in the mines of the Downtown district and Carbonate Hill but is less prominent in the more siliceous ores of Breece Hill and vicinity. Crystals of pyrolusite were identified by Emmons, and most of the manganese ores were assumed by him and also by Ricketts to be in the form of the dioxide. Later investigations by G.M. Butler and J.D. Irving, however, showed that much psilomelane is present.

ZINC MINERALS

In the Sulphide Zone

SPHALERITE (ZINC BLENDE)

With the exception of pyrite, sphalerite or zinc blende (ZnS) is the most abundant mineral in the Leadville ores. It constitutes a large percentage of many of the blanket ore bodies and the lodes but occurs very sparsely in magnetite-pyrite contact-metamorphic ores.

The sphalerite is in several places segregated into certain portions of an ore body and constitutes a high-grade zinc ore, but more commonly it is intimately mixed with pyrite and galena. The most abundant variety of zinc blende is granular and massive, with a dark-brown to nearly black color and a resinous luster. The grains are without crystal boundaries except where they project into cavities. In the finest-grained material they are less than 0.01 millimeter in diameter and from that they range up to 2 millimeters. The coarser-grained masses contain numerous vugs lined with sphalerite crystals, most of which are twinned. In some large vugs the crystals attain diameters of more than half an inch. These large crystals were common in the Moyer, Tucson, A.Y., Minnie, and adjoining mines of southern Iron Hill.

The zinc blende minded in the Leadville district is not pure but it is the dark-brown to nearly black variety marmatite, which, as shown by the chemical analyses below, contains a high percentage of iron. This iron content has made magnetic concentration of the blende possible. Three analyses by Warwick are quoted on page 11.[18]

[18] Bain, H.F., U.S. Geol. Survey Mineral Resources, 1905, p.384, 1906

Chemical analyses of ferruginous zinc blende (marmatite)

	Adams	Col. Sellers	Yak
Zinc[a]	52.8	47.6	45.1
Sulphur	34.7	35.7	36.4
Iron[b]	12.1	14.8	17.8
Silica	0.2	0.4	0.2
	99.8	98.5	99.5

a Includes cadmium which varied from 0.1 to 0.35 percent
b Includes manganese which varied from 1.3 to 3.7 percent.

Allen and Crenshaw, [19] in their discussion of the physical chemistry of sphalerite and wurtzite, have analyzed several varieties of sphalerite ranging in content of iron from 0.15 to 17.06 percent.

Recalculations of the analyses usually show that the iron is present not as mechanically mixed and finely divided pyrite but as FeS, presumably in some form of combination with the ZnS. Some samples of sphalerite contain as high as 20 percent of iron.

In the Oxidized Zone

SMITHSONITE

Smithsonite ($ZnCO_3$) is the most abundant of all the oxidized zinc minerals and forms large blanket bodies, replacing the limestone and also the manganosiderite of the primary mineralization. The bulk of the zinc obtained from oxidized ores is derived from smithsonite. Two varieties are especially common at Leadville. One is a dense, compact gray to brown massive rock with sparsely scattered irregular cavities (**Plates 49, *D*; 50, *C*, *D***). It is impure and contains varying amounts of the isomorphous iron, magnesia, and manganese carbonate molecules. It strongly resembles slightly altered limestone and was for many years mistaken for limestone. The other is a fine drusy variety, mostly light brown but in part also colorless to white, or occasionally pale green, generally found lining cavities in the dense variety (**Plates 50, *A*, *B***). This drusy variety at several places forms thin layers alternating with a black mineral (hetaerolite?) and locally with ferric oxide. Botryoidal and fibrous varieties are comparatively rare. Although pure smithsonite should contain 52 percent of metallic zinc, the presence of impurities considerably reduces the zinc content so that the carbonate ore mined rarely contains more than 40 percent and ranges down to 15 percent.

A third variety, comparatively uncommon at Leadville, has a cellular structure (**Plates 51, *F***). It occurred on the second level of the Wolftone mine and formed an extensive layer from 18 inches to 3 feet thick immediately beneath a mass of sulphides 10 feet thick, which was in turn overlain by a roof of porphyry. This structure is caused by the intersection of numerous thin plates of crystalline smithsonite and is believed to have been developed by deposition in shattered limestone, the intervening fragments of which were subsequently dissolved.

HYDROZINCITE

Hydrozincite, a basic zinc carbonate ($ZnCO_3.ZnO_2H_2$), has been reported to occur here and there as a dull-lustered white, soft, earthy alteration product of smithsonite.[20] In the workings accessible to Loughlin, however, the only earthy white material found in the oxidized zinc ores proved, on testing, to be zinciferous clay described on pages 15-19.

[19] Allen, E.T. and Crenshaw, J.L., Am. Jour, Sci., 4th ser., vol. 34 , p. 347, 1912
[20] Butler, G.M., Some recent developments at Leadville, second paper, The oxidized zinc ores: Econ. Geology, vol. 8, p. 8, 1913; reprinted in Colorado School of Mines Quart., vol. 8, April, 1913.

AURICHALCITE

Aurichalcite is a basic carbonate of zinc and copper ($2(Zn,Cu)CO_3.3(Zn,Cu)(OH)_2$) whose zinc content ranges, according to different analyses, from 50 to 59 percent and whose copper content ranges from 15 to 22 percent. The pure mineral, according to Penfield,[21] contains 53 to 54.4 percent of zinc and 20 to 21.2 percent of copper. The mineral is of pale-green to sky-blue color, of pearly luster, and very soft; it occurs in drusy coatings or divergent tufts of columnar or needle-like crystals.

The only deposits of aurichalcite noted by Loughlin in Leadville were in two small stopes above the first level of Ibex No. 1 (Little Johnny claim). Here the aurichalcite occurs as pale bluish-green crystals forming druses or cavity fillings in light-brown zinc carbonate ore (**Plate 52, *A***). In thin section (**Plate 52, *B***) the cavity fillings were found to consist of a mixture of aurichalcite and calamine. The calamine predominated, forming diverging groups of blade-like crystals, in and through which were scattered tufts of fine needle-like to fibrous crystals of aurichalcite. A thin rim of drusy smithsonite separated the calamine and aurichalcite in places from massive brown ore. One of the pockets was found to have a matrix of nearly or quite isotropic silica, in which the crystals of aurichalcite and calamine were embedded. The silica preserved to some extent the granular texture of the massive carbonate ore, proving that it had grown in part, or been enlarged, by replacement of the massive ore, and indicating that the zinc in the calamine and aurichalcite had been, at least in part, derived from the zinc in the massive ore. The source of the copper is not apparent, but its presence is not surprising, as the original sulphide ores in the vicinity contain considerable copper. It is said that ore of this variety from the Ibex No. 1 has run as high as 4 percent copper, but that no allowance for the copper is made by the ore buyers. Ore of a similar kind is said to have been mined in the Rattling Jack claim, whose shaft is a short distance southeast of the Ibex No. 1 shaft.

A few microscopic needles of aurichalcite were found in a thin section (**Plate 52, *C***) of a calamine-quartz vein cutting low-grade reddish-brown zinc ore in the Belgian mine (Fenton's lease in 1913). Here also the aurichalcite grew simultaneously with the calamine; the two zinc minerals grew inward from the sides of the vein, and their terminations are embedded in a central filling of chalcedonic quartz. Some of the aurichalcite needles are bent, and fragments of calamine blades, which may have been broken from the margins, are inclosed in the central portion of the vein, suggesting that there was a sluggishly flowing fluid (or gelatinous) silica during or just after the growth of the aurichalcite and calamine crystals.

The fact that these were the only occurrences of aurichalcite noted in the district indicates that the mineral is a very minor constituent of the general run of the oxidized zinc ores. Its relative abundance in the Ibex, which lies in the copper-gold belt, is significant, and its occurrence in considerable quantities is doubtless limited to this belt.

CALAMINE

Calamine ($H_2Zn_2SiO_5$) occurs typically in fine to coarse druses of white to colorless bladed crystals (Plates 49, *A*, *B*), or in aggregates of diverging crystal groups, which may partly or completely fill cavities. Sheaf-like aggregates, composed of crystals welded along their brachypinacoids, are occasionally found. The crystals in these cavities are tabular parallel to the brachypinacoid, which is vertically striated. Many of the crystals are terminated by a blunt point formed by two macrodomes; others by a sharper point where the blunt macrodomes are subordinate to steep macrodomes. Less commonly the nearly flat brachydomes predominate, producing a blunt chisel-like termination, and in a few specimens the "chisel edge" was seen to be truncated by the basal pinacoid. One small pyramid face

[21] Penfield, S.L., On the chemical composition of aurichalcite: Am. Jour. Sci., 3d ser., vol. 41, pp. 106-108, 1891.

was noted by Butler.[22] Prism faces are present but not conspicuous. The calamine also fills small fractures, in a few of which it is accompanied by amorphous or microcrystalline silica. In one exceptional specimen, found by R.S. Fitch on the dump at the Adams shaft, August, 1913, calamine crystals are coated with minute quartz crystals. The calamine crystals have grown upon both massive and drusy smithsonite and on red and brown iron oxides and black manganese oxides. (See Hetaerolite.) They may inclose small particles of the iron and manganese minerals and be correspondingly darkened in color. They are also found in pockets or fractures in limestone near zinc carbonate ore bodies, and some of which are described below. One specimen, found on the May Queen dump, was so filled with brown oxide of iron as to have a brown opaque appearance and only its crystal habit gave a clue to its identity. In this and certain other specimens the calamine appears to have grown, at least in part, by the replacement of brown massive smithsonite ore along cavities or fractures. In still other specimens where the calamine rests upon other drusy minerals or fills a network of fractures inclosing sharply angular fragments of brown carbonate ore, the calamine was unquestionably deposited by infiltrating waters without detectable replacement.

HETAEROLITE ("WOLFTONITE")

The mineral hetaerolite was not recognized at Leadville until the development of the oxidized zinc ores was begun. It was at first believed to be a new species and was therefore, named wolftonite,[23] after the mine in which it was found, but further study proved it to be hetaerolite. It is composed principally of oxides of zinc and manganese, with smaller amounts of silica and water. Opinions differ as to its chemical formula. The mineral was first describe by Moore[24] in 1877 from a specimen found at the Passaic zinc mine, Sterling Hill, near Ogdensburg, Sussex County, N.J. Moore described the physical properties and occurrence of the mineral and stated it to be a zinc hausmannite ($ZnO.Mn_2O_5$)[25] but published no analyses. It occurred in association with chalcophanite in ocherous limonite, the chalcophanite usually forming a thin coating over it.

In 1910 Palache[26] studied a new lot of material from Franklin Furnace, N.J., and agreed with Moore that the hetaerolite was a zinc hausmannite. He assigned it to the tetragonal system of crystallization and stated that it had an indistinct cleavage. The material was analyzed by W.T. Schaller, of the United States Geological Survey (see column 1 on p. 14), and shown to contain small amounts of silica and water, the water being attributed to a slight admixture of chalcophanite.

In 1913, Ford and Bradley[27] gave a description and analysis of a specimen of the Leadville hetaerolite, taken from the Wolftone mine. They described it as a rare vug-filling mineral, having a radiating mamillary structure, whose outer surfaces are generally smooth and rounded. The mineral showed a splintery structure. Under the microscope, the finest fragments were birefringent and had an extinction parallel to the prism edges, but no further indication of its crystal form could be discovered. Its hardness was found to be between 5.5 and 6, and its specific gravity was determined as 4.6. Its luster was submetallic, its color dark brownish to black, with a bright varnish-like exterior, and its streak dark

[22] Butler, G.M., Some recent developments at Leadville, second paper, The oxidized zinc ores: Econ. Geology, vol. 8, p. 7, 1913.
[23] Butler, G.M., op. cit., p.8.
[24] Moore, G.E., Preliminary notice of the discovery of a new mineral species: Am. Jour. Sci., 3d ser., vol. 14, p. 423, 1877.

[25] The formula for haumannite is Mn_3O_4 or $MnO.Mn_2O_3$.
[26] Palache, Charles, Contributions to the mineralogy of Franklin Furnace, N.J.; Am. Jour. Sci., 4th ser., vol. 29, pp. 177-187, 1910.

[27] Ford, W.E., and Bradley, W.M., On hetaerolite from Leadville, Colo.: Am. Jour. Sci., 4th ser., vol. 35, pp. 600-604, 1913.

chocolate-brown. It was infusible but on charcoal with sodium carbonate gave the characteristic zinc oxide coating and with fluxes gave the color reactions indicative of manganese. It was easily dissolved in hydrochloric acid, giving off chlorine gas. In the closed tube it yielded water but did not give off oxygen. The index of refraction of hetaerolite was determined by Ford and Bradley to be above 1.78. It was determined by E.S. Larsen, of the United States Geological Survey, from material collected by Loughlin to be 2.19 and 2.22.

The mineral is of widespread occurrence in the oxidized zinc deposits of Leadville, though Loughlin saw no specimens equal in size to those obtained in one part of the Wolftone mine. It was also found by Philip Argall on the fourth level of the Tucson mine, filling small fractures in manganosiderite, well below the levels where oxidized zinc ores have been mined.[28] The mineral occurs mostly as thin drusy bands, alone or alternating with smithsonite, around cavities; also as fillings of small fractures, or as linings of fractures that are centrally filled with calamine or zinciferous clay. Its surface may be exposed, or it may be covered by calamine druses, the crystals of hetaerolite appearing to end abruptly where those of calamine begin. In some specimens small central clusters of distinct hetaerolite crystals grade outward into black stains that spot or mottle a considerable part of the brown carbonate ore. This relation leads to the suggestion that all the black manganese oxide stains and spots in the zinc carbonate ores may be incipient segregations of hetaerolite and not of psilomelane, as would at first be supposed. Wherever seen, these black stains bear the same paragenetic relations to the later smithsonite and to calamine as the undoubted occurrences of hetaerolite. Locally, hetaerolite may be the most conspicuous mineral in the ore, giving it a black or brownish-black color. In one specimen of this character, from the Tucson mine, the hetaerolite crystals are very distinct, having grown along intersecting fractures and inclosing dark-brown soft, earthy material of low zinc content. In other specimens of similar color, the mineral is not visibly crystallized. The Tucson specimen strongly indicates that the manganese from the massive carbonate ore, which left a residue composed largely of iron oxides. This origin is also suggested by several other specimens, some of which contained undoubted hetaerolite and others only the black stains.

In column 1 below is an analysis made by W.T. Schaller[29] of hetaerolite from Franklin Furnace, N.J.; in columns 2 and 3 are analyses of the Leadville hetaerolite made, respectively, by W.M. Bradley[30] and by Chase Palmer, of the United States Geological Survey; and in column 4, a partial analysis by G. Haigh.[31]

Analyses of hetaerolite

	1	2	3	4
Mn_2O_3	60.44	MnO 50.34	49.13	45.90
O	---	5.99	5.50	---
Fe_2O_3	0.77	---	0.67	5.9
ZnO	33.43	37.56	37.66	37.1
CaO	---	Trace	Undet.	---
SiO_2	1.71	2.69	2.91	[a]2.0
H_2O	2.47	4.36	3.78	4.7
H_2O+	1.42			
	100.24	100.94	99.65	95.6

[a] Insoluble.

In discussing analysis 2, Ford and Bradley state that the structure of the mineral was such as to suggest that the silica is due to the presence of calamine, and that if so, about 10 percent of calamine is present – a large amount to escape discovery; but they thought that the fibrous structure of the hetaerolite

[28] Specimen taken in June, 1914, and sent to Loughlin for identification
[30] Ford, W.E., and Bradley, W.M. op. cit., p. 602.
[31] Haigh, G., partial analysis quoted by Ford and Bradley.

might well conceal this amount. By recalculation, with allowance for the calamine, analysis 2 is found to correspond closely to the formula $2ZnO.2Mn_2O_3.H_2O$. Recalculation of analysis 1, including H_2O but not SiO_2, yielded the same formula, which Ford and Bradley concluded should be the formula for hetaerolite, instead of $ZnO.Mn_2O_3$, as stated by Moore and later by Palache; but they add that "it may be that the exact composition of hetaerolite cannot be settled until purer material can be analyzed."

The best specimens collected by Loughlin show the hetaerolite to be a distinctly earlier growth than calamine, and the purest material, when crushed to a fine powder and examined under the microscope, gave no indication of calamine, even fine specks of which should be easily distinguishable from hetaerolite. Chemical analysis (column 3 in the preceding table) shows it, however, to be practically identical with the material analyzed by Bradley (column 2). G.M. Butler[32] has expressed the conviction that the silica is an essential constituent of the mineral but has not suggested a corresponding formula. Nevertheless, the fact that silica and the excess of ZnO over that necessary for the ratio $2ZnO.2Mn_2O_3.H_2O$ are in the same ratio as in calamine is certainly significant, although just what the significance is must for the present be left to speculation.

CHALCOPHANITE

Chalcophanite, like hetaerolite, is a manganese-zinc oxide, with the formula $(Mn,Zn)O.2MnO_2.2H_2O$, containing about 21 percent of zinc oxide.[33] It is closely associated with hetaerolite, both at Franklin Furnace, N.J., and at Leadville, Colo. It differs from hetaerolite in certain physical and chemical properties. In some specimens collected by Loughlin at Leadville, it forms druses of minute tabular crystals of the rhombohedral system, coating botryoidal surfaces and filling cracks in hetaerolite. In others it forms foliated crusts coating brown smithsonite and covered in turn by calamine druses. (**Plate 49, *C***). Dana states that it also forms stalactitic and plumose aggregates. Its hardness, as given by Dana, is only 2.5; its specific gravity 3.91. Its luster is metallic and brilliant, its color bluish-black to iron-black; and its streak chocolate-brown. In the closed tube it gives off water and oxygen and exfoliates slowly, and its color changes to a golden bronze. Before, the blowpipe a similar change of color takes place, accompanied by slight fusion on thin edges, and it is this bronzy appearance that has given rise to the mineral name.

Since the above paragraph was written, specimens of Leadville chalcophanite collected by F.B. Laney have been studied by Ford,[34] whose description verifies the properties above mentioned. He found that very thin plates under the microscope are sufficiently transparent to give a negative uniaxial interference figure.

ZINCIFEROUS CLAY

Three varieties of zinciferous clay have been recognized in the Leadville mines – white, brown, and black. The white and brown are the most abundant. The white clay (**Plate 51, *A***) is very similar in appearance to kaolin and is one of the materials included under the local name "Chinese talc." The fresh material, however, is harder (about 3) and of more waxy luster than kaolin and does not slake or become plastic even when immersed in water for several days. Its fracture is conchoidal. Weathered or leached portions of it are of earthy appearance and slake readily in water. It has been found at the base of

[32] Written communication.

[33] Dana, J.D., System of mineralogy, 6th ed., p. 256.

[34] Ford, W.E., Mineralogical notes: Am. Jour. Sci., 4th ser., vol. 38, p. 502, 1914.

porphyry sheets in the Waterloo[35] and New Dome mines, forming in the latter a layer 1 to 2 feet thick that separates the sill from an underlying body of reddish-brown zinc carbonate ore. It has also been found in the Yankee Doodle mine, where it forms a layer about 2 feet thick immediately beneath a thin bed of silicified shale. These occurrences are of sufficient size to be called small ore bodies. Here and there are fissure deposits and small patches and cavity fillings of clay in the zinc carbonate ore bodies.

One specimen found on the New Discovery dump contains calamine veinlets, locally expanded into drusy vugs, so distributed as to suggest that the calamine was formed in shrinkage cracks from material extracted from the clay.

Under the microscope, the clay from the Yankee Doodle appears as an interlocking aggregate of minute fibers, of pale-brown color, non-pleochroic, with rather strong birefringence and positive elongation. Its mean index of refraction is a little above 1.58. The general appearance of the fibers is very similar to that of sericite fibers. Clay of similar megascopic appearance, from a pronounced fissure in the Maid of Erin mine, has optical properties more like those of kaolin, being traversed by a network of sericite-like fibers of higher birefringence and containing a few small calamine birefringence and containing a few small calamine crystals. These features, together with the relatively low specific gravity of the material, suggest that it is kaolin containing a small percentage of zinc, mostly in the form of the sericite-like mineral.

The brown variety is more widely distributed but is nearly all limited to small deposits, such as the light-brown seams along bedding and joint planes and a few cavity fillings. Those along bedding and joint planes are of bright waxy luster and of uniform dense texture (**Plate 51, *B***); those filling vugs are of more or less waxy luster and may have a pronounced finely banded structure (**Plate 51, *E***, strongly resembling that of a sedimentary clay. Both varieties slake rapidly in water but lack the high degree of plasticity so characteristic of ordinary clays. The bright waxy material slakes into small chips or splinters but does not become plastic; material somewhat softened and dulled by weathering has a tendency to become plastic but lacks the stickiness of ordinary clay, as well as the characteristic odor.

An exceptional occurrence of the brown variety, sufficiently large to be called a small ore body, was seen in the Belgian mine (Fenton's lease in 1913), replacing limestone along fissures just beneath a sheet of Gray porphyry. It was identical in appearance with low-grade zinc carbonate ore, but yielded no effervescence when immersed in hydrochloric acid. In this section, it was found to consist of aggregates of the minutely fibrous sericite-like mineral, more or less stained and obscured by iron and manganese oxides. Microscopic vugs contained growths of the same mineral with radial arrangement around the borders. The larger of these vugs, or local enlargements of veinlets, contain calamine and the sericite-like mineral so intimately mixed as to indicate that the two must have grown at the same time, though the sericite-like mineral evidently began first, giving rise to the radial borders. It was traversed by many short veinlets of calamine with black borders of manganese oxide. Other manganese spots and streaks were also present.

A partial analysis by R.C. Wells shows the presence of 17.8 per cent of insoluble matter and 18.7 per cent of zinc oxide (or 15 per cent of zinc). The remainder as shown by qualitative test, contained a large amount of iron oxide and small amounts of magnesia and lime. The insoluble matter doubtless indicates the amount of silica in the sericite-like mineral, or zinciferous clay. The zinc oxide represents a little calamine as well as the sericite-like mineral. The material evidently consists essentially of zinciferous clay, iron oxide, a little calamine, and a little manganese oxide.

The black variety was noted in conspicuous amount only at one place, where the white clay in the Yankee Doodle mine was locally stained by manganese oxide.

[35] Emmons, S.F., Geology and mining industry of Leadville, Colo.; U.S. Geol. Survey Mon. 12, p. 560, 1886. Hillebrand, W.F., idem, p. 605.

The chemical composition of the zinciferous clays is shown by the following analyses.

Analyses of zinciferous clays

	1	2	3	4	5
SiO_2	37.54	35.97	35.33	35.57	36.49
Al_2O_3	24.76	8.81	10.38	10.80	7.06
Fe_2O_3	0.64	---	---	0.40	2.48
FeO	---	---	---	Undet.	Undet.
MgO	0.71	0.80	0.71	0.82	0.97
CaO	0.63	1.87	1.62	0.48	1.44
ZnO	18.43	35.40	33.05	31.49	33.46
PbO	---	---	---	None	Undet.
Na_2O	0.36	---	---	Undet.	Undet.
K_2O	0.66	---	---	Undet.	Undet.
H_2O+	[a]11.07	[a]7.20	[a]7.42	6.32	7.06
H_2O-	5.03	10.26	11.64	Undet.	Undet.
CO_2	---	---	---	None	Undet.
P_2O_5	---	---	---	Undet.	Undet.
	100.10	100.31	100.15	[b]86.88	88.99
Zn	---	---	---	25.30	26.88

[a] Hillebrand's analysis as tabulated gave only total water, but the amount of hygroscopic water in each analysis is stated in the text (op.cit., p. 605).
[b] By comparison with analyses 1, 2, and 3, the deficiency appears to be chiefly hygroscopic water.

1, 2, 3. "Alteration product of porphyry," Lower Waterloo mine. W.F. Hillebrand, analyst. U.S. Geol. Survey Mon. 12, p 603, 1886.
4. White zinciferous clay, Yankee Doodle mine. George Steiger, analyst.
5. Brown zinciferous clay, New Discovery mine. George Steiger, analyst.

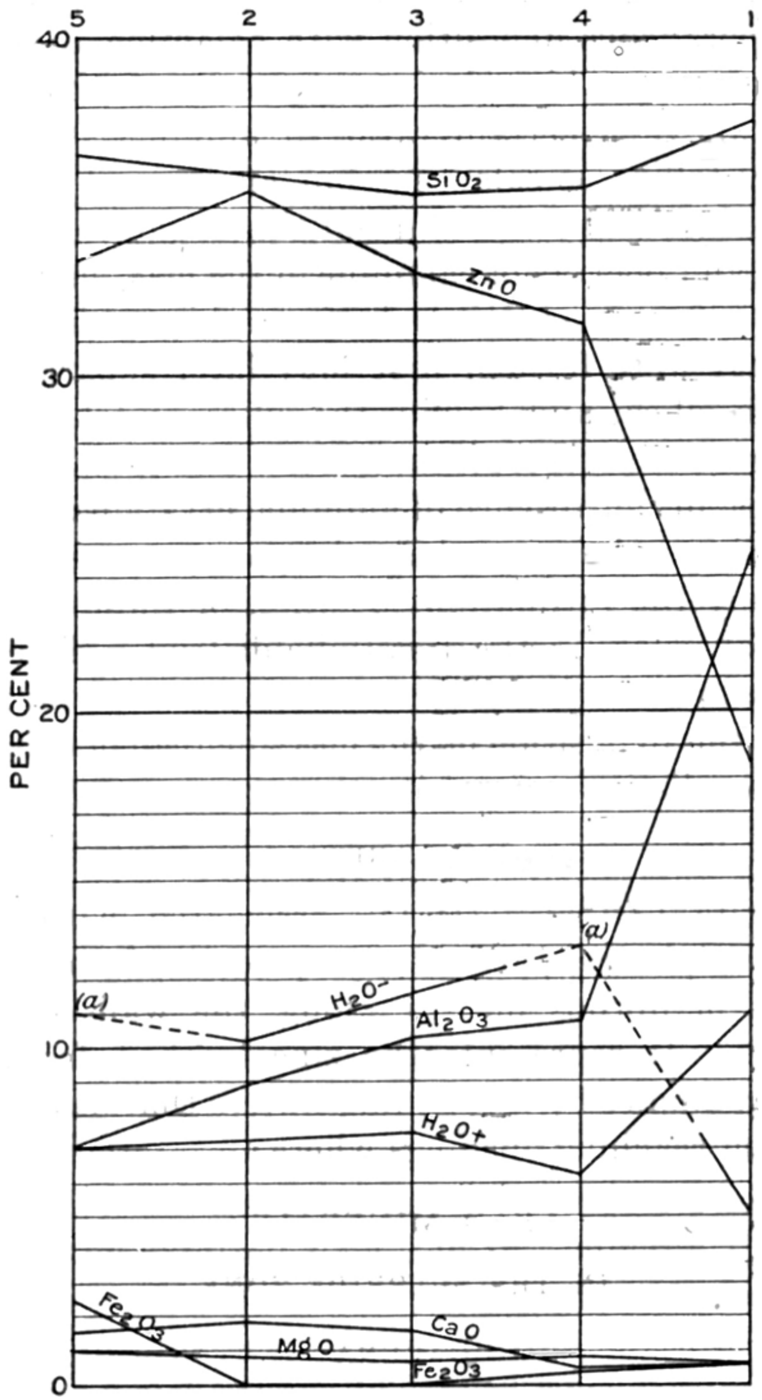

Figure 49. Percentages of constituents in zinciferous clays, arranged in order of increasing alumina. See table on page 18.

The first three analyses represent material obtained directly under porphyry; the fourth represents the Yankee Doodle deposit, beneath a silicified shaly bed; the fifth represents the brown, finely banded type. In spite of variations in the mode of occurrence and appearance, the five analyses are very similar to one another in many respects, but attempts to calculate the mineral composition of the ore yield varying and only inconclusive results. The Yankee Doodle material (No. 4), after kaolin and calamine are calculated, has still an excess of silica and zinc, the molecular proportion of the former being a little more than double that of the latter. In the brown-banded variety (No. 5), the alumina and all the zinc can be assigned to kaolin and calamine, respectively, leaving an excess of silica an combined water in the approximate ratio of 11 to 2. Attempts to find some definite relations between certain constituents by plotting their percentages on a diagram (**Figure 49**) do not give very definite evidence, except that the percentage of zinc oxide (ZnO) varies inversely as that of alumina (Al_2O_3). The birefringence of the clays shows that crystalline matter is present, and it may be suggested that they contain kaolin or some closely related aluminum silicate, its optical properties changed by dissolved impurities, but if it were suggested that such an aluminum silicate held the other constituents in solid solution, it would be necessary to assume that one molecule of it could hold in solution several molecules of each of the other substances – a questionable property. The low-grade clays, furthermore, show in thin section that the more highly birefringent mineral forms a network impregnating a mass whose optical properties are like those of chalcedonic silica and kaolin. If the highly birefringent portion could be analyzed separately, it would probably show as high a ratio of zinc oxide to alumina as the high-grade clays. The fact that the percentage of zinc oxide varies inversely as the percentage of alumina suggests replacement by zinc of aluminum. The low-grade deposits indicate that such replacement has occurred in clays previously deposited, but at least some of the high-grade clays indicate that zinc has taken the place of aluminum in solution and that the zinciferous clay has resulted from direct chemical precipitation.

Whatever its true nature, the zinciferous clay has certain relations to definite minerals, as is shown by its contemporaneous deposition with calamine, described on page 15. This relation may suggest that when zinc is above a certain ratio to alumina, its excess may crystallize as calamine, but analyses of Missouri "tallow clays"[36] hardly bear out this suggestion. The veinlets and pockets of calamine in the clay, mentioned on page 16, suggest that under favorable conditions, the clays that were formed first may later separate into calamine, silica, and kaolin, the silica and kaolin remaining as a microscopic mixture. The fact that zinc and silica, in the absence of alumina, crystallize readily as calamine and opal or chalcedony or quartz is demonstrated by the intimate association of these minerals in several places in the Leadville district. The presence of alumina therefore seems the critical factor in causing the deposition of the clays instead of calamine and other distinct minerals.

GOSLARITE

Goslarite ($ZnSO_4 + 7H_2O$), associated with other soluble sulphates, particularly epsomite, forms white coatings of fibrous masses along the walls of mine workings. It represents the zinc leached from sulphide ore bodies by descending waters that have evaporated on reaching openings where air is circulating.

LEAD MINERALS

In the Sulphide Zone

GALENA

Galena (PbS) occurs in large amount in the unoxidized portions of the blanket ore bodies, although it is not so widespread as pyrite or sphalerite. Like both pyrite and sphalerite, it forms some masses in which other sulphides are very scarce or absent, but more commonly it is mingled with pyrite and sphalerite in varying amount. It occurs in greatest abundance in the western portion of the district. In the lodes, galena is abundant at some places and entirely lacking at others, but on the whole, it is a minor constituent of the ores shipped.

Galena occurs mostly in granular masses, and to a minor extent as well-developed crystals lining cavities. The massive galena consists of irregular grains without crystal boundaries, and the sizes of the component grains vary greatly. Where the galena is pure, the largest crystals attain an inch in diameter. More commonly, however, they are one-eighth inch or less. In the finer-grained varieties of mixed ores, galena occurs scattered through the mass in minute grains, but pure fine-grained masses, known as steel galena, have not been observed by the writers in the Leadville district, nor have any occurrences been noted in which twinning structure has been developed in the galena by pressure.

Large fractures lined with galena crystals were observed in the Moyer, Tucson, A.Y. and Minnie, Wolftone, and many other mines. Where the incrusting galena crystals are large –that is, from three-fourths inch to 2 inches in diameter –their surfaces are usually dull and show the results of etching by ground waters. Thin crusts of mixed, carbonates cover the faces of many of the crystals. These crystals are usually cubes modified by the octahedron. Twin crystals are frequently seen.

Another variety of galena in peculiar crystal form occurs in considerable quantity in nearly all the mines, and is especially abundant in the mines of Iron and Carbonate Hills and Graham Park. These crystals are brilliant and in places occur in great profusion as linings in the cavities of the ores (**Plates 47, *B*, and 48, *E***). Many of the cubes are twinned, and some of their faces are built up by peculiar rounded irregular and incomplete accretions. Many of these accretions consist of smaller and smaller superposed

[36] Seamon, W.H., The zinciferous clays of southwest Missouri and a theory as to the growth of calamine of that section: Am. Jour. Sci., 3d ser., vol. 39, pp. 38-42, 1890.

layers (*A*, Plates 48, *E*). These layers are similar in origin to those giving the "Gothic window" effect to pyrite crystals (p. 2). Some portions of the crystals, usually on the under sides next to the wall on which they are attached, are rounded and irregular, resembling semi-fused material. This appearance is not due to fusion, however, buy may be interpreted as a variation of the accretionary growth just described, in which the decreasing size of the successive layers is so gradual that no lines of division can be seen between them.

An unusual occurrence of drusy and stalactitic galena was noted on the sixth level of the Tucson mine. This galena had grown upon zinc blende crystals in vugs in sulphide ore along the hanging wall of the Tucson fault. The stalactites were as much as half and inch in length and were distinctly later than the blende or the few crystals of chalcopyrite that accompanied it. The galena was coated with a dusty film that may have been argentite, as the ore at this place assayed 80 ounces to the ton in silver. This occurrence of galena suggests secondary origin, but it is impossible to distinguish sharply between primary (hypogene) and secondary (supergene) galena, for the other forms of galena, as well as the stalactites, have crystallized on the whole later than the blende and other sulphides. The mode of occurrence of the stalactites, however, accords with other observed occurrences and experiments that have been discussed by W.H. Emmons[37] in showing that secondary galena may be deposited on blende or pyrite, whereas secondary silver sulphide may be deposited on galena, blende, or pyrite. Analyses of the ores appear to indicate that nearly all the galena in Leadville contains antimony. It is probable that some bismuth is also present in this mineral.

Although frequently found intersecting other sulphides, the galena is believed to be, with the rare exception just noted, a primary mineral. Nodules of it are scattered through the oxidized ore, where it has been the last mineral to yield to complete oxidation. Such nodules usually carry a higher proportion of silver than the galena found in the distinctively primary zone. All the galena in the Leadville district carried silver, and although the ratio of silver to lead is far from constant, the proportion of silver is usually greater in the galena than in pyrite and sphalerite.

The studies made by Laney indicate that the silver is present in argentite inclosed in or intergrown with galena. No outward characteristics distinguish the galena high in silver from that which is low in silver. A fuller discussion of the silver content of galena will be found on pages 27 and 31; and p.30 in Chapter 9.

In the Oxidized Zone

MINIUM

Minium (Pb_3O_4), the sesquioxide of lead, occurs in many of the oxidized ores of the district, especially in those which have resulted from the oxidation of sulphides that contained large proportions of galena. It occurs intermingled with cerusite and iron oxides and in places incloses small residual particles of galena. It has been found in a number of mines, notably in the Rock, Dome, and Bessie Wilguns mines, on Rock Hill, and it is probably common elsewhere, though no published reports on it are available. A specimen from the Rock mine was described in 1890 by J.D. Hawkins,[38] of the Globe Smelting & Refining Co., as follows:

> The mineral was found between two ledges of outcropping rocks, one of porphyry and the other of limestone, the ore of the mine being carbonate of lead, with occasional occurrences of galenite. The minium does not occur as a solid mass but its interspersed with cerusite, and close examination also showed small particles of galenite occurring with the cerusite. The galenite found in the analysis, however, is not this. The

[37] Emmons, W.H., The enrichment of sulphide ores: U.S. Geol. Survey Bull. 529, pp. 84-86, 1913; The enrichment of ore deposits: U.S. Geol. Survey Bull. 625, pp. 137-140, 1917.

[38] Hawkins, J.D., Minium from Leadville: Am. Jour. Sci., 3d ser., vol. 39, pp. 42-43, 1890.

sample taken for analysis was a very carefully picked one, a lump of the mineral being broken up, and the red particles of minium alone being taken. This sample was again carefully picked over in order to insure the absence of anything else than the pure mineral. The analysis gave the following results:

Insoluble in HCl	7.51	Insoluble:	
Pb Calculated as Pb_3O_4.	91.39	SiO_2	2.00
Fe_2O_3	0.80	$Al_2O_3.Fe_2O_3$	0.41
V_2O_5	0.52	Pb 4.42, PbS	5.08
	100.22		7.77

From the cubical fracture of the minium, resembling that of galenite, and occurrence of galenite in the red minium, it would appear that the minium here is a pseudomorph after galenite. The vanadic oxide which was found in the mineral no doubt existed as vanadinite, which has been frequently found in Leadville.

The occurrence of sulphide of lead in the pure mineral is rather remarkable and also suggestive. Externally the particles of minium showed no evidence of the presence of any other mineral; it was not until the powdered mineral had been treated with hydrochloric acid and all PbO dissolved that the galenite could be observed. This seems to be conclusive evidence that the minium in this case was a direct alteration from galenite. A like deduction is forced as regards the plattnerite lately found in the Coeur d'Alene Mountains, Idaho, where all the lead ore is sulphide.

LITHARGE (MASSICOT)

Litharge (PbO) occurs here and there in the more ocherous varieties of oxidized lead ores in the form of a light-yellowish earthy material. It has not been definitely identified by the writer but is mentioned by Emmons in the Leadville monograph, page 376[13]. Litharge may be readily distinguished from minium by its difference in color. Neither of these oxides is of commercial importance in the district, although they may be more abundant in the earthy ores than it would be possible to prove without the aid of complete analyses.

CERUSITE

Cerusite ($PbCO_3$) forms one of the most widespread and commercially important of the minerals of the oxidized lead ores. By far the largest portion of the lead in the oxidized zone is in this mineral. It occurs in greatest abundance in blanket deposits but is also present in greater or less quantities in those parts of the lodes, which originally carried considerable galena. It is a prominent minor constituent of mixed sulphide from which zinc blende has been leached and in which pyrite has been tarnished or coated with chalcocite. In ore of this kind, the cerusite fills cracks and interstices and has clearly been deposited from descending solutions, in contrast to the great bulk of cerusite, which has formed by the oxidation of galena without noticeable migration.

There are few mines in the Leadville district which do not contain at least a small portion of this mineral in their oxidized ores, especially the iron and manganese oxides, in which the crystals may be visible or may be detected only by chemical analysis. Cerusite occurs in three well-recognized forms – as large crystals; as aggregates of small crystals, generally loosely bound together and known as sand carbonate; and irregularly disseminated in masses of dense silica, which are usually termed hard carbonate. The large crystals of cerusite are found either embedded in manganese and iron oxides or in clay, and occur at many places as radiating clusters or as drusy linings in cavities in the harder ores. Some crystals are white and glassy; others are discolored by minute inclusions of darker minerals, some of which have been proved to be the silver sulphide argentite. Occasionally, minute crystalline specks of silver chloride are found coating the crystals of cerusite. It has been shown by many assays and analyses

[13] Emmons, S. F., Geology and mining industry of Leadville, Colo.; U. S. Geol. Survey Mon. 12, p. 560, 1886.

of the Leadville cerusite that this mineral always carries a little silver, which is generally believed to be present either in the form of minute argentite inclusions or minute scattered specks of chloride or bromide.

Large crystals of cerusite were found frequently in the ores worked in the early development of the district. As the work done by the writers was confined largely to the sulphide deposits and to those portions of the oxidized ores which were of lower grade in both lead and silver, the only specimens which they observed were those preserved in the many private collections in Leadville. There are numerous cavities in the galena which are lined with large transparent crystals of cerusite having the form of long prisms capped by the pyramid.

"Sand carbonates" and "hard carbonate" are described under "Oxidized lead ores"

ANGLESITE

In the irregular nodules of galena found in the oxidized ores, the galena is usually surrounded by a thin crust made up mostly of anglesite ($PbSO_4$). From this occurrence it is inferred by Emmons that the alteration of the galena passed first through sulphate and then into carbonate. This inference is in accord with observations by Weed and others in regard to the manner in which galena is altered by oxidizing waters.

LANARKITE

Masses of dull blackish "bismuthiferous lanarkite, or sulphato-carbonate of lead and bismuth," are reported by Guyard[39] to have been found in the Florence mine, presumably as an oxidation product of "schapbachite," but no occurrences of this sort have been seen by the writers, and no other record of the occurrence of this mineral has been found in the literature. According to Dana's "System of mineralogy" lanarkite is a basic sulphate of lead (Pb_2SO_5 or $PbSO_4.PbO$).

CALEDONITE

The bluish-green mineral caledonite [$(PbCu)_2(OH)_2SO_4$] is reported from the Lillian mine, on Printer Boy Hill, by Dana,[40] but no full description of it has been found in the literature.

WULFENITE

Molybdenum has been detected by analysis in several of the sulphide ores of the Leadville district, and it is natural that the oxidation products, wulfenite ($PbMoO_4$), should be found occasionally in the oxidized ores. It has not been seen by the writers, although in the Leadville monograph, Emmons mentions its occurrence, and it is reported by Guyard to have been found in the Little Chief mine. The mineral is evidently rare and of no commercial importance in this district.

DESCLOIZITE OR DECHENITE

A vanadate of lead and zinc occurs in small quantities as a deep brick-red coating on siliceous gangue in the oxidized ores. Ricketts[41] mentions surfaces 6 inches or more across which are completely covered by it. It is of no commercial importance. Dechenite ($Pb(Zn)O.V_2O_5$), the anhydrous vanadate, has been reported, but Dana[42] suggests that the mineral so called is probably descloizite ($4Pb(Zn)O.V_2O_5.H_2O$), the hydrous vanadate.

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[39] U.S. Geol. Survey Mon. 12, p. 616, 1886.

[40] Dana, J.D. and E.S., System of mineralogy, 6th ed., p. 1090, 1909.
[41] Op. cit., p. 29.
[42] Dana, J.D. and E.S., System of mineralogy, 6th ed., p. 790, 1909.

VANADINITE

Vanadinite [$(PbCl)Pb_4V_3O_{12}$] has not been observed in the Leadville district by the writers, but it was reported by J.D. Hawkins, of the Globe Smelting & Refining Co.,[43] to have been frequently found at Leadville. It was believed by him likewise to be present in the minium, which was found in the Rock mine. Vanadium is frequently found in the oxidized ores of the Leadville district, and its presence would probably have been likewise detected in the sulphide ores had tests ever been made for it. It is possible that some of the greenish hexagonal crystals that have been reported as pyromorphite may have actually been vanadinite. The similarity between the two minerals renders their distinction, without careful tests, somewhat difficult.

PYROMORPHITE

Pyromorphite [$(PbCl)\ Pb_4P_3O_{12}$] occurs in considerable quantities in nearly all the oxidized lead ores of the district. In some places it is easily observed in the hand specimen; in others its presence can be detected only by analysis, as it is thoroughly mingled with the lead carbonate and iron and manganese oxides. Many analyses of oxidized ore show considerable quantities of phosphorus pentoxide and of chlorine, a large part of which, as calculation shows, must be present in the form of pyromorphite. The analysis quoted on page 9 and that given below[44] illustrate this fact.

Analysis of carbonate ore from the Waterloo mine

PbO	77.98	Pyromorphite	38.5
P_2O_5	6.48	Cerusite	53.9
CO_2	10.18	Cotunnite	1.1
Cl	0.84	Cerargyrite	0.1
Ag	0.047	CO_2 in gangue	1.3
	95.527		94.9

The cotunnite ($PbCl_2$) represents a small excess of chlorine over the quantity necessary for pyromorphite and cerargyrite. No chloride of lead has been recognized among the ore minerals, and any present is evidently in minute grains.

Slender, tapering, yellowish-green crystals of pyromorphite, as much as an inch long, are frequently found, single and as radiating clusters, in the linings of cavities in the oxidized ores of both blanket ore bodies and lodes (Plate 48, *B*). Many beautiful specimens of this mineral have been obtained from Leadville.

Pyromorphite was also observed in the Evening Star mine, together with cerusite, galena, and a little calcite, cementing a breccia of sulphide and porphyry.[45]

SILICATE OF LEAD

Small reddish crystals from the oxidized ores of certain of the Carbonate Hill mines were determined by Guyard[46] to be a silicate of lead. As he gave no analysis of this material, the mineral species cannot be definitely stated. No silicate of lead occurring in reddish crystals is listed in Dana's "System of mineralogy."

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[43] Am. Jour. Sci., 3d ser., vol. 39, p. 43, 1890.
[44] U.S. Geol. Survey Mon. 12, p. 599, 1886.
[45] U.S. Geol. Survey Mon. 12, p. 602, 1886.
[46] Idem, p. 616.

PLUMBOJAROSITE

Plumbojarosite ($PbO.3Fe_2O_3.4SO_2.6H_2O$), a hydrous basic sulphate of lead an ferric iron, was found in 1913 in the Yankee Doodle mine in the bottom of an old lead stope, just above a small oxidized zinc stope. It had been called "contact matter" but was known to contain considerable lead. The mineral occurs as a yellowish-brown, soft, earthy mass, with a rather shiny luster and a smoother feel than is characteristic of iron oxide or iron-stained lead carbonate. Under the microscope, the material is seen to be essentially homogeneous and to consist of minute grains, some of which show a partial to complete six-sided outline under very high magnification. It is much finer grained than the material from Beaver County, Utah, figured by Butler.[47]

Material of the same kind was found under Gray porphyry in the Lower Waterloo mine by Ricketts and by Emmons during the first survey of the district, and analyses of it are quoted on page 230 (not in this report). It was, however, not recognized as a distinct mineral species, owing doubtless to its earthy appearance and close resemblance to other materials of varying though similar qualitative composition, but was regarded as consisting chiefly of a mixture of sulphates. Plumbojarosite was not recognized as a distinct species until 1902.[48]

In 1919, similar material was found with cerusite and remnants of galena in a stope 90 feet above the eighth level of the Penrose mine.

COPPER MINERALS

Hypogene Minerals

CHALCOPYRITE

Chalcopyrite ($CuFeS_2$) is present in comparatively small quantity as a primary constituent of sulphide ores and is associated with both high-temperature and moderate-temperature minerals. In the magnetite ores of Breece Hill, it accompanies pyrite, the two minerals forming irregular patches and streaks that ramify through the magnetite. In many of the blanket deposits, it cannot be detected without a microscope, but Laney's studies of polished sections of the sulphide ores have proved that the zinc blende contains many minute inclusions of chalcopyrite. Recalculation of the chemical analyses of ores given in Chapter 9 indicates that their copper content is due to small particles of chalcopyrite. In the veins it is more conspicuous, though still the most subordinate of the common sulphides, and is associated with pyrite, to a less degree with sphalerite, and here and there with galena. So far as observed, the chalcopyrite forms interstitial irregular grains and small masses scattered among the other sulphides. No well-formed crystals have been found.

In some places in the veins, and even in the pyritic blanket ore bodies, chalcopyrite forms irregular streaks through the massive pyrite. These streaks are not fracture fillings and appear to be a feature of the original ore. An unusual occurrence of this kind was found on the third level of the Henriett-Maid mine. In this mine, a body of sulphides extended from the Parting quartzite through the White limestone as far down as the Lower or Cambrian quartzite. The upper 30 feet consisted of a mixture of sphalerite and pyrite. The next 10 to 12 feet consisted of pyrite containing about 30 ounces of silver to the ton. The third layer, 20 feet thick, consisted of pyrite containing 15 ounces of silver to the ton. Beneath this was a mass of solid pyrite 80 feet thick containing streaks of chalcopyrite and a higher silver content than either of the two layers above.

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[47] Butler, B.S., Occurrence of complex and little known sulphates and sulpharsenates as ore minerals in Utah: Econ. Geology, vol., 8, p. 313, 1913.
[48] Hillebrand, W.F., and Penfield, S.L., Some additions to the alunite-jarosite group of minerals: Am. Jour. Sci., 4th ser., vol. 14, p. 213, 1902.

Chalcopyrite was present in the high-grade silver ores found in the quartzite in the lowest levels of the Tucson mine, and there in part intergrown with zinc blende and galena, though for the most part, it was later than the blende and earlier than the galena. It is likewise present in much of the ore from the White limestone throughout a large part of the Iron Hill area. In the shoots of mixed sulphide ores between the fourth and eighth levels of the Tucson mine, chalcopyrite and its alteration products are localized in those parts of the Tucson reverse fault where siliceous gangue is prominent.

It is difficult to determine conclusively whether the chalcopyrite in these places is all hypogene or in part supergene; but no evidence strongly suggestive of its supergene origin has been found. It is relatively abundant in the lodes where descending waters have been active; but in such places, it is so tarnished as to resemble bornite and is commonly coated with chalcocite. Elsewhere in the same lodes where there is no evidence of alteration by descending waters, chalcopyrite is irregularly distributed in the interstices among grains of pyrite and zinc blende. It is therefore, believed that the lode was more permeable and subject to alteration where chalcopyrite was abundant, rather than that both chalcopyrite and chalcocite were formed by supergene waters.

TETRAHEDRITE

The sulphide ores from the Leadville district, in striking contrast to those from southwestern Colorado and many other of the Colorado districts, contain little tetrahedrite ($Cu_8Sb_2S_7$). The mineral has been observed in one of the veins of the Ibex mine in small tetrahedral crystals, forming drusy linings in vugs in pyrite and chalcopyrite. Light-gray minerals reported as tetrahedrite have been found on Breece Hill in considerable quantity, but careful examination has generally proved that they are bismuth minerals, either kobellite, lillianite, or some undetermined sulphide containing bismuth and antimony. For example, specimens of supposed gray copper found in the Ibex No. 4 shaft proved to contain high percentages of bismuth but no copper. The tetrahedrite that has been identified is usually rich in silver and is presumably the argentiferous variety, freibergite.

Supergene Minerals

IN THE OXIDIZED ZONE

NATIVE COPPER

Metallic copper is occasionally found in the oxidized ores, usually associated with clay, and appears to have been precipitated from sulphate solutions by the chemical action of the clay. It was found on the fifth level of the Ibex mine in branching, irregular masses, some of considerable size, ramifying through the moist, plastic clay. It has also been found as thin flakes in oxidized ores, notably in Iron Hill.[49] It has never proved of commercial importance.

CHALCANTHITE

The blue hydrous sulphate of copper, chalcanthite ($CuSO_4.5H_2O$), is found in considerable quantity in many of the mines of the district. It is usually found in the uppermost portions of sulphide and partly oxidized ore bodies. The mineral there occurs as scattered fibrous grains mingled with oxides and residual grains of sulphide. It also forms stalactites hanging from the roofs of drifts and stopes driven along veins.

This mineral is now forming in many places, and it is probably deposited in workings from which the water has been largely drained by artificial means. After the water has been pumped out of the mine, surface waters passing down through the oxidized zone may become saturated with copper sulphate and

[49] Blow, A.A., Am. Inst. Min. Eng. Trans., vol. 18, p. 168, 1890.

upon reaching an opening where they may partly evaporate, deposit the sulphate. Chalcanthite in commercial quantity was found in the Ibex mine (See Chapter 13).

MALACHITE

Malachite ($CuCO_3.Cu(OH)_2$) occurs sparingly in the oxidized zone of the Leadville district, being found partly as films and crusts in fractured porphyry and partly mingled with manganese and iron oxides in the upper portions of the oxidized ores. It is perhaps one of the least common of the oxidized minerals in the district, and its rarity is surprising in view of the abundance of limestone and the degree to which this rock has been permeated by oxidizing waters.

AZURITE

The blue basic carbonate of copper, azurite ($2CuCO_3.Cu(OH)_2$), is even more uncommon than malachite. It is occasionally found in small quantity in the upper-most portions of oxidized ores, particularly in the lodes. It occurs very rarely in the blanket ores.

CHRYSOCOLLA

Chrysocolla ($CuSiO_3.2H_2O$), the hydrated silicate of copper, although rare in the Leadville district, is more common in the oxidized ores than the carbonates azurite and malachite. It fills irregular cavities in masses of limonite and manganese oxides, where it generally ranges from bluish-green to deep green.

IN THE SULPHIDE ZONE

CHALCOCITE

Chalcocite (CuS) has never been identified in Leadville as a constituent of the unaltered primary ore, but it is one of the most constant constituents of the enriched sulphide ores, where it occurs in two ways – as a thin sooty film coating cracks and fractures in the other sulphides, especially chalcopyrite and pyrite; and as a gray metallic-lustered coating on fragments of chalcopyrite and pyrite or a filling in the fractures of pyritic ore.

The sooty variety of chalcocite is by far the more common. It resembles the black oxide of copper, melaconite or tenorite, but chemical tests verify its identity as chalcocite. It is particularly well developed in the lodes where descending waters have been able to penetrate to the greatest depths reached by the mines and have been confined in their action to a small mass of ore.

It is probable that the larger portion of the copper in the ores of the Breece Hill area and in those along the Tucson-Maid fault is present as chalcocite, although chalcopyrite also is an abundant constituent.

The manner in which the chalcocite occurs in the pyritic or other sulphide ores depends upon the number and distribution of the fractures. In some places, the entire mass of ore is slightly shattered and is permeated by chalcocite, which not only fills the fractures but also accumulates as coatings on the walls of vugs or cavities in the original ore. In other places, the fractures are few and usually larger. An occurrence of this kind was seen in the third level of the Greenback mine, where a flat blanket body of nearly pure pyrite was intersected by narrow vertical veinlets of chalcocite. The average content of copper in this body was 0.5 percent. The increase in copper is generally greater where chalcocite is disseminated throughout masses of pyrite.

In the lower levels of the Penn mine, chalcocite formed a stringer along the central and more cavernous part of the lode. The lode contained 8 percent of copper in its richest part and was worked for copper and gold until the chalcocite diminished, in depth, to an insignificant quantity. The gold content decreased with that of copper. A similar occurrence was found in one of the veins on the tenth level of the Ibex mine, where the maximum content of copper was 10 percent.

SILVER MINERALS

In the Hypogene and Supergene Sulphide Zones

Although practically all the sulphide ores that occur in the Leadville district carry greater or less quantities of silver, definite recognizable silver minerals are rare. The argentiferous variety of tetrahedrite – freibergite – and certain of the ruby silver minerals have been found but are so scarce that they may almost be disregarded. The intergrowth of argentite, bismuthinite, and galena, formerly called schapbachite, argentiferous lillianite, and argentiferous kobellite, have formed rich ore in a few places, as in the lowest levels of the Tucson mine; but with these exceptions, the silver is concealed in or among the common sulphides, probably in the form of argentite.

ARGENTITE

Argentite (Ag_2S) is rarely if ever visible in the common sulphide ores of the district, although it is doubtless present in close association with galena and with pyrite in the pyritic and siliceous silver ores.[50] It is found in considerable quantity, however, in the rich silver-bismuth ore such as was mined from large cavities in the Cambrian quartzite in the Tucson mine. There it is microscopically intergrown with bismuthinite and galena, in an outer crust an inch or more thick covering an inner crust of coarse-grained galena, which in turn covers a mixture of zinc blende and pyrite. The outer crust, and in places the inner crust, have a spongy appearance.

Argentite also occurs in the oxidized ores as minute specks in cerusite which produce a dark discoloration and account in some degree for the silver content of lead carbonate ore. Argentite is also reported by Blow as present in the residual nodules of galena that occur in the lowermost portions of the oxidized zone on Iron Hill.

In the Oxidized Zone

CHLORIDES, BROMIDES, AND IODIDES

Silver in the form of bromide, chloride, and to a small extent, iodide, is present in the oxidized ores throughout the district. Locally these minerals are visible, but for the most part, they are microscopic and their presence is disclosed by chemical analysis. The material termed “chlorides and bromides” by miners usually consists largely of yellowish basic ferric sulphates and green or blue films of copper carbonate accompanied by enough microscopic silver chlorobromide to yield high assays. The prevailing varieties are the green chlorobromide embolite [Ag(BrCl)] and the colorless chloride cerargyrite (AgCl), each of which contains a very small amount of the iodide molecule. Emmons stated that the chloriodide was also present in less quantity and mentioned minute yellow crystals of the iodide, iodyrite (AgI), in the Chrysolite mine. Brilliant yellowish crystals along joints in lead carbonate ore were found in the Weldon mine but not analyzed. As no additional noteworthy data on these minerals were obtained during the second survey, the following paragraphs embody the descriptions of Emmons, Hillebrand, and Guyard in the Leadville monograph[51] and of Ricketts in his study of the ores.[52]

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[50] Nissen and Hoyt (Econ. Geology, vol. 10, pp. 172-179, 1915) have shown that the silver in argentiferous galena is usually present as microscopic argentite, though it may also occur as tetrahedrite or native metal. See also Finlayson, A.M., Econ. Geology, vol. 5, p. 727, 1910.

[51] U.S. Geol. Survey Mon. 12, pp. 376, 548-549, 600-601, 619-620, 1886.

The mineral embolite is invariably light greenish, soft, and sectile and does not change color on exposure to light. It occurs in scales and plates as single grains or aggregates of such grains, and as rough crystalline coatings on the walls of crevices. The crystalline structure can be seen through a magnifying glass.

It is present in ore of several varieties – hard siliceous matter with numerous intersecting joints and crevices, yellow basic iron sulphates, granular lead carbonate, and locally lumps of decomposing galena. Specimens of carbonate of lead have frequently been found containing 5 to 10 percent of silver, largely present as chlorobromide. Only a few pounds of such rich ore have been found at any one place, and rarely do many tons from one shoot average more than 100 ounces to the ton.

Lumps of chloride weighing a few ounces have frequently been found, but very few have weighed more than a pound. Emmons mentioned a mass from the Chrysolite mine that weighed more than 100 pounds.

The three analyses given below illustrate the range in chemical composition of typical chloride ores relatively free from other minerals. Nos. 1 and 2, from the Robert E. Lee and Amie mines, respectively, represent the pale-green mineral generally called embolite, and No. 3, from the Big Pittsburgh mine, represents colorless material that is practically pure cerargyrite.

Analyses of typical chloride ores

	1	2	3
Chlorine	13.78	9.80	99.925
Bromine	85.63	89.99	None
Iodine	0.59	0.21	0.075
	100.00	100.00	100.00
Equivalent:			
Silver chloride	21.59	15.75	99.966
Silver bromide	77.99	84.09	None
Silver iodide	0.42	0.16	0.034
	100.00	100.00	100.00

In analysis 1, the proportion of the chloride to the bromide is 4:11; in analysis 2 it is 1:4. In order to determine the relative proportions of chlorine, bromine, and iodine throughout the district, Guyard analyzed a mixture of lead fumes collected in the dust chambers of eight smelters with the following results:

Silver chloride, 89.10; equivalent to chlorine, 82.45.
Silver bromide, 10.45; equivalent to bromine, 16.83.
Silver iodide, 0.45; equivalent to iodine, 0.72.

NATIVE SILVER

Native silver is found at many places in the oxidized ores of the Leadville district. Although greatly subordinate to the chlorides, it is much more common than was supposed during the first survey. It is present in the blanket ores and less abundantly in the lodes. In a few places it is sufficiently abundant to constitute the principal silver-bearing mineral of the ore.

The native silver occurs both as wire silver and as small plates, scales, or flakes, scattered through the gangue or country rock. It is found in cavities in sulphides, where it has probably been precipitated by

[52] Ricketts, L.D., The ores of Leadville, pp. 27, 30-38, Princeton, 1883.

reaction between the sulphides and descending waters. The wires are generally small, but some attain lengths of half and inch or more, with striations parallel to their elongation. Some specimens of siliceous ore are formed of bluish, cavernous jasperoid in which plates of native silver from 3 to 10 millimeters in diameter are profusely disseminated. To a minor degree, the scaly silver is partly coated with thin bluish tarnish, presumably due to the presence of a small portion of sulphide on the outside of the mineral.

NATIVE GOLD

Native gold has been found in varying quantity in many of the Leadville ores. Although most of the ore classed as gold-silver or gold-copper ore, whether primary or altered, contains gold only in microscopic or submicroscopic grains, gold in coarse flakes and wires has been seen in the enriched parts of several of the lodes and closely associated blanket ore bodies in the eastern part of the district, notably in the Ibex, Garbutt, Winnie-Luema, Big Four, Colorado Prince, Great Hope, Printer Boy, and Lilian (Florence) mines.

It has also been found in the original sulphide ore of the London mine and other properties on the east slope of the Mosquito Range and may, therefore, be expected locally in similar ores within the Leadville district. No native gold has ever been observed in the ores of the Iron Hill or Downtown districts, even in the famous "gold ore shoot"[53] and the rich gold-silver ore on the lower levels of the Tucson mine.

In the placers gold was present as irregular flakes and nuggets. No distinctly crystalline gold has been seen or reported from any of the deposits.

In the Ibex mine, gold is reported to have occurred in much of the ore containing considerable zinc blende. A specimen of ore seen in the office of the Ibex Co. contains crystals of sphalerite coated with films of gold. Irving noted several similar occurrences in the Lake City district, Colo. A specimen collected by J.W. Furness[54] from a prospect 10 feet deep about 6 miles northwest of Alma, at an altitude of 13,000 feet, consists of sphalerite, galena, and quartz cutting quartzite, and the sphalerite contains several streaks or flakes of gold. Much of the gold lies in cleavage cracks or suggests an imperfect zonal arrangement parallel to faces of sphalerite crystals.

Wire and leaf gold occurred very abundantly in a seam of sulphide which was found on the sixth level of the Ibex about 200 feet south of the Big Four shaft and which was associated with certain highly siliceous ores interbedded with black "Weber shales." Some of the richest ore found in the Ibex mine was taken from this locality. The oxidized siliceous ore in one of the stopes above the third level of the same mine contained a small but remarkably rich seam of leaf and wire gold mingled with decomposed silicified porphyry. Sixteen sacks mined from this seam carried more than 50 percent gold. In a specimen from this locality, seen in the office of the Ibex Mining Co., the gold occurs in a seam of compact jasperoid between limestone and porphyry. The jasperoid is stained deep brown by iron, has a conchoidal fracture, and contains sheets of gold in the joints. Some of these sheets are from 1 to 2 inches across. The gold is pure yellow and 0.860 fine. Another specimen in the company's office, from the sixth level of the Ibex mine, shows a large cluster of zinc blende and pyrite crystals which form a coating half an inch thick on a quartz seam. The quartz, partly stained by oxidation, shows many irregular openings, which contain free gold, mostly in long wires but partly in leaf-like plates.

Native gold occurs also in the oxidized zone in some of the lodes that penetrate porphyry. In the No. 7 vein of the Ibex mine, it occurs on the tenth level, at the junction of the oxidized and the sulphide ores, as thin leaves on sheeting planes in the porphyry. It formed some rich ore in the Hahnewald stope. Gold has been found abundantly mingled with the oxides and to a greater extent with the partly oxidized sulphides in the southern part of the Winnie-Luema lode. Some of the ore here ran as high as 100 ounces to the ton in gold, and leaf and wire gold occurred in considerable quantity. The blanket ores of the

[53] Blow, A.A., op. cit., p. 168.

[54] Presented to U.S. Geol. Survey; No. 79 in collection of polished sections of ores.

Florence (Lilian) mine carried large quantities of native leaf gold on a narrow contact between the limestone and the overlying White porphyry. The "contact matter" or "vein material" consisted of kaolin or a similar clay in which the native gold was disseminated. Gold also occurred in narrow seams, which extended up from the contact for 10 feet or more into the porphyry. Four hundred pounds of ore from one of these seams yielded $10,000. Small quantities of similar rich ore, or "metallics," averaging less than 1 ton a year, have been shipped annually from the Breece Hill area.

According to information obtained by Emmons[55], the gold in the Great Hope mine was found in iron-stained "vein material" and Parting quartzite; but the character of the material on the dump, as well as the surprisingly small thickness, 60 feet, reported for the Blue limestone led him to suggest that the matrix was jasperoid rather than quartzite. A sample taken from the mine by Tom Gilroy in 1923 consisted of iron-stained jasperoid containing a few visible flakes of gold and a few small vugs lined with pyromorphite. The ore produced in the early days, however, contained some very coarse gold. It is said that between 400 to 500 tons of siliceous gold ore, averaging 1½ ounces of gold and 4 ounces of silver to the ton, was mined at that time, and that one lot of 3,000 pounds yielded 31 ounces of gold to the ton.

The downward concentration of gold in the lodes and related blankets is attributed by W.H. Emmons[56] to the presence of considerable manganese in the ores and wall rocks and of alkaline chlorides in the supergene waters. Reaction between the chlorides and manganese oxides, according to this view, liberated chlorine, which dissolved gold and carried it downward until it was precipitated by contact with sulphides particularly sphalerite, or by ferrous sulphate or some other precipitating agent in the ground water. Where sulphide ore thus enriched in gold has been later subjected to oxidation, the coarse gold has resisted re-solution to a considerable extent and remained as residual flakes or wires in the soft, iron-stained siliceous gangue.

This residual gold is the evident source of the placer gold in California Gulch and its tributaries. In spite of the short distance between the placers and their source, the fineness of the gold was considerably increased during the transfer. For example, Emmons stated that the placer gold at the mouth of Nugget Gulch was worth from $17 to $19 an ounce, whereas that from the veins in the Printer Boy mine was worth only $15 an ounce.[57] As the placer deposits had been exhausted long before Emmons first visited the district, no further details concerning the physical characteristics of the placer gold could be obtained.

It is significant that California Gulch was not scoured by ice during the last stage of glaciation. Water escaping into it from the side of the Iowa Gulch glacier at the east and west ends of Printer Boy Hill aided in the removal of fine rock debris and in the concentration of gold. The absence of placers in South Evans Gulch, which was glaciated, is in marked contrast. Material eroded from the gold deposits in the northern part of Breece Hill must have been washed into that gulch but was later removed by the glacier.

Native gold has been found in the "lake beds" and in the glacial moraine material far out on the eastern slopes of the Arkansas Valley. Angular native gold was found in a trench in such material in the center of sec. 22, T. 9 N., R. 80 W.

[55] U.S. Geol. Survey Mon. 12, pp. 500-501, 1886.
[56] Emmons, W.H., Am. Inst. Min. Eng. Trans., vol. 42, pp. 3-73, 1912.
[57] U.S. Geol. Survey Mon. 12, p. 516, 1886.

BISMUTH MINERALS

In the Sulphide Zone

BISMUTHINITE

Bismuth in small quantities is a rather constant constituent of a large part of the sulphide and oxidized ores of Leadville. Its presence is shown by the analyses of ores on page 30 (Chapter 9) and in Chapter 11 (not in this report) (compare Mon. 12, p. 606) and in analyses of chamber and flue dust, which contained from 0.01 to 0.05 percent of metallic bismuth.[58] Bismuthinite (Bi_2S_3) is the only primary bismuth mineral whose identity has been established. Kobellite, lillianite, and schapbachite have also been reported, but most specimens that have been studied have proved to be microscopic intergrowths of bismuthinite and other sulphides. A few have not been satisfactorily identified. It is doubtful if bismuthinite has been found in the ores of Leadville except in these intergrowths, or with argentite, as microscopic inclusions in galena. One of these intergrowths was found coating other sulphides in the rich silver ore that lines cavities in the Cambrian quartzite of the Tucson mine and proved to be very similar to the "lillianite" in the Lilian mine. Both of these occurrences have been studied by Laney and identified as intergrowths of bismuthinite, argentite, and galena.

"Kobellite" from the mines of the Lilian Mining Co., Printer Boy Hill, was described by H.F. and H.A. Keller.[59] It occurs in nodules of various sizes, the largest 7 feet in diameter, which are usually more or less oxidized. The fresh material has a fine-grained structure, steel-gray color, and dark streak. Three analyses were made, with the results given in columns 1 to 3, below.

Analyses of bismuth minerals

	1	2	3	4	5	6
Bismuth	32.62	33.31	33.89	37.11	11.60	33.23
Lead	43.94	44.28	44.03	36.90	20.0	48.21
Silver	5.78	5.49	5.72	8.58	6.06	Undet
Copper	Trace	0.03	Trace	0.08	1.70	1.74
Zinc	---	---	---	Trace	0.60	---
Iron	---	---	---	0.18	20.6	Trace
Sulphur	15.21	15.27	15.19	15.18	28.0	15.73
Antimony	---	---	---	---	---	0.24
Gangue:						
Lime	0.15	0.14	0.17	0.03	1.4	---
Insoluble	---	---	---	1.33	6.0	---
	97.21	98.52	99.00	99.39	---	99.15

1-3. "Kobellite" from Lilian mine.
4. "Lillianite" from Ballard mine, R.C. Wells, analyst.
5. "Silver ore" from Cord mine, collected by Mr. Hartwell, manager. Analysis by J.W. Hawthorne, chemist of Empire Zinc Co., 1923.
6. Homogeneous, fibrous radiating lillianite from Gladhammer, Sweden. E.W. Todd, analyst.

The bismuth determinations are regarded by the authors as somewhat low, and in Nos. 2 and 3 there was probably also a loss of lead. The formula derived by the Kellers from their analyses was $3PbS + Bi_2S_3$. They remark that the mineral is interesting, inasmuch as it contains high percentages of silver,

[58] Guyard, Antony, U.S. Geol. Survey Mon. 12, pp. 712-716, 1886.
[59] Am. Chem. Soc. Jour., vol. 7, p. 7.

whereas antimony is entirely absent. Kobellite, however, according to Dana's "System of mineralogy," contains antimony. In 1889, H.F. Keller[60] described under the name kobellite a mineral for which he deduced the formula $2(Pb,Ag_2,Cu,Fe)(Bi_{2/3}\ Sb_{1/3})_2S_3$. At the close of this article, he suggested that the name lillianite be used for the lead-bismuth-silver mineral which occurs in the Lilian mine and contains no antimony. For this he gave the formula $3(Pb,Ag_2)S.Bi_2S_3$. It thus appears that the so-called kobellite from the Leadville district is in reality "lillianite." An analysis of the "lillianite" from the Ballard mine by R.C. Wells is given in column 4 of the table and may be compared with the three original analyses of the ore from this mine in columns 1 to 3. A very similar analysis is that of fibrous radiating lillianite ($3PbS.Bi_2S_3$) from Gladhammer, Sweden, given in column 6. This material was examined microscopically by Walker and Thomson and found to be homogeneous. It thus appears that a compound of this composition may exist, but the "lillianite" from the type locality in the Leadville district is a mixture of three minerals.

The "schapbachite" of Leadville, which also consists of sulphides of lead, silver, and bismuth and was reported by Guyard[61] to be present in the Florence (Lilian) mine, is evidently, like "lillianite," a mixture of sulphides. The original specimen from Schapbach, Bavaria, was so considered by Sandberger,[62] and a specimen examined by Murdoch[63] proved to be a mixture of two undetermined minerals.

Similar material has been produced from the Cord mine and is represented by analysis 5. The specimen analyzed was presented by Mr. Hartwell, manager of the York tunnel and related properties, to J.A. Ettlinger, who examined it microscopically and reported no visible intergrowth. Its megascopic minerals included siderite, pyrite, and chalcopyrite scattered through a dark-gray fine-grained metallic material, which is a mixture of lead, silver, and bismuth sulphides. It contained 1,783 ounces of silver and 0.40 ounce of gold to the ton.

In the Oxidized Zone

Bismutite ($Bi_2O_3.CO_2.H_2O$; exact composition doubtful) was found by Irving in the high-grade bismuth ores in the Ballard mine, and tests of oxidized ores prove the presence of bismuth, probably as bismutite, in several mines. In the Ballard mine, bismutite occurs in irregular pockets and lenses or lenticular masses 6 inches to a foot or more in thickness, which are mingled with a yellowish, ocherous gold ore. The bismuth carbonate is here a light-grayish earthy massive material with a greenish cast. It is extremely heavy and is reported by the managers to have yielded 80 percent of bismuth. In the laboratory it yielded strong tests for bismuth and carbon dioxide but contained no lead nor other metals. The oxidized ore from the Florence mine also contained large quantities of bismuth, probably in the form of bismutite. Small unaltered kernels of "lillianite" are frequently found in the bismutite masses. The chemical tests show that the bismutite contains little or no silver. Lanarkite is described on page 22 under oxidized lead minerals.

ARSENIC MINERALS

Arsenopyrite is described on page 3 under iron minerals. Native arsenic is mentioned by Dana as having been found in the ore deposits of the Leadville region, but this statement evidently refers to a mineral reported by Clarence Hersey to have been found in the silver-gold mine "5 or 6 miles west of Leadville." The arsenic occurred in nodular concretionary forms and was very brittle.[64]

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60 Zeitschr. Krist. Min., vol. 17, p. 67, 1889.
61 U.S. Geol. Survey Mon. 12, p. 616, 1886.
62 Sandberger, F., Neues Jahrb., p. 221, 1864.

63 Murdoch, J., Microscopical determination of opaque minerals, p. 38, New York, 1916.

64 Am. Jour. Sci., 3d ser., vol. 39, p. 161, 1890.

TUNGSTEN MINERALS

Wolframite and scheelite have been found in small scattered amounts in the siliceous pyritic gold ore of the South Ibex stockwork in Breece Hill.[65]

Wolframite tends to occur in dull brownish-black masses, which terminate abruptly in the vein against pyrite and quartz, or against scheelite. These masses contain many small cavities, where some faces and angles of wolframite crystals have developed, but these are generally so corroded that no adequate idea of the crystal form can be gained. In one specimen, however, there is an isolated crystal over half an inch long, projecting into a small vug. The crystal is of flat rhombic or wedge-shaped outline. The broad faces are those of the clinopinacoid *b* {010} as they are parallel to the perfect cleavage. The narrow faces are the orthopinacoid *a* {100} and probably the steep dome *t* {102}. No other faces are represented on this crystal. Some faces that are not corroded are rather strongly striated, the striations probably lying parallel to the prism zone. The hardness is apparently as low as 3, as even glistening surfaces are scratched by calcite. This low value may be due in part to the corrosion of the mineral but may also be characteristic of the manganese tungstate hübnerite in contrast to the iron tungstate ferberite, whose hardness is given by Dana[65a] as 5 to 5.5. The luster, though dull for the masses as a whole, is submetallic on cleavage surfaces and uncorroded crystal faces. The color, though prevailingly brownish black, is dark reddish on thin, translucent cleavage flakes. Thin flakes under the microscope are red to yellow. The streak is chocolate-brown to reddish brown. No quantitative analysis of the mineral has been made, but qualitative tests prove it to contain considerable amounts of manganese and tungsten. These results agree with the low hardness (3) and partial transparency in indicating that the mineral belongs to the hübnerite or manganese tungstate part of the wolframite series, as contrasted with ferberite, the iron tungstate, which is harder (5) and opaque.[65b]

The wolframite masses contain numerous small grains of pyrite, some of which are intimately intergrown with wolframite. The intergrowths consist of bladed or tabular individuals of wolframite in diverging groups and separated one from another by thin layers of pyrite. Wolframite comprises two-thirds to three-fourths of the intergrowth. Wolframite is also intergrown on a small scale with scheelite in the central parts of certain scheelite crystals.

The scheelite occurs in localized aggregates, some closely associated with masses of wolframite, others with pyrite and quartz. In some places, massive scheelite is surrounded by massive pyrite; in others scheelite crystals, growing on quartz or pyrite crystals, line vugs. The crystals are imperfect doubly terminated pyramids of the tetragonal system, truncated by narrow pyramid faces of the second order. Pyramidal cleavage surfaces are distinct though not prominent. The hardness lies between 4 and 5, the luster is resinous to adamantine, and the color is rather light brown in the larger crystals to pale yellowish in small translucent grains. The crystal surfaces show no conspicuous effects of corrosion. They are free from intergrowths other than those with wolframite already mentioned and grow upon all the other minerals in the veins.

The relations, already described, of the vein minerals to one another indicate that while there were overlaps in the periods of growth, the general order of deposition was as follows: (1) Sericite, quartz, and pyrite in parallel growth, the sericite forming only at the beginning of the stage; (2) pyrite and wolframite, the latter predominating; (3) very little pyrite, a little wolframite, and abundant scheelite, the

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[65] Fitch, R.S., and Loughlin, G.F., Wolframite and scheelite at Leadville Colo.: Econ. Geology, vol. 2, pp. 30-36, 1916.

[65a] Dana, E.S., System of mineralogy, 6th Ed., p. 983.

[65b] The chemical properties of hübnerite and scheelite described in this paper have been verified by Frank L. Hess, and the physical properties by W.T. Schaller, both of the U.S. Geological Survey.

scheelite continuing to form after the other two minerals had ceased. According to Hess[65c] this seems to be the usual paragenetic relation of scheelite to wolframite, or ferberite, in tungsten veins.

GANGUE MINERALS

QUARTZ

Quartz (SiO_2) occurs in greater or less amount in nearly all the sulphide and oxide ores of the district. It is present in lodes, blanket deposits, and contact-metamorphic ores, and is developed with sericite on a microscopic scale as an alteration mineral in the igneous rocks. It varies greatly in amount, as may be seen from the silica percentages in the tables of ore analyses given on pages 24–33, Chapter 9.

The percentage of quartz in the sulphide ores ranges from very high to almost zero. It is generally least in the magnetite-pyrite ores and highest in certain pyritic sulphide bodies. Throughout the eastern part of the district, the ores are much more quartzose than in the western part, but exceptions occur in both parts of the district.

In some of the ores, both sulphide and oxide, the quartz occurs as linings of cavities, and in places shows minute clear, glassy, prismatic crystals, which are generally free from inclusions. Definite crystals of quartz are less common in the massive sulphide ore. Some of the oxidized ores of the Ibex mine consist of a loose sandy aggregate of small quartz crystals mingled with oxides of iron and ocherous minerals. Very fine colorless crystals of quartz have been found coating calamine crystals in low-grade oxidized zinc ore from the old Mikado dump. Microscopic quartz has been found in parallel growths with brown iron oxide and in agate-like growths lining vugs in the iron oxide. These quartz crystals, together with the chalcedony and opal, were among the latest minerals to be deposited in the oxidized zone.

There is no difficulty in distinguishing the quartz accompanying sulphide ores from the original quartz of the country rocks. The quartz of the sulphide ores is seen under the microscope to consist of distinct crystals and irregular grains, comparatively clear and free from strain effects, whereas the original quartz of the country rocks shows marked strain and characteristic rows of minute inclusions. Much of the quartz of the ore bodies contains inclusions in relatively small quantity, which in some crystals are arranged parallel to the crystal boundaries. A few of these inclusions appear to be fluid, but most of them are indeterminate.

In both blanket deposits and lodes, the quartz is more usually present as irregular anhedral grains, which make up a dense aggregate, in part sufficiently coarse to resemble quartzite and in part so extremely fine-grained as to have received the name of flint or jasperoid. This flinty variety is one of the commonest products of siliceous replacement in the Leadville district. It occurs in nearly all the mines in greater or less amount. In many places where fissure veins pass through limestone, the limestone adjacent to the fissures has been altered to jasperoid. In the Fryer Hill and Downtown areas, there are extensive layers of the jasperoid or flint which carry practically no valuable metals and extend far beyond the limits of profitable mining. Here and there the quartz in the jasperoid masses has a coarser texture and is filled with minute cavities lined with quartz crystals. This quartz has a grayish appearance and may be rich both in gold and silver.

In texture, the jasperoid usually shows clearly its development by replacement from the limestone, for it exhibits all gradations from anhedral grains to perfectly developed prismatic quartz crystals. These crystals are usually arranged in interlocking aggregates so that triangular cavities are observed between them. Where a rock has been completely altered to jasperoid, as in some varieties of siliceous ore from the Resurrection mine (analysis on p. 73, Chapter 13), the anhedral grains lie among the completely developed crystals. Frequently a perfect crystal of quartz will be seen embedded in an anhedral grain. This structure shows that the development of perfect quartz crystals is the first step in the

[65c] Hess, F.L., and Schaller, W.T., Colorado ferberite and the wolframite series: U.S. Geol. Survey Bull. 583, p. 12, 1914.

process of silicification. As the process continues, the limestone around the earlier-formed crystals is itself replaced, and the result is an interlocking aggregate of perfectly bounded quartz crystals embedded in a groundmass composed of anhedral grains representing the later stages in the replacement of the original limestone.

CHALCEDONY AND OPAL

Clearly recognizable chalcedonic silver is extremely rare or absent in the primary ores of Leadville. Its absence is significant, as chalcedony is one of the characteristic forms of silica found in the relatively low-temperature (epithermal) vein zone, whereas the Leadville ores were formed at higher (mesothermal and hypothermal) temperatures.

Opal ($SiO_2.nH_2O$) and chalcedony occur in considerable quantities as alteration products in porphyry and in ore bodies of the Leadville district. They are believed to have been derived from the decomposition of silicates either in country rocks or in sericite masses within the ore bodies in the zone of oxidation. In some places, they form beautiful opalescent layers a quarter of an inch thick and 6 or 8 square inches in area.

Chalcedony and opal have been found, usually in small amounts, associated with aurichalcite and calamine, in oxidized zinc ores in the Ibex (Little Johnny) and Belgian mines. They form the matrix of cavity or fracture fillings, and the two zinc minerals are embedded in them (Plate 52).

WOLLASTONITE

Wollastonite ($CaSiO_3$), a silicate of calcium, is confined to the contact-metamorphic deposits of magnetite. It has so far been recognized in only one deposit of this ore – that cut in the My Day drill hole at a depth of 350 feet below the surface. It appears here as small whitish irregular masses, ranging from 0.5 to 10 millimeters in diameter, of extremely irregular form and distribution. Its character cannot be determined in the hand specimen. Under the microscope, it appears as divergent or fibrous aggregates and can be readily identified.

SERICITE (MUSCOVITE AND PARAGONITE)

The name sericite is here used to include fine-grained silky-lustered varieties of muscovite ($HK_2Al_3(SiO_4)_3$) and paragonite ($H_2NaAl_3(SiO_4)_3$), which appear identical even in thin section. The muscovite is one of the minerals that have been developed most abundantly in the igneous rocks of the Leadville region by the mineralizing waters that have produced the ore deposits. It has been formed by the reaction of these solutions with the feldspars of the igneous rocks, the "Weber grits," the "Weber shales," and certain quartzite beds and is commonly accompanied by calcite and minor quantities of chlorite and epidote.

The distinctly secondary sericite occurs in small microscopic irregular flakes, usually in aggregates, in the igneous rocks; also in soft clay-like masses that accompany nearly all the ores. The sericite flakes in the igneous rocks range from the exceedingly minute size up to 1 millimeter or more in length. Where alteration has proceeded very far, the porphyries have been changed almost entirely to aggregates of these sericite flakes, with the original quartz for the most part, unaffected. (**Plate 55, *C*.)** Outlines of feldspar phenocrysts are observable in these thoroughly altered porphyries, but the mineral is entirely changed to a felt-like mass of sericite with probably some minute grains of secondary quartz. In even the less decomposed varieties of porphyry (**Plates 46, *A*; 55, *B***), sericite is abundantly present, as may be seen from their calculated mineral composition on (original) pages 46-51 (not included in this report).

In many places, sericite or a very similar mineral, is present in white dense masses that appear identical with kaolin; but the indices of refraction are equal to or slightly lower than those of typical sericite. Some of these masses are plastic when wet and with kaolin and alunite are included under the local term “Chinese talc” (See p. 37, analysis1)

In nearly all the veins of the Leadville district, a large amount of soft, clay-like gouge is mingled with the ore, either as layers of selvage between the ore and the walls or as plate-like partings in the interior of the ore mass. Where the fissures are filled with broken rock material, this clay-like matter is distributed throughout the mass, but with no regularity in its position. When examined microscopically, the clayey material proved to consist mostly of finely divided sericite, with little or no kaolin. Its plasticity, however, suggests the presence of some mineral –like leverrierite or montmorillonite.

The only indication of paragonite in the Leadville district is in the recalculation of the chemical analysis (p. 6) representing manganosiderite cut by veinlets of quartz, sulphides, and a mineral that appeared identical microscopically with the typical sericite of the altered rocks and lodes but was evidently composed mainly of the soda mica with very little of the potash mica molecule. This occurrence raises a question as to the relative quantities of the two micas in the sericite of the district. The two minerals are so similar optically, that the question can be answered only by a great many chemical tests. So far as the chemical analyses of altered igneous rocks indicate, the potash variety is by far the more abundant.

CHLORITE

Chlorite ($H_8(Mg,Fe)_5Al_2Si_3O_{16}$) is the most common alteration product of the dark silicates of the intrusive porphyries and pre-Cambrian granite. It is characteristic of the altered rock at some distance from the larger lodes, along which the immediate wall rock has been replaced by quartz and sericite. The chlorite in the Cambrian and Parting quartzites may be in part correlated with that in the altered porphyries, but for the most part, is regarded as a primary constituent of the quartzite.

EPIDOTE

Epidote ($HCa_2(Al,Fe)_3Si_3O_{13}$) is another alteration product in the igneous rocks and is closely related to chlorite and sericite in origin. In some places it is pseudomorphic after the feldspar and may be easily recognized by its yellowish-green color. Occasionally, well-formed prismatic crystals have been found in small cavities. Although epidote is regarded as a common mineral in contact-metamorphic deposits, it is inconspicuous in the deposits of this class in the Leadville district.

RHODONITE

Rhodonite ($MnSiO_3$) is present in the lodes of the Ella Beeler group, in Iowa Gulch, in narrow parallel bands alternating with other minerals. No other occurrence of rhodonite in the Leadville district has been found.

SERPENTINE

Serpentine ($H_4Mg_3Si_2O_9$ or $3MgO.2SiO_2.2H_2O$) occurs exclusively as a gangue mineral of the magnetite-pyrite ores in the Penn, Comstock , and Ibex mines. In these ores it is probably the result of the decomposition of the pyroxene (diopside) or an olivine (forsterite). It is most abundantly present in the highly oxidized and hydrated ores from the old surface workings and upper levels of the old Breece iron mine, or, as it is now termed, the Penn mine. It forms a micro-granular aggregate through which the magnetite is profusely scattered as minute grains with partial crystalline form. It also occurs in an exceedingly irregular distribution throughout the magnetite, giving a contorted appearance to the rock, as shown in **Figure 50**.

The serpentine is in part smooth and massive, in part very finely granular. Its usual color varies from whitish to light green, and many of the specimens from the Penn mine are colored red by iron oxide.

In some places, the massive serpentine is penetrated by thin seams of a very clear white variety of serpentine. No fibrous serpentine has been noted at Leadville.

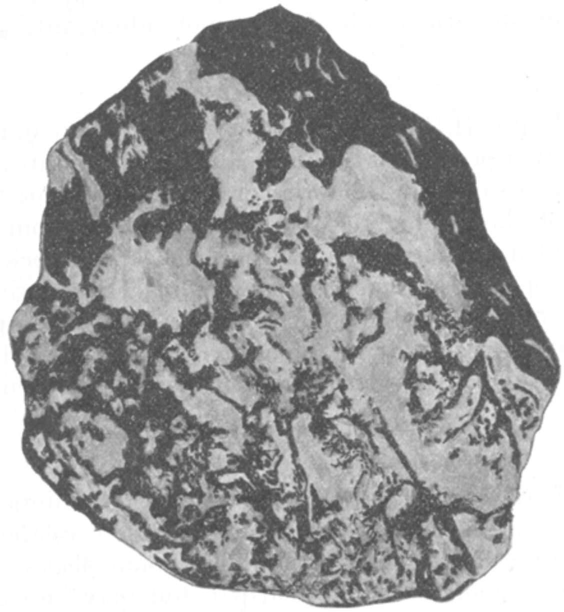


Figure 50. Serpentine irregularly distributed through magnetite ore, giving a distorted appearance. Part of the serpentine is stained red by iron oxide.

CLAY-LIKE MATERIAL

At several places in the oxidized and sulphide enrichment zones, there are large masses of white clay-like material, commonly referred to as "talc" or "Chinese talc" but containing no true talc. This material is mostly associated with ore bodies; it is probably most abundant along the base of the main sheet of White porphyry and is present along certain other porphyry sheets. It is also prominent in the shaly White limestone close by enriched sulphide ore bodies, as in the Golden Eagle and adjacent mines in Breece Hill, and spots and considerable masses of it have been found within enriched or partly leached sulphide ores, as in the gold-copper ore of the Golden Eagle and the loose-textured ore in the Mikado mine near the Mikado fault. These occurrences within limestone and ore are found on close study to be largely due to the replacement of carbonates, either the original dolomite and calcite of the rock or the manganosiderite disseminated through the sulphides. The masses along porphyry contact are doubtless due, in part at least, to replacement of the Blue or White limestone, although this relationship was evidently not considered when the contacts in the oxidized zone were most available for study. Other masses form rims around blocks of porphyry and have obviously been derived from them.

Masses of clay, in part heavily stained by iron and manganese oxides, are present between deposits of lead carbonate above and zinc carbonate below. In a few places these masses were stained green by absorbed copper. White, brown, and black clays containing considerable zinc have been described on pages 15 and 16. The gouge along and within fault zones, some of it white and some colored bluish gray by minute inclusions of pyrite and other opaque matter, may also be considered with this clay-like material.

Analyses of white clay-like material

	1	2	3	4	5
SiO_2	48.72	43.36	4.55	24.47	27.89
Al_2O_3	34.01	37.78	35.60	38.05	33.79
Fe_2O_3	0.56	---	2.26	0.93	---
FeO	0.66	---	---	0.77	---
CaO	---	0.22	Trace	0.23	0.53
MgO	1.11	0.30	Trace	0.30	1.14
K_2O	9.88	Trace	2.73	2.72	2.83
Na_2O	0.67	---	5.28	1.30	1.56
H_2O	4.22	17.95	15.05	16.67	[a]16.51
SO_3	---	Trace	34.55	15.48	15.75
	100.03	99.91	100.00	[b]101.15	100.00

[a] By difference
[b] includes 0.23 P2O5.

1. Amie mine, in ore body. Ore collection No. 55b.
2. New Discovery mine. Ore collection No. 55a.
3. Big Pittsburgh mine, contact of Gray porphyry. Ore collection No. 56c.
4. Morning Star mine. Ore collection No. 56.
5. Swamp Angel tunnel, contact of White porphyry. Ore collection No. 56b.

This material, according to available analyses, consists of hydrated aluminum silicates and alunite in varying proportions. Of the material represented by the above analyses, No. 1, from the Amie mine, consists mainly of very finely divided sericite. Its calculated mineral composition is sericite 89 percent (including 5 percent of the paragonite molecule), chlorite (pennine) 4 percent, silica 6 percent, and hydrous iron oxide 0.7 percent. Hillbrand[66] describes it as grayish white with pearly luster, compact, and very soft, rubbing off on the fingers. It was evidently derived directly from porphyry, as it contained remnants of feldspar crystals, which were removed by washing before analysis. This material was less clay-like than the other four samples. Similar material, which under the microscope proved to consist almost entirely of sericite, has been noted in other parts of the district, some of it in unaltered ore, and there are doubtless gradations in composition from such material to material represented by the other analyses.

Material from the New Discovery mine, represented by analysis No. 2, was pure white, veined with manganese oxide, compact, and soft (hardness=2), rubbing off on the fingers when dry. When fresh and moist it had a greenish opaline appearance and was translucent on thin edges but became opaque on exposure. The sample analyzed contained no manganese oxide. After two or three years exposure to air, it still retained 3.36 percent of hygroscopic water. No further loss of water took place below 160°–170° C, although the sample became black owing to the carbonization of organic matter. The analysis shows 0.8 percent too much alumina and 4.9 percent too much water to agree with the formula for kaolin but corresponds closely to published analyses of halloysite, an amorphous mixture of alumina, silica, and water. No microscopic description is available to show whether it consists of amorphous or crystalline material or a mixture of both. Similar material was found in the Morning Star and adjacent claims and analyzed by Ricketts.[67]

The material represented by analysis No. 3, from a Gray porphyry contact in the Big Pittsburgh mine, was pure white and resembled the sericite of No., 1. Calculation from the analysis gives soda alunite 67.7 percent, potash alunite 19, sericite 4.8, kaolinite 1.8, goethite 2.5, free silica 1.6, and excess

[66] U.S. Geol. Survey Mon. 12, pp. 603-604, 1886.

[67] Ricketts, L.D., The ores of Leadville, pp. 28-29, Princeton, 1883

water 2.66. The minor constituents are arbitrarily chosen in the absence of microscopic data. As the material did not have the hygroscopic properties shown by Nos., 2, 4, and 5, the excess water is presumably distributed in the different minerals.

No. 4, from the Morning Star mine, and No. 5, from the White porphyry contact in the Swamp Angel tunnel, were also white streaked with iron and manganese oxides. The calculated mineral composition of No. 4 is soda alunite 16.7 percent, potash alunite 23.2, sericite 0.8, kaolinite 51.9, excess alumina 1.9, and excess water 4.0. The excess alumina may be present as diaspore or hydrargillite, as in certain high-alumina clays, or may with the calculated kaolinite be present in an amorphous mixture. The excess water is again strikingly abundant. Hillebrand found only 1.23 percent of hygroscopic water, and the greater part of the excess is evidently distributed among the different minerals. No. 5, by the same method of calculation, contains 19.9 percent each of soda and potash alunite, 4.8 percent of sericite, and 42.8 percent of kaolin. Instead of excess alumina, it contains 5.8 percent of excess silica. Excess water amounts to 5.0 percent, whereas Hillebrand found 4.58 percent of hygroscopic water. The amount of calculated excess water that cannot be definitely accounted for as hygroscopic is greatest in Nos. 2 and 4, where hydrous aluminum silicate is present and alumina is in excess of the kaolin ratio. No. 4, with the greatest excess of alumina, also has the greatest excess of non-hygroscopic water. Hillebrand suggests that lime and magnesia in Nos. 4 and 5 might be present with alumina in indefinite hydrated silicates, but as residual grains and small lumps of residual carbonates have been found in similar white clays in the district, the lime and magnesia may quite as well represent unreplaced particles of the Blue limestone.

CALCITE

Calcite ($CaCO_3$) is rare as a primary gangue mineral accompanying the sulphide ores but is abundant in much of the oxidized ore. It occurs most commonly in small crystals, lining cavities in ore and gangue, but large and handsome rhombohedrons on cerusite ore from the Evening Star were noted by Ricketts.[68] Many of the oxidized zinc ores and associated iron and manganese ores contain cavities lined with colorless to white flat, disk-like rhombohedrons of calcite. These crystals lie with their edges normal to the cavity walls and represent the latest mineral growth in these ore bodies. Crystals of calcite have also been found lining caves in the oxidized zones of many of the mines, and veinlets are present in the oxidized zone.

ARAGONITE AND NICHOLSONITE

Aragonite ($CaCO_3$), the orthorhombic form of calcium carbonate, is confined even more strictly than calcite to the oxidized zone and the walls of drifts and stopes. It is occasionally found in close association with the oxidized zinc ores but has not been noted in direct contact with zinc ore minerals. It forms diverging to spherical radiating columnar aggregates, or groups of such aggregates (**Plate 51, *C***), usually if not invariably white. The one occurrence found by the writer formed pockets in brown siliceous iron oxide. So far as its general appearance and mode of occurrence are concerned, aragonite may be mistaken at first glance for calamine; but it lacks the characteristic bladed form of calamine and can further be distinguished by its brisk effervescence in very dilute hydrochloric acid.

The aragonite studied by the writer proved to contain little or no zinc, but a variety containing as much as 10 percent of zinc ($Ca(Zn)CO_3$) was studied by G.M. Butler, who gave it the name nicholsonite. According to Butler,[69] nicholsonite is identical with aragonite in all but three particulars. The specimens with high percentages of zinc have a higher specific gravity than aragonite, show a decided adamantine rather than a vitreous luster, and have a better cleavage (good pinacoidal and poor prismatic) than pure

[68] Op. cit., p. 29.

[69] Butler, G.M., Some recent developments at Leadville, second paper, The oxidized zinc ores: Econ. Geology, vol. 8, pp. 8-9, 1913.

aragonite. The nicholsonite was found in the oxidized iron-manganese ore in the Blue limestone and was named after S.D. Nicholson, of the Western Mining Co., who brought it to Butler's attention.

DOLOMITE

Dolomite ($CaMg(CO_3)_2$) is present in the leaner ores as unreplaced rock; also as white rhombohedrons lining vugs in sulphides and as small granular masses inclosing sulphide grains. In these occurrences it may be confused with manganosiderite, which is far more abundant. Gradations between the two minerals are common, and they cannot be distinguished without chemical analysis or determination of index of refraction.

Dolomite also occurs characteristically as white striped patches in the Blue limestone near ore horizons. These patches consist of roughly parallel streaks of white dolomite alternating with streaks of the Blue limestone. Some of them contain vugs lined with unit rhombohedrons of dolomite. Qualitative tests show the white dolomite to contain little if any more iron than the blue dolomite of the country rock, and the patches are attributed to recrystallization of the rock material and the elimination of its carbonaceous matter. Similar striped patches accompany the ore bodies in the Red Cliff district, to the north, and are aptly termed "zebra rock."

ANKERITE

Ankerite [$(Ca,Mg,Fe)CO_3$] was found by Philip Argall in the Mikado mine in 1919. It filled or lined small cavities in granular zinc blende and was similar to drusy siderite and dolomite in its paragenetic relations. It may be far more abundant than the lack of other known occurrences would indicate, for it so closely resembles both siderite and dolomite in appearance and mode of occurrence that it is easily overlooked. The relation of ankerite to the other carbonates has obviously not been determined.

RHODOCHROSITE

Although the rhodochrosite molecule ($MnCO_3$) is present in practically all the carbonates that form constituents of the primary ores of Leadville, it is very rare as a distinct mineral. It is said to have been found in veinlets in the sulphide ore in the A.Y. and Minnie mine, and it is reported to have been present in considerable abundance in the ores from the Mammoth mine, in Evans Gulch. These occurrences have not been seen and are not supported by chemical analyses; the possibility that the reported rhodochrosite is manganosiderite is therefore not excluded. Authentic rhodochrosite has been reported in considerable quantity in certain of the lodes of the Ella Beeler group and occurs abundantly in the Dinero vein, in the Sugar Loaf district.

BARITE

Barite, or heavy spar ($BaSO_4$), occurs rather sparingly in most of the Leadville district, except in the outlying area around the head of Iowa Gulch and in the Downtown and Fryer Hill areas. In the Iowa Gulch area, it is characteristic gangue mineral accompanying quartz, galena and blende in sulphide ores and quartz and cerusite in the corresponding oxidized ores. In the Downtown and Fryer Hill areas it is frequently found in local irregular masses composed of tabular crystals in divergent aggregates. Single crystals range from half an inch to 2 inches in diameter. These masses have been found mainly in or close by oxidized ore bodies, but their relations to the ores and wall rocks indicate that they were deposited with the original sulphide ore. No well-developed crystals have been found in these masses, but a few small yellow tabular crystals bounded by prism and basal faces were found in vugs in brown siliceous iron oxide from East Fryer Hill. These were clearly of later origin than the iron oxide and must have been deposited during a late stage of the period of oxidation. Some white crystals in vugs in sulphide ore said to come from the Yak tunnel were also seen but gave no indication of secondary origin. These crystals had been mistaken by lessees for cerusite, which they resembled rather closely.

ALUNITE

Although no alunite [$(KNa)Al_3S_2O_{11}.3H_2O$] has been identified by microscopic study, its presence in clay-like material is indicated by analyses 3, 4, and 5 on page 38. Owing to the inaccessibility of most of the workings in the oxidized zone during the resurvey, it has not been feasible to gain a quantitative idea of the presence of alunite, or a very definite idea of its mode of occurrence and relations to other supergene minerals.

EPSOMITE

Epsomite ($MgSO_4 + 7H_2O$) has been found at a number of localities a linings of fibrous material or capillary crystals, along the walls of drifts, both in the oxidized zone and in the sulphides that lie not far below the lower limit of oxidation. The fine, needle-like fibers are in places arranged with their longer axes perpendicular or at a high angle to the wall from which they project, so that they bear a strong resemblance to a coating of frost covering a surface of rock. These crusts, though not rare, are not so common as the other sulphates, goslarite, chalcanthite, and melanterite, all of which have been deposited by the evaporation of descending mine waters.

SULPHUR

Native sulphur is frequently found in the oxidized ores mingled with cerusite and other oxidized minerals. Emmons states that a mass of sulphur 2 feet in diameter associated with a little cerusite was found in a drift extending northward from the north incline in Iron Hill. It was free from iron and had evidently "resulted from the reduction of galena, the lead having been removed in the state of carbonate."[70]

[70] U.S. Geol. Survey Mon. 12, p. 397, 1886.

P L A T E 4 6

A. THIN SECTION OF TYPICAL SERICITIZED WHITE PORPHYRY IN EARLIEST STAGES OF THE PROCESS

B. CRYSTALS OF SPECULARITE REPLACING DOLOMITE

C. CRYSTALS OF SPECULARITE REPLACED IN PART BY PYRITE OF A LATER PHASE OF MINERALIZATION

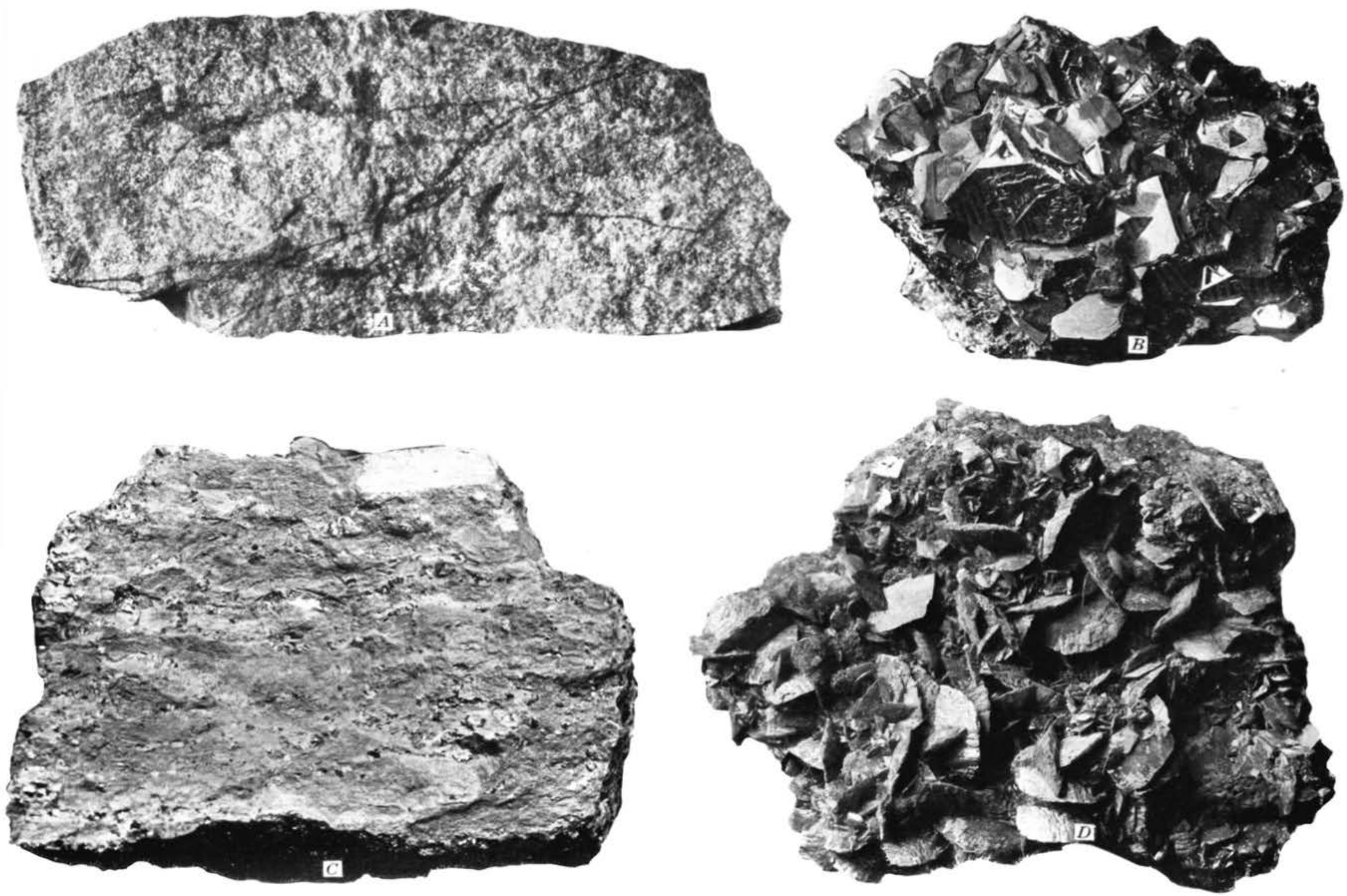


PLATE 47

A. MASSIVE MANGANOSIDERITE CUT BY DARK VEINLETS OF SULPHIDES AND QUARTZ WITH A LITTLE SIDERITE

B. FRESH GALENA CRYSTALS TYPICAL OF VUG LININGS IN LEAD SULPHIDE ORES OF CARBONIATE HILL AND GRAHAM PARK

C. ALTERED SHALY LIMESTONE IMPREGNATED WITH DARK GRAINS OF MAGNETITE AND LIGHT GRAINS OF PYRITE

D. MANGANESE-BEARING SIDERITE IN LARGE CRYSTALS LINING CAVITY IN LEAD-ZINC ORE FROM BLANKET BODY IN THE EAGLE (IRON MASK) MINE AT REDCLIFF

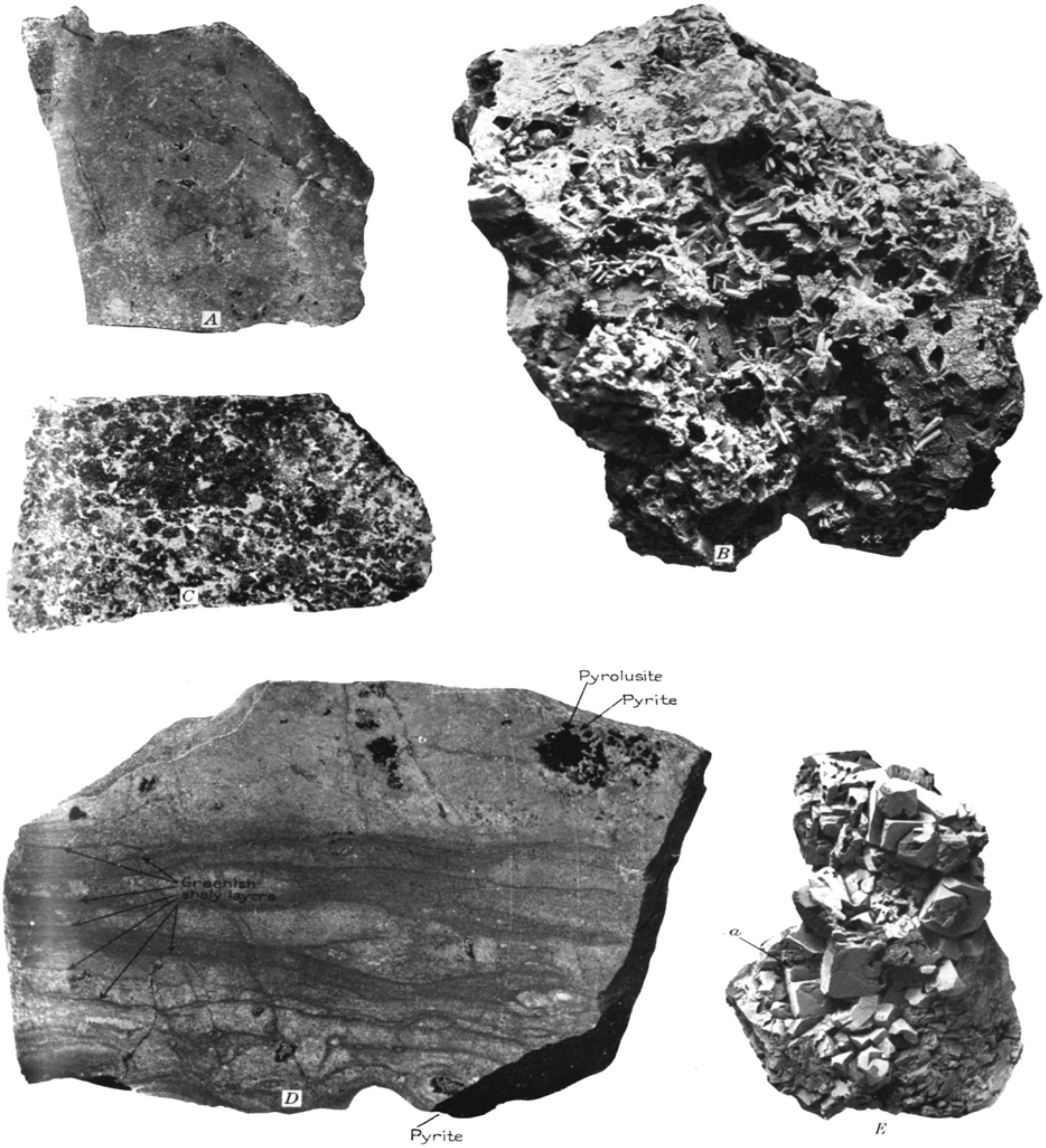


PLATE 48

A. FINE-GRAINED MANGANOSIDERITE CUT BY VEINLETS OF GALENA, PYRITE, AND SPHALERITE
Vugs lined with manganosiderite crystals

B. PYROMORPHITE CRYSTALS FROM OXIDIZED ORE IN THE IBEX MINE NEAR NO.2 SHAFT

C. PHOTOMICROGRAPH OF MANGANOSIDERITE ALMOST COMPLETELY REPLACED BY SULPHIDES
Light-gray areas manganosiderite; white areas are cavities filled with white kaolin; dark areas are pyrite, galena, and sphalerite; black areas are in unidentified mineral

D. MASSIVE MANGANOSIDERITE WITH SHALY LAYERS THAT PRESERVE BEDDING OF ORIGINAL WHITE LIMESTONE
Contains a few impregnations of pyrite and pyrolusite, the latter marking the beginning of oxidation

E. CORRODED GALENA CRYSTALS WITH INCOMPLETELY DEVELOPED SURFACES
Common in vugs in lead sulphide ores of Carbonate Hill and Graham Park

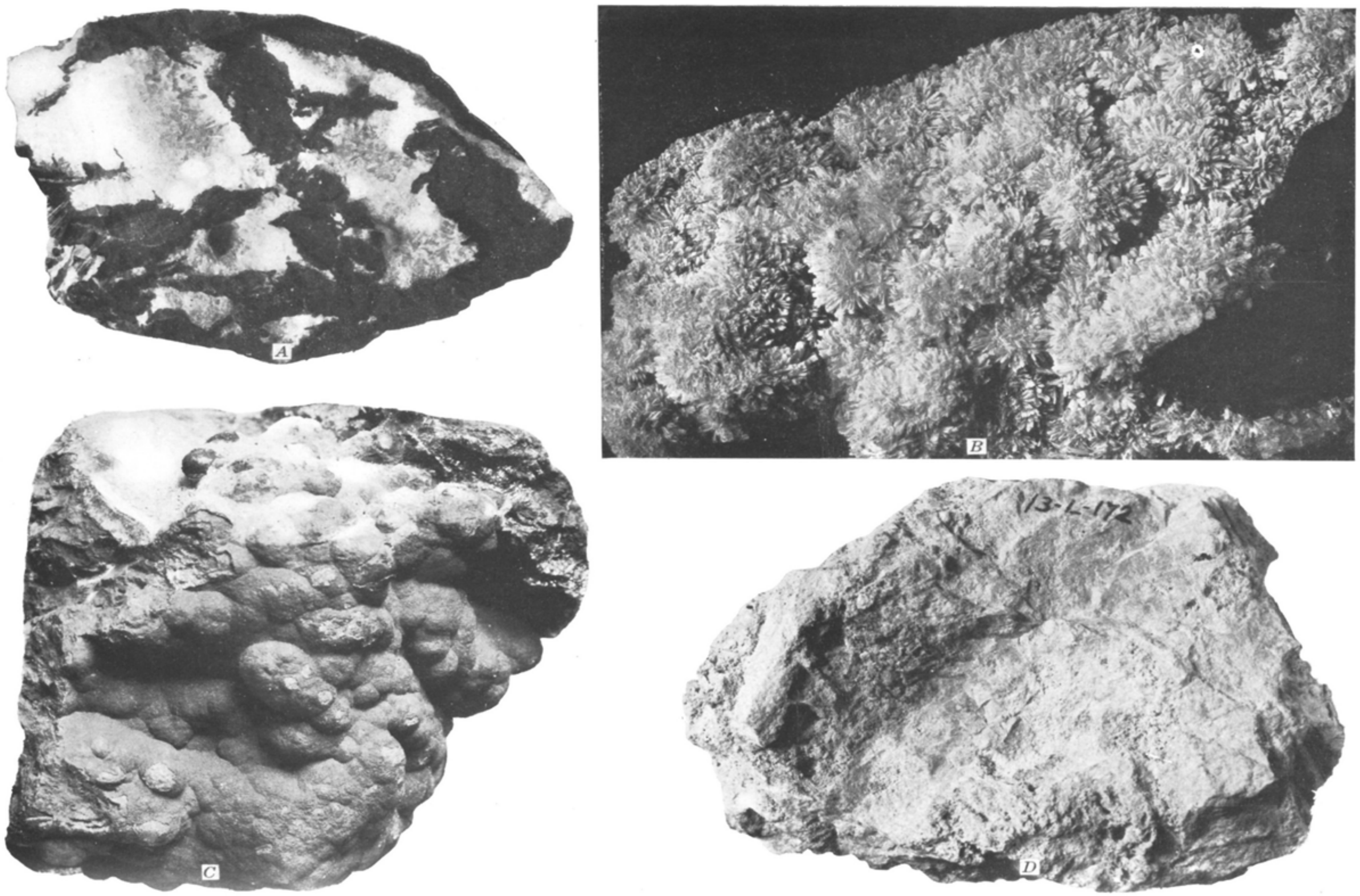


PLATE 49

A. BROWN ZINC CARBONATE ORE WITH WHITE DRUSES OF CALAMINE , WOLFTONE MINE

B. CALAMINE DRUSE COATING BROWN ZINC CARBONATE ORE, NEW DISCOVERY MINE

C. CHALCOPHANITE (BLACK) COATING BROWN ZINC CARBONATE ORE AND COVERED IN PART BY CALAMINE, NEW DISCOVERY MINE

D. GRAY FINE-GRAINED ZINC CARBONATE ORE, POROUS IN PLACES FROM THE LEACHING OUT OF UNREPLACED MANGANOSIDERITE, WOLFTONE MINE.

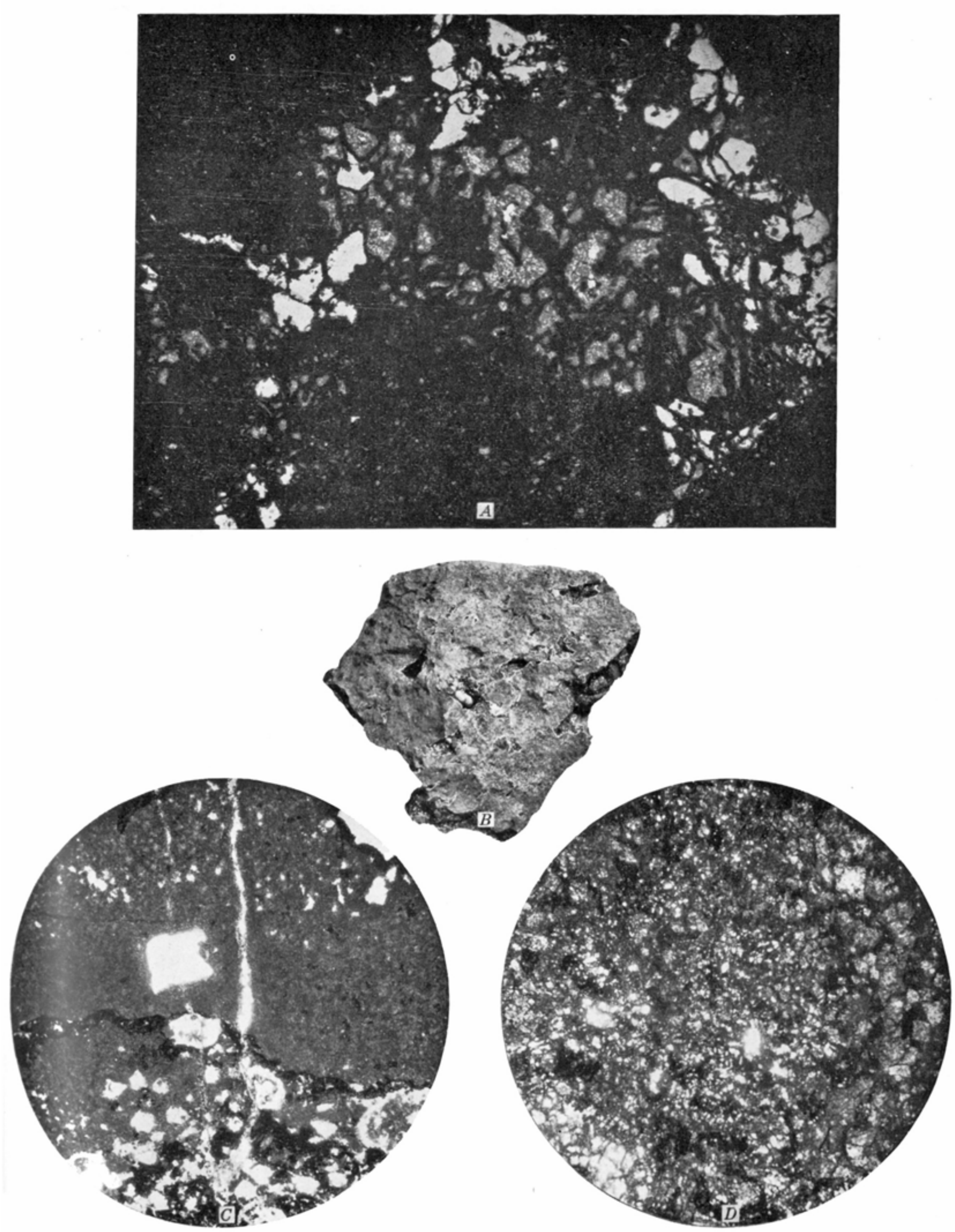


PLATE 50

A. PHOTOMICROGRAPH OF BROWN ZINC CARBONATE ORE WITH FINE DRUSES OF SMITHSONITE, DOME MINE

B. SPECIMEN SHOWN IN A

C. PHOTOMICROGRAPH OF GRAY ZINC CARBONATE ORE INCLOSING REMNANTS OF SULPHIDE OR, WOLFTONE MINE

D. PHOTOMICROGRAPH OF FINE-GRAINED ZINC CARBONATE REPLACING COARSE-GRAINED MANGANOSIDERITE, WOLFTONE MINE
The white spots are holes made during the grinding of the sections

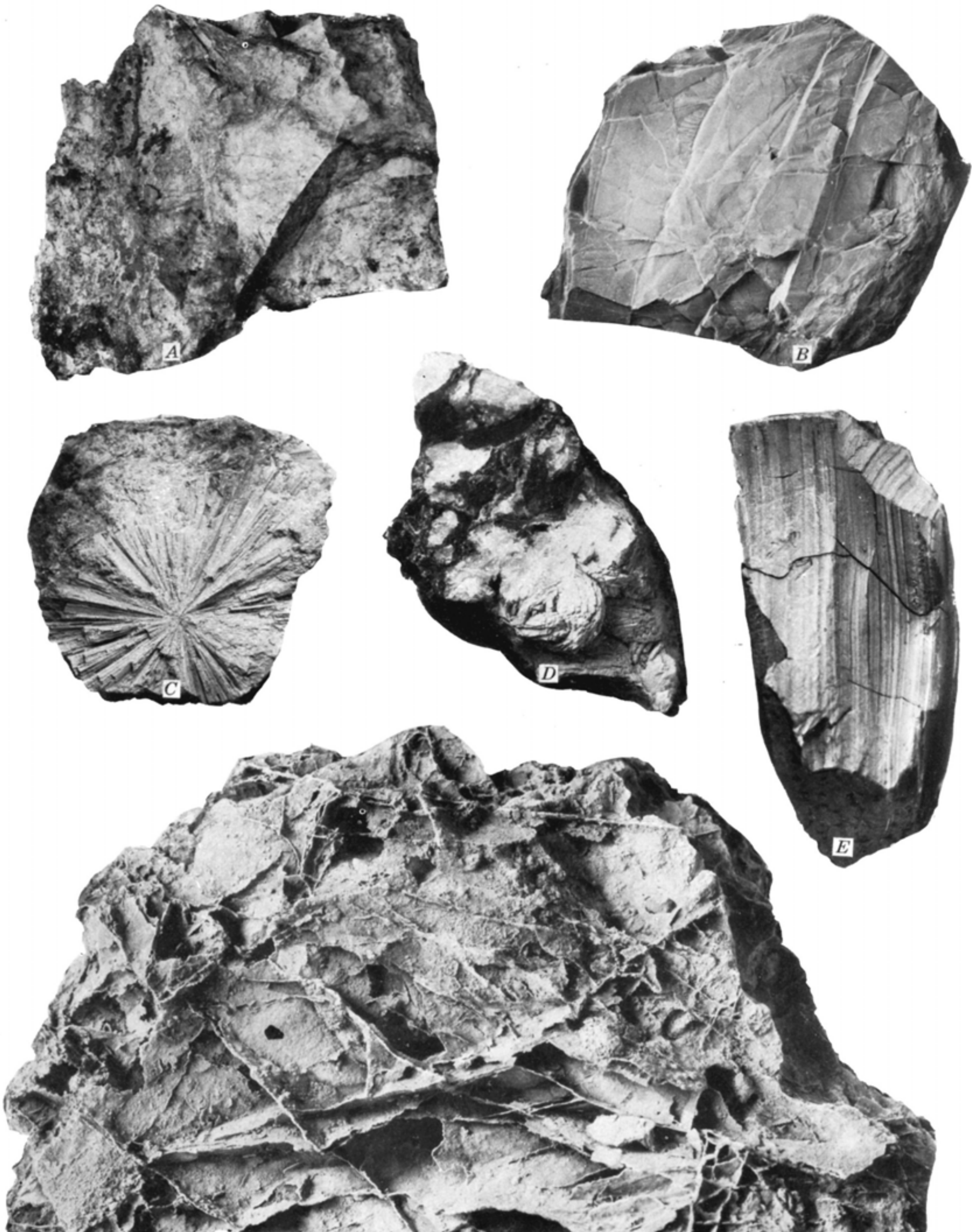
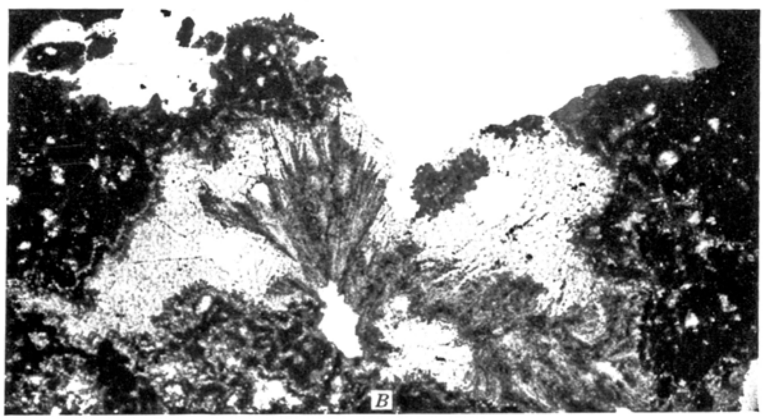


PLATE 51

A. WHITE ZINCIFEROUS CLAY, YANKEE DOODLE MINE
B. BROWN DENSE ZINCIFEROUS CLAY, NEW DISCOVERY MINE
C. ARGONITE FILLING CAVITIES IN BROWN IRON OXIDE
D. ARGONITE FILLING CAVITIES IN BROWN IRON OXIDE
E. BROWN BANDED ZINCIFEROUS CLAY, NEW DISCOVERY MINE
F. CELLULAR SMITHSONITE FROM SECOND LEVEL OF MOYER MINE



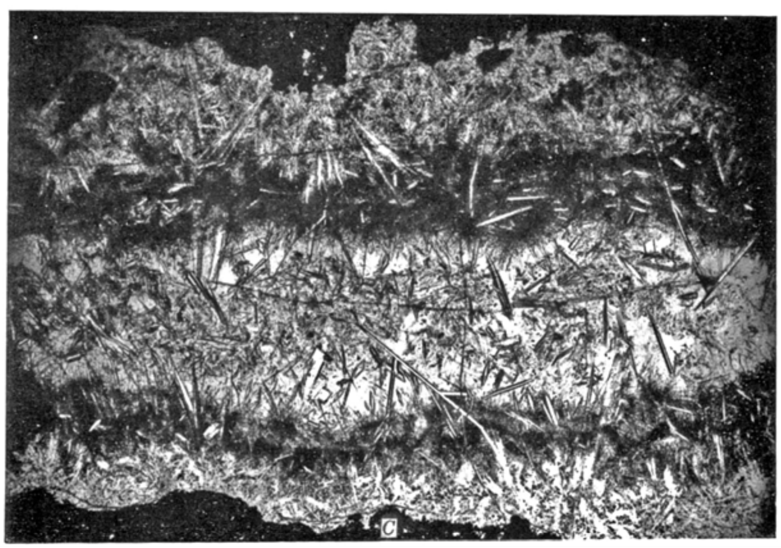


PLATE 52

A. BROWN ZINC CARBONATE ORE WITH DRUSES OF AURICHALCITE, LITTLE JONNY MINE
The aurichalcite is white in the picture but pale bluish green in nature

B. PHOTOMICROGRAPH SHOWING DARK RADIATING NEEDLES OF AURICHALCITE AND WHITE RADIATING AND CRISSCROSSING BLADES OF CALAMINE FILLING CAVITY IN BROWN ZINC CARBONATE ORE, LITTLE JONNY MINE

C. PHOTOMICROGRAPH OF VEINLET CONSISTING OF PRISMS OF CALAMINE AND LONG NEEDLELIKE CRYSTALS OF AURICHALCITE IN A MATRIX OF OPALINE SILICA< WITH WALLS OF LOW_GRADE BROWN ZINC ORE, BELGIAN MINE

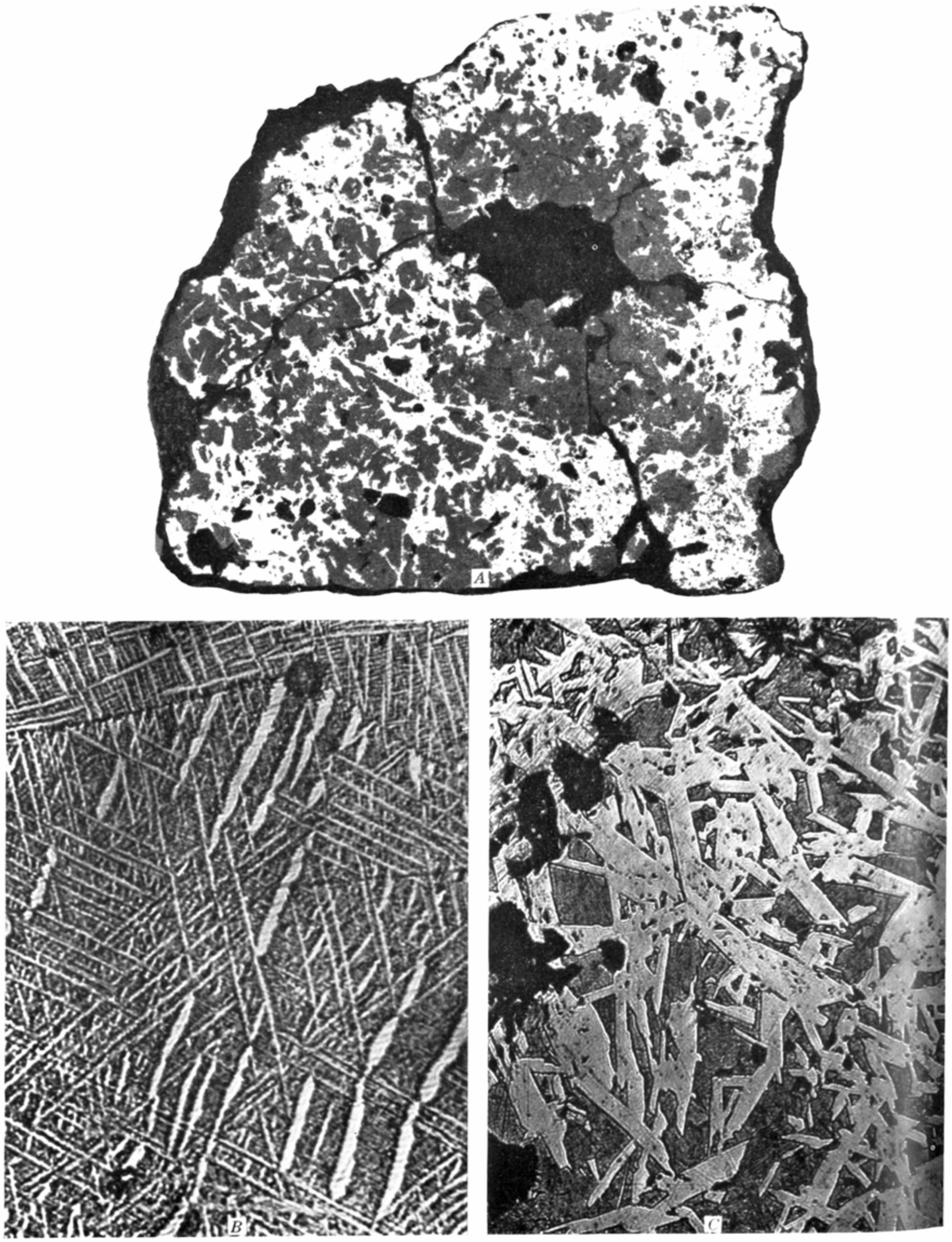


PLATE 53

A. INTERGROWTH OF PYRITE AND SUPPOSED LILLIANITE OR SCHAPBACHITE

B. PHOTOMICROGRAPH OF LILLIANITE AN INTERGROWTH OF BISMUTHINITE AND ARGENTITE, BALLARD MINE

C. PHOTOMICROGRAPH OF LILLIANITE AN INTERGROWTH OF BISMUTHINITE AND ARGENTITE, TUCSON MINE

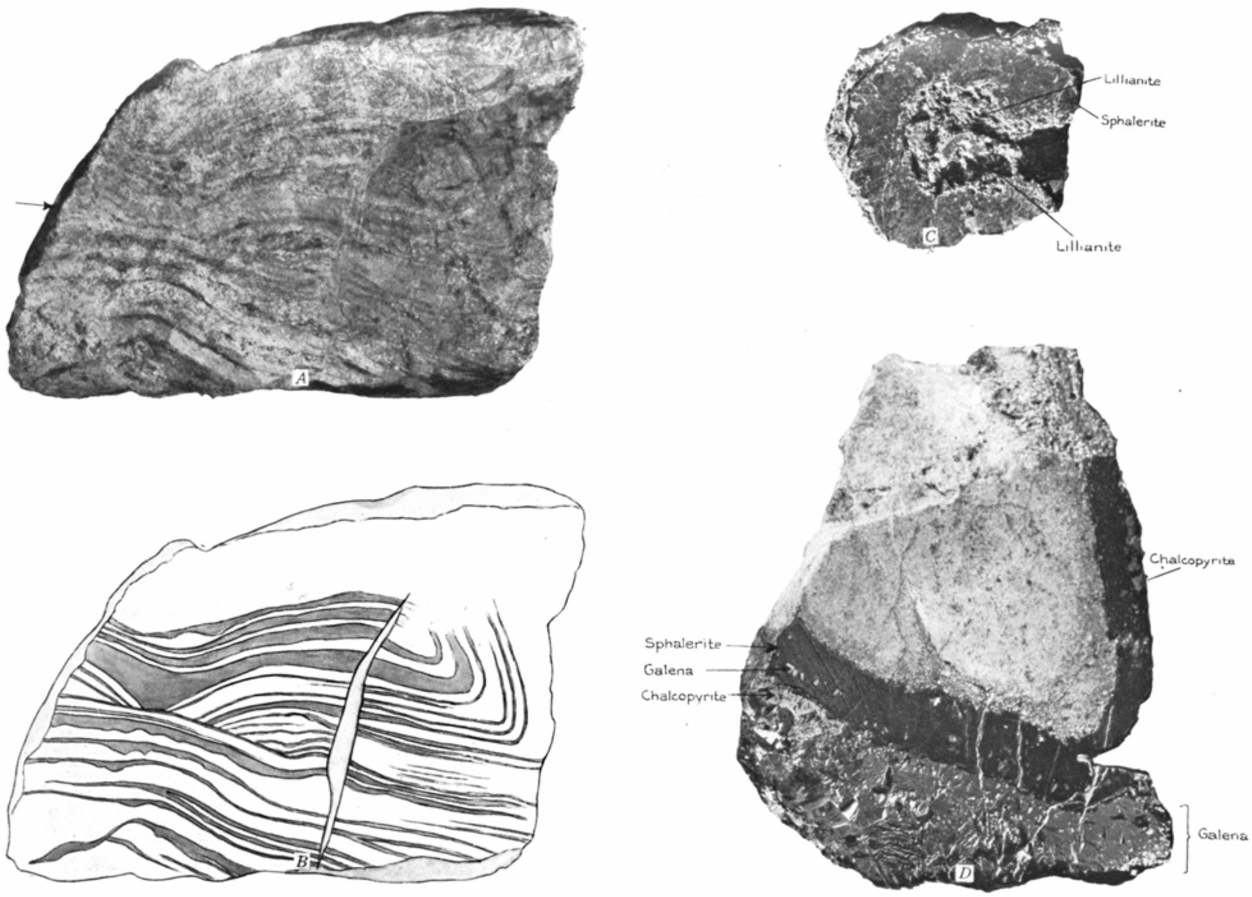


PLATE 54

A. ALTERNATE DISTORTED BANDING OF PYRITE AND SPHALERITE AND PYRITE-SPHALERITE MIXTURES, SHOWING FOLDING OF ONE SET OF LAYERS TRUNCATED BY A SECOND SET
B. DIAGRAM SHOWING MORE CLEARLY THE UNCONFORMITY OF BANDING ILLUSTRATED IN A
C. PHOTOMICROGRAPHS OF ORE CONTAINING LILLIANITE, TUCSON MINE

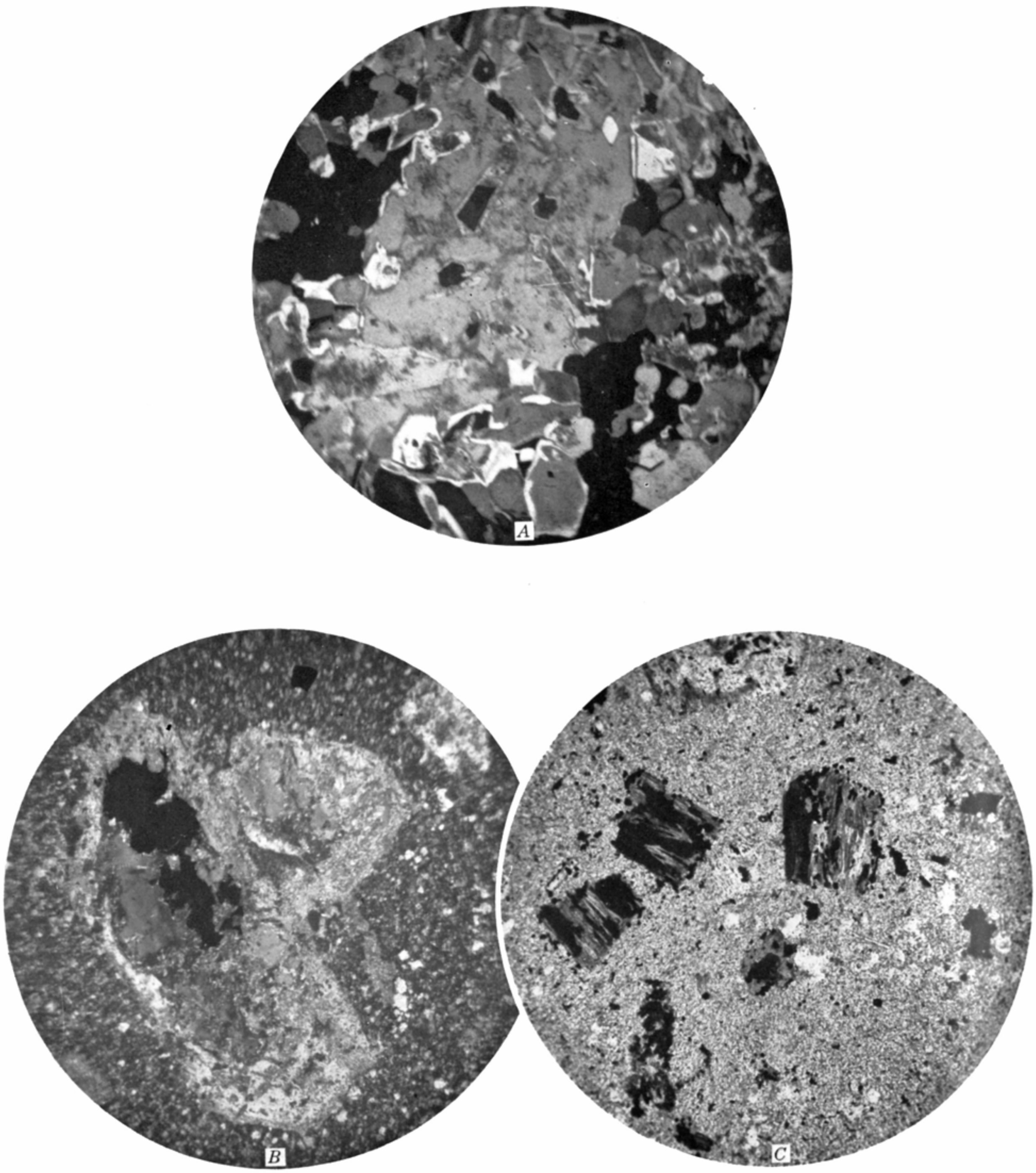


PLATE 55

A. THIN SECTION OF JASPEROID OR COMPLETELY SILICIFIED LIMESTONE FROM FISSURE VEIN IN RESURRECTION MINE

B. THIN SECTION OF MODERATELY SERICITIZED GRAY PORPHYRY

C. THIN SECTION OF GRAY PORPHYRY SHOWING MEDIUM TO ADVANCED STAGE OF PROPYLITIC ALTERATION

CHAPTER 9

PRIMARY (HYPOGENE) ORES AND ORE BODIES

In the chapter on mineralogy (Chapter 8) some idea is given of the material constituting the ores. In the present chapter the distribution of the ore bodies and the chemical and physical features of the different kinds of primary or hypogene ore are described.

HYPOTHERMAL OR "CONTACT-METAMORPHIC" ORES

The term "contact-metamorphic" applied to ore signifies a replacement deposit composed of minerals formed at high temperature close to the contact of an intrusive igneous mass with which the ore is in close genetic relation. The ores included in this class at Leadville conform to this meaning as regards mineral composition and distribution around an intrusive stock, but their genetic relation, as shown on page 209 (not in this report), is not so close to the exposed porphyry as to some later unexposed intrusion within the stock.

These ores are commercially the least important. Iron ore of this class altered by oxidation has been shipped since the early days from the Breece iron or Penn mine, but other shipments have been limited to ore that has been cut and enriched by later pyritic gold ore.

Distribution

These ores, in which magnetite and specularite are the principal metallic minerals, are found in quantity only in the Breece Hill area. These two minerals, however, are minor constituents of ores elsewhere in the district-for example, along the Tucson and Maid faults in the Iron and Carbonate Hill areas-and contact-metamorphic ores cannot be sharply separated from the more abundant sulphide ores in distribution, form or mineral composition.

The largest magnetite ore bodies have been found in the Penn, Nettie Morgan, Comstock, and Robert Burns mines and on the sixth, seventh, and eighth levels of the Ibex mine. Another body 7 feet thick was cut between two Gray porphyry sheets in the My Day drill hole at a depth of 350 feet. They are all irregular replacement deposits in limestone and in this respect may be termed "blanket" ore bodies. In some places the limestone is entirely replaced and the ore is bounded by walls of intrusive porphyry. Where unreplaced masses of limestone remain, their boundaries with the ore are in part gradational and in part sharp. The limestone bordering the ore in the Robert Burns and Comstock mines is readily identified as Blue limestone both by its lithologic character and by its stratigraphic position above the Parting quartzite. The limestone wall rocks in the Penn and Ibex mines are also believed to be Blue limestone, but the structure in both mines is so complicated that this is not certain.

Character

The hypothermal ore consists of a mixture of magnetite, specularite, and in places dark-red hematite and pyrite, with minor quantities of chalcopyrite and a little zinc blende and galena. Red massive siliceous hematite has been found only in the old open cut of the Breece iron or Penn mine, where the ore has long subjected to oxidation. The gangue consists of the silicates; serpentine, wollastonite, epidote, and sericite, the carbonate siderite, which contains varying quantities of magnesium and manganese, and a little quartz. Magnesite may be associated with the serpentine but has not been identified. The serpentine is an alteration product of a pyroxene or olivine. Serpentine and siderite are the most abundant gangue minerals. Wollastonite has been found only in the My Day drill hole but has doubtless been destroyed or obscured elsewhere by alteration processes. Epidote occurs very sparingly, and other silicates characteristic of contact-metamorphic ores are absent.

The central parts of the ore bodies consist of magnetite with varying amounts of specularite, which together constitute 80 per cent or more of the whole. A chemical test of this ore by W. F. Hillebrand in the laboratory of the United States Geological Survey proved it to be entirely free from titanium, chromium, magnesium, phosphorous, and zinc. Near the edges serpentine and carbonates increase in quantity, and in some places magnetite is disseminated through adjoining shaly limestone. Even in the purest masses of magnetite, small irregular interstitial grains and patches of siderite are present. This mixture of magnetite and siderite is the most common variety of the ore.

Serpentine is most abundant in the open cut of the Breece (Penn) iron mine, though it is present to some extent in all the magnetite ores. An analysis of the serpentine-magnetite ore from the Breece iron mine is given on page 3.

Pyrite occurs in part as irregular, rather coarsely crystalline patches, from which irregular branches extend into the massive magnetite. It also fills distinct fractures in the magnetite. It is accompanied in both modes of occurrence by quartz, which varies directly in quantity with the pyrite. As these minerals increase in quantity they mark a gradation into siliceous pyritic ore. This ore was for the most part, however, deposited distinctly later than the magnetite. Quartz is inconspicuous or absent in the purer magnetite masses.

Around the edges of the contact-metamorphic ore bodies magnetite impregnates the strata for considerable distances (**Plate 47, C**; Chapter 8, p. 43). The magnetite forms bluish streaks and is accompanied by sericite and pyrite. Under the microscope parts of the linear groups or streaks of magnetite are seen to be enclosed in relatively large pyrite cubes which have replaced the adjacent rock material. Here as well as within the main mass of ore the pyrite was formed subsequently to the magnetite.

Analysis of contact-metamorphic ore from Breece (Penn) iron mine
[R. C. Wells, analyst]

SiO_2	19.01	H_2O+	5.88
Al_2O_3	[a]20.23	TiO_2	.18
Fe_2O_3	13.71	ZrO_2	None
FeO	9.90	CO_2	1.85
MgO	24.35	P_2O_5	.14
CaO	.03	MnO	.02
Na_2O	.42	FeS_2	4.17
K_2O	.09		100.50
H_2O	.43		

[a]The high alumina is unaccounted for in Irving's description. It may be present as spinel and chlorite and may have been supplied by shaly beds just above the Parting quartzite.

Very little of the magnetite-pyrite ore is entirely free from oxidation. In some places where oxidation is rather pronounced a good deal of vivianite is present, which indicates the presence of considerable phosphorous, in contrast with the test by Hillebrand cited on page 1 but in accordance with the analysis above.

The ores containing magnetite are characteristically low in gold and silver except where pyrite and quartz are conspicuous. They rarely contain more than half an ounce of gold and a few ounces in silver to the ton.

MESOTHERMAL ORES

Veins and Stockworks

EARLY HISTORY

Veins including single veins and vein zones, have been known and worked in the Leadville district for more than 60 years, but throughout a great part of this time their commercial importance and geologic significance have received comparatively little attention. The Printer Boy vein was discovered in 1868 and is reported to have produced between $600,000 and $800,000 in the first two years of its history. Other deposits that were producers of some importance in the late seventies and early eighties are the Ontario, Tiger, Green Mountain, Ready Cash, 5-20, and Colorado Prince veins and the Antioch stockwork.

The discovery of carbonates in 1874 and the almost immediate rise of the blanket ore bodies to a preeminent position in the production of the district lessened interest in the veins until 1891, when the development of productive veins in the Ibex mine began to attract general attention. Since then discoveries of rich ore shoots from time to time have maintained a fluctuating interest in the veins. That certain recent developments in these veins were proclaimed by some writers[1] as discoveries of a kind of ore deposit whose existence was hitherto unsuspected in the district was not surprising, as there had been little publicity regarding the most steadily productive veins.

The danger of serious legal complications regarding apex rights that might have arisen if the existence of veins were too widely advertised may readily explain the apparent neglect of a significant geologic fact, even if the vast production of the blanket bodies had not for so long overshadowed all other forms of deposits. But the increasing number of veins that have become productive in the district, the mining of rich ore from several of them, and the discovery of connections between veins and blanket ore bodies have gradually gained for the lodes or veins general recognition.

CLASSIFICATION

The veins are classified for purposes of description as major and minor. These terms are used here primarily to indicate relative economic importance, but as all the longer and more continuous veins so far discovered have fortunately been profitable or have offered hopeful indications at some points along their courses, the grouping would hardly be altered if it were based on size alone. Each of the veins classed as major either has in fact been extensively explored or appears to justify considerable development work. The veins classed as minor include some which are fairly wide; these have as a rule been explored only for very short distances but have commonly been shown by exploration of adjacent ground to be short or discontinuous. Some of the minor veins that have been found remain undeveloped because of their small size or the low grade of their ore.

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[1] Ralston, O.C., Leadville fissure veins: Mines and Minerals, vol. 32, p. 549, 1912. Butler, G.M., A Leadville fissure vein: Econ. Geology, vol. 7, pp. 315-323, 1912; Colorado School of Mines Quart., vol. 8, pp. 1-8, 1913.

NUMBER OF DEVELOPED VEINS

Irving obtained information more or less complete on 53 major veins, from nearly all of which ore has been produced, and 76 minor veins. Others doubtless remain to be discovered as development work is extended.

Only four stockworks have been mined. These are the Antioch and South Ibex, in Breece Hill, and two in the Cord mine, in Iron Hill. The Antioch is in porphyry in the vicinity of several minor veins; the South Ibex, mostly in “Weber Grits”, is contiguous with the Ibex No. 4 vein where it passes close to the Garbut vein; the Cord stockworks, in Cambrian quartzite and Gray porphyry, are enlargements of the Cord vein at its intersection with the Tucson-Maid fault.

DISTRIBUTION AND GROUPING

The veins are chiefly confined to the portion of the Leadville district lying east of the 106˚ 15′ meridian, and nearly all of those within this area lie east of the Weston fault. Of those that lie to the west of the Weston fault only six are known to have been productive-one each in the Penn, Tucson, Cord-White Cap, Wolftone, and Greenback mines and one of very minor importance in the Penrose mine. A number of veins too small for development have been discovered in the Yak and Agwalt tunnels west of the Weston fault and in the Antioch workings.

It is quite possible that a few more veins may yet be found in the western portion of the district wherever the lower strata have not been extensively explored but exploration as a whole has already been extensive in this part of the area, and the small number of lodes discovered is evidence of their relative scarcity.

The distribution of the veins in the eastern part of the districts is shown on **Plate 56**. On this plate the spacing of the veins does not show them in exactly their true relations, as they have been found at many different depths, and only a few have been traced to the surface. Owing to the slight vertical range of most of them it is impracticable to represent them on a single horizontal plane.

The veins in the area east of the Weston fault are either isolated, as the Winnie-Luema, Sunday, and Silent Friend, or lie closely spaced in well-defined groups. The four principal groups, named in the order of their economic importance, are the Ibex, Big Four, Resurrection, and Ella Beeler. To these may be added the Iron Hill group and the Carbonate Hill group. Each of these groups is included within a very small area and is separated from its neighbors by correspondingly broad areas that are practically barren or undeveloped. Thus the Ibex group contains no less than 70 veins, all included beneath a surface area 1,400 by 2,000 feet; the Big Four group, nine veins in an area 1,500 by 1,200 feet; the Resurrection group, nine veins within an area 1,600 by 800 feet; and the Ella Beeler group (south of the Leadville district), seven veins in an area 1,200 by 3,000 feet. The Iron Hill group includes the Cord vein and one or more veins parallel to it in the Cord mine. The Carbonate Hill group includes a developed vein on the eighth level of the Wolftone mine and one on the seventh level of the Greenback mine, besides a few veins too small to work. Further exploration may add other veins to these two groups.

The spacing of the veins within the several known groups is so close that it does not seem likely that the wide intervening areas are wholly devoid of veins. As the veins present few outcrops and therefore must be discovered mainly in underground workings, it appears possible that the failure to find veins in some area may be due to lack of underground exploration. This possibility is strengthened by the fact that the Sunday, Luema, Penn, Silent Friend, and Printer Boy veins were found in comparatively isolated positions well out in the largely barren areas intervening between the groups.

DISTRIBUTION OF VEINS IN COUNTRY ROCK AND RELATION TO STRUCTURAL FEATURES

The veins intersect all the bedrock formations in the Leadville district, except the rhyolitic agglomerate. Only the smaller and less continuous veins occur within a single kind of rock, and this rock is usually one of the intrusive porphyries. All the veins that are productive or that have been traced for more than a hundred feet pass from one formation to another; the walls of some veins, indeed, present a bewildering succession of formations. This is particularly true of the Ibex group of veins on Breece Hill, where the sedimentary formations are cut by an unusually large number of porphyry sheets, some of which are very irregular.

The veins have been little disturbed by deformation since their deposition. They are broken here and there by recent faults, most of which are to small and too widely spaced to affect mining seriously.

All the larger and continuous veins have been found in those rock masses, which consist of alternating sedimentary beds and porphyry sheets. Within the large mass of Gray porphyry that forms the western slope of Breece Hill many fissures are present, but they are all small and discontinuous and have so far proved disappointing. There seems to be some probability that the more massive and tougher body of Gray porphyry has offered a greater resistance to extensive fracturing than the complex made up of different varieties of rock. The shale strata are also unfavorable, especially along the faults of considerable size; veins that are productive elsewhere are likely to pinch where one or both walls consist of shale.

Most of the larger veins are in faults of considerable size. The Ella Beeler vein, in the Iowa Gulch area, according to information supplied by Charles J. Moore, lies in the Weston fault, which shows more displacement than any other mineralized fault. South of the Iowa fault the vein is in the reverse part of the Weston fault, between an eastern hanging wall of pre-Cambrian granite and a footwall of White porphyry, Blue limestone, and lower formations; north of the Iowa fault it continues between an east wall of "Weber grits" and a west wall of White limestone and lower formations. There are several parallel slips in the fault zone, and several veins in the Ella Beeler group; and more exploration is necessary before the structural relations are thoroughly understood. Other veins that clearly occupy faults of considerable size are the Silent Friend, Nevada, Winnie-Luema, Modoc, Garbutt, and Ibex No. 4. The Sunday vein has also been reported to occupy a fault, but the amount of displacement has not been recorded.

RELATION OF VEINS TO EROSION

With the exception of the Garbutt, Sunday, and possibly the Printer Boy veins, whose early history is little known, the important veins of the Leadville district have been discovered by underground workings. The scarcity of outcrops is due to three distinct causes: (1) The fissure fillings are much less resistant to erosion than the inclosing wall rocks; (2) a heavy mantle of "wash", glacial debris, and "lake beds" almost wholly covers the district, and in the areas from which it is absent fissures are notably scarce or entirely absent; (3) the great majority of veins so far mined do not extend upward to the bedrock surface. They either terminate upward in the flat blanket ore bodies, as in the Resurrection mine, or simply die out and disappear before reaching the surface, as in parts of the Ibex mine.

Of those few veins which have been actually traced to the bedrock surface, two, the Garbutt and Sunday, crop out in "Weber grits". The rest are found in the deeply eroded portions of the district-for example, north of the Colorado Prince fault, where several veins have been traced up to the bedrock surface, notably the Luema-Winnie, Louise, Big Four, St. Louis, and South Winnie.

The prevalence of veins in the more deeply eroded areas suggests that shale beds, particularly the "Weber shales", acted as barriers against which the veins terminated upward in blanket deposits; but intense mineralization at Breece Hill and on the western slope of Ball Mountain reached into the "Weber grits". Well-defined outcrops in this mineralized area are scarce, owing to the abundance of disintegrated rock or "wash", but the great amount of leached silicified grits and porphyry proves that mineralization has been extensive and suggests that additional veins await discovery in this area. Further deep exploration beneath the large blanket deposits in the western part of the district may disclose veins similar to those in the Cord, Greenback, and Wolftone mines.

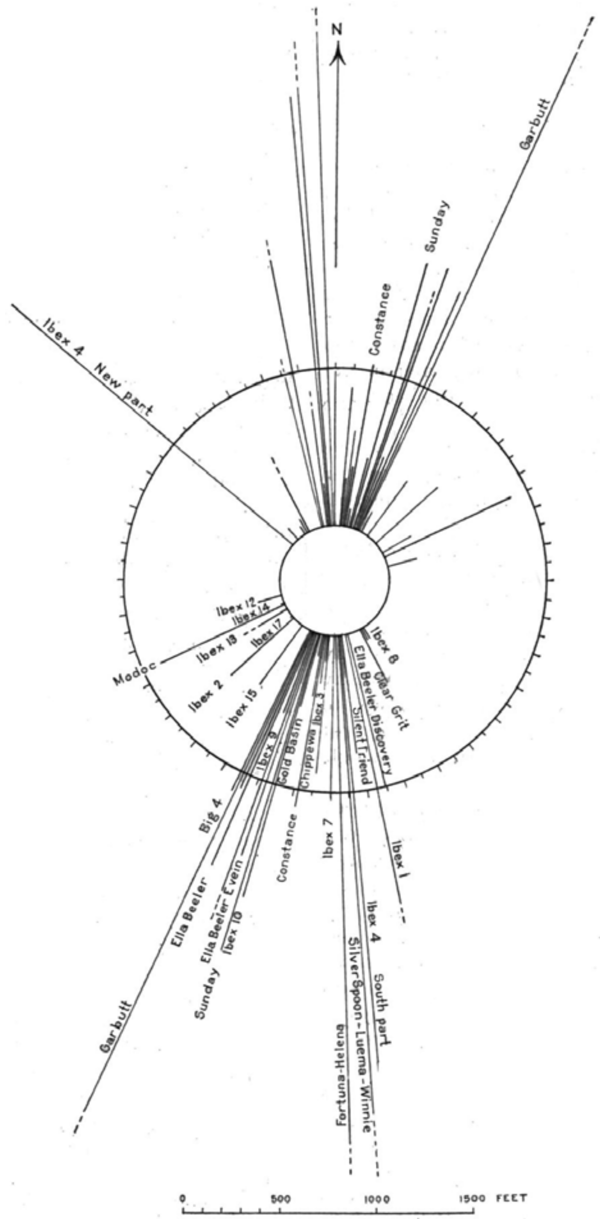

Figure 51. Strike and relative explored length of most of the major veins of the Leadville district.

STRIKE, DIP, AND COORDINATION

PREVAILING ATTITUDE

The veins for the most part strike north to north-northeast. Exceptions are the crescent-shaped fault fissures containing the Ibex No. 4 and No. 5 veins, the northern parts of which strike northwest, and the Modoc vein, which strikes east-northeast. The prevailing direction of strike is represented in **Figures 51 and 52**, in which the average directions are plotted about a common central point and the approximate length of the veins is represented by the length of the respective radiating lines. Most of the major veins trend within an arc of 42˚, N. 12˚ W. to N. 27˚ ., but a few strike between N. 30˚ E. and N. 75˚E, and the northwestern part of the Ibex No. 4 vein strikes N. 50˚ W. The greatest production has come from the group of more northerly trend, and this doubtless accounts for the rather general impression that all veins of the district have north-south trends.[2] The strikes of the minor veins in the Ibex mine (figure 52) range through a greater arc, but most of them are within the same arc as those of the major veins.

Most of the veins dip at high angles, usually between 70˚ and 90˚. A few dip at considerably lower angles. Thus the Constance vein, on the south side of Iowa Gulch, dips as low as 38˚ in places, and other veins dip between 50˚ and 60˚; but these are outnumbered by veins of nearly or quite vertical dip. An average of 34 observations is 74˚, which may serve as an approximate general average.

[2] Boehmer, Max, Am. Inst. Min. Eng. Trans., vol. 41, pp. 162-163?, 1911.

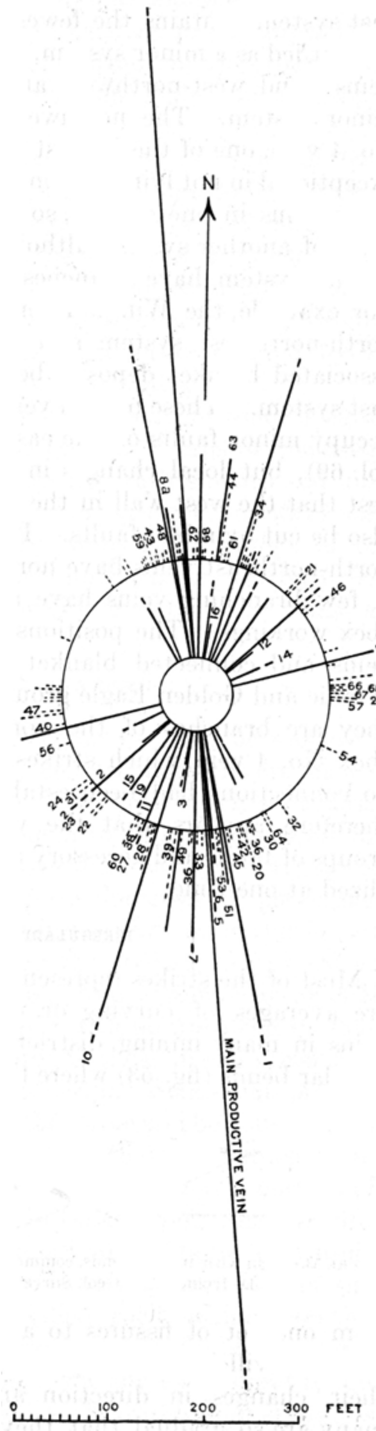

Figure 52. Strike and length of major and minor veins in the Ibex mine. The lines indicate minor lodes are not continued through the circle, and their length is shown by the portions outside the circle..

Variations of dip occur on all the veins. The attitude of some approximately vertical veins ranges from a vertical position to a very steep dip, which is here to the west and there to the east. In the main or west vein of the Big Four group the dip in the upper levels was vertical but as the vein was followed downward it assumed a west dip at gradually smaller angles. In general the dips change little along the strike but they change very markedly in a few veins; the No. 15 vein of the Ibex, for example, has a dip of 75˚ W. at one end and a dip of 75˚ E. at the opposite end.

Although Figures 51 and 52 give little indication of more than one rather poorly defined system, Plate 56 indicates three fairly well defined systems of veins—north-northwest, north-northeast and east-northeast. The north-northeast system is the most prominent and contains the largest number of productive veins, including the southern parts of the crescentic veins. The north-northwest system also includes some of the most continuous and productive veins in the district, including the Winnie-Luema, Silent Friend, Nevada, Penn, and a few of the Ibex group. The east-northeast system contains the fewest productive veins and is regarded as a minor system. A few scattered minor veins trend west-northwest and may be considered a minor system. The northwestern part of the Ibex No. 4 vein, one of the longest and most productive is exceptional in not lying within any of these systems.

No veins in one system, so far as known, intersect those of another system, although certain major veins of one system have branches belonging to another. For example, the Winnie-Luema vein belongs to the north-northwest system and its branches and their associated blanket deposits belong to the east-northeast system. These branch veins, so far as discovered, occupy minor faults on the east side of the main vein (Plate 69, chapter 13), but local changes in position of strata suggest that the west wall in the Silver Spoon mine may also be cut by minor faults. In the Resurrection mine north-northeast veins have north-northwest branches. A few branching veins have also been found in the Ibex workings. The positions of the north-northeast veins and connected blanket deposits in the Little Winnie and Golden Eagle ground (**Plate 57**) suggest that they are branches of the northwestern part of the Ibex No. 4 vein, which strikes about N. 50˚ W., but no connections had been established up to 1925. It therefore appears that the veins occupy conjugate groups of faults and accessory fissures that were mineralized at one time.

IRREGULARITIES

Most of the strikes represented in Figures 51 and 52 are averages of curving or undulatory veins. The veins in many mining districts are characterized by angular bends (**Figure 53**) where the vein filling alternates from one set of fissures to another. Some veins in the Leadville district approach this character, but their changes in direction are rarely sharp, and many are so gradual that they appear due to curvature of single fissures rather than to intersections of different fissures. Where faulting has taken place along intersecting fissures, however, the development of auxiliary breaks around the intersections, as suggested in figure 28 (extra figures and plates), and the shearing away of the sharp angles may develop a pronounced curvature. To what extent the curves of the veins at Leadville are original features of single fissures or fissure zones and to what extent they are effects of faulting along intersecting fissures is not known.

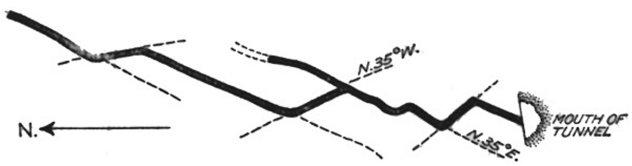

Figure 53. Vein with angular bends, common in many mining districts. (After J. D. Irving, U. S. Geol. Survey Bull. 478, p. 42, 1911)

A very few of the veins are approximately straight in their developed parts. The others may be divided into crescentic lodes and lodes of irregular curvature.

Crescentic veins.—Crescentic veins are those with dominant curvatures in one direction only. The radii of curvature differ for different veins but are fairly constant for individual veins. The thickening of some veins, as the Ibex Nos. 4 and 5, in the middle parts of their courses accentuates their crescentic appearance. Ten crescentic veins have been recognized. Their regularity is somewhat disturbed by minor flexures, but their great size makes them conspicuous when mapped. (See plates 56 and 57.) The 10 crescentic veins so far developed and their radius of curvature (in plan) are listed below.

	Radius (feet)		*Radius (feet)*
Ibex No. 4	950	Resurrection No. 1	1,700
Ibex No. 5	950	Resurrection No. 7	1,700
Ibex No. 3	200	Resurrection No. 6	1,500
Ibex No. 15	140	Gold Basin	420
Ibex No. 16	130	Winnie-Luema	6,400

The crescentic form is more pronounced in some veins than in others, and where the radius is large, as in the Winnie-Luema, the curvature is so gradual that but for the extensive development of the vein it could scarcely be detected. The Ibex No. 4 and No. 5 veins are strongly curved in their middle parts but become practically straight for considerable distances in both directions (plate 57).

The dip of all these veins except one is toward the inner side of the crescent but is subject to minor deviations. In some of the veins the angle of dip is least at the top and increases rapidly downward, so that the side which is concave in horizontal section is convex in vertical section (**Figure 54**). The Ibex No. 4 and No. 5 veins are nearly parallel veins of this character only 180 feet apart. Neither is perfectly continuous on all levels; each in places breaks up into slightly overlapping parts. Some of the minor veins between them have similar curvature. The other crescentic veins are less thoroughly known.

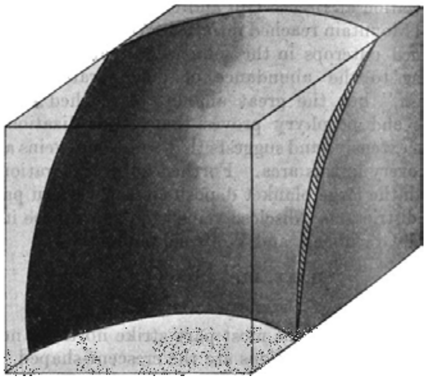

Figure 54. Vein with angular bends, common in many mining districts. (After J. D. Irving, U. S. Geol. Survey Bull. 478, p. 42, 1911)

Veins of irregular curvature.—The most conspicuous veins of irregular curvature are the Ibex Nos. 1, 2, 8, and 9, the Garbutt, and the Big Four. The Ella Beeler, Constance, Clear Grit, Helena and Fortune veins, in the Iowa Gulch area, are also of this class. Some of these veins are roughly crescentic as a whole, and others deviate about equally on either side of a straight course. Some undulate principally in their middle parts and become practically straight near one or both ends. The local trends tend to shift from one major system of strike to another, but the transitions, as already noted, are along smooth curves. Local changes in trend rarely exceed 40˚.

Other irregularities.—Besides variations in strike and dip, other features, such as minor parallel veins, pinches and swells, "horses", and branchings, are noteworthy. Minor parallel veins are of common occurrence, and several of them have proved large enough or rich enough to be worked, notably in the Ibex mine and along the Winnie-Luema veins. It is a somewhat common characteristic of the veins at Leadville, as elsewhere, that where ore has been deposited in a sheeted zone the main vein occupies only a minor portion of the zone, and parallel minor veins are irregularly distributed along each side of it. In some places where the main vein thins out a parallel vein thickens, and the workable part of the vein consists of a steplike series of closely related veins. Most of the minor parallel veins in the district have been discovered thus far accidentally. Systematic crosscutting to prospect for such veins as well as for parallel major veins has been much neglected and is one of the first things to be considered in the efforts to increase the productivity of veins under development and to discover new veins.

Swells and pinches are present in nearly all the veins. Most of the swells are due to a thickening of the brecciated material that originally filled the fissure which was especially subject to replacement by ore. Veins that enter readily replaceable limestone may either widen into lenticular bodies or send out flat blanket masses along certain beds. Many such occurrences are known. Other veins cross limestone beds without appreciable increase in width, and examination of the few accessible occurrences of this kind has shown that the limestone was protected from replacement by clay gouge along the walls of the fissure. Even a thin gouge may be an effective protection against replacement.

The pinches seen are due to the strong development of gouge or to the presence of considerable shale on one or both walls of the vein. The pay shoots of the Garbutt vein are found, in part at least, where the walls are coarse-grained "Weber grits", quartzite, or Gray porphyry, whereas the intervening spaces are marked by pinches between shale walls or by a mingling of vein minerals and unreplaceable shale fragments within the vein. The shale in the upper levels belongs to the Weber (?) formation and that in the lower levels to the "transition shales" at the top of the Cambrian quartzite. Horses of included rock are few, but some of them are large—for example, the Big Four lode contains a large granite "horse" which occurs well above the nearest point at which the vein lies between granite walls. In other veins smaller horses are occasionally found. They are rarely, however, in their original positions but have been considerably affected by differential movement of the two walls.

Most of the veins are very free from small irregular branches extending into the outer walls of the fissure zone. The outer walls are generally smooth and uninterrupted, and the intervening ground consists of shattered rock separated by veins and stringers of ore. Small branches have been noted in the Garbutt vein, however, particularly where one or both walls are shale.

TERMINATIONS

Most of the veins become too thin or too low in grade for mining before their terminations are reached. Where the terminations have been reached or closely approached the veins pinch to a knife-edge, split into a maze of small veinlets, or terminate abruptly against shale or against rhyolite agglomerate of post-mineral age. Most of the veins in the Ibex mine thin to very narrow seams both along the strike and upward and downward along the dip. Many veins appear in the lower levels of the Ibex of which no trace can be found above, and likewise many of those in the upper levels thin out downward along the dip. Some veins pinch out in both directions along the strike and both upward and downward along the dip, so that the entire vein is completely included within the explored portion of a rock mass. The Winnie-Luema vein narrows down at the south end to a small, unprofitable vein, and in its northernmost part it is a wide network of small veins, separated by silicified rock, which have been found to be of too low grade for profitable mining.

Owing to the prevailing low angle of dip of the country rocks, changes in wall rock are less numerous along the strike than along the dip of veins, and terminations of veins are mostly independent of wall rock. The upward terminations of several veins, however, as stated on pages 5–6, are controlled by some particular stratum; commonly the "Weber shales". Some of the stronger vein fissures cut through the thinner shaly beds at lower horizons but fail to penetrate the "Weber shales". Where their walls were sufficiently sealed by gouge changes in the kind of wall rock have had no influence on the mineralogy or thickness of the vein, but along many veins where the walls were imperfectly sealed the limestone between layers of shale or sheets of porphyry has been replaced by blanket ore shoots. Some small veins terminate in blanket bodies beneath such an impervious cap, and some of these blanket bodies connect with other small local veins that extend upward through the shale or porphyry to limestone at a higher horizon, where they connect with another blanket body (**Figure 55**). These relations were clearly shown in White limestone in the Golden Eagle workings of the Ibex mine in 1922, but the blanket bodies at the top of the Blue limestone, worked in the early days, have long been inaccessible. Their trends are generally parallel to those of the veins, however, and descriptions by those who have worked in them suggest that they are the upward terminations of veins (plate 57).

The downward terminations of minor veins may be found connected by blanket bodies or mineralized streaks along bedding planes with lower minor or major veins. The downward limits of the major veins, however, have not been reached and are not likely to be, as the ores are likely to become of too low grade for mining after the downward limits of sulphide enrichment have been reached.

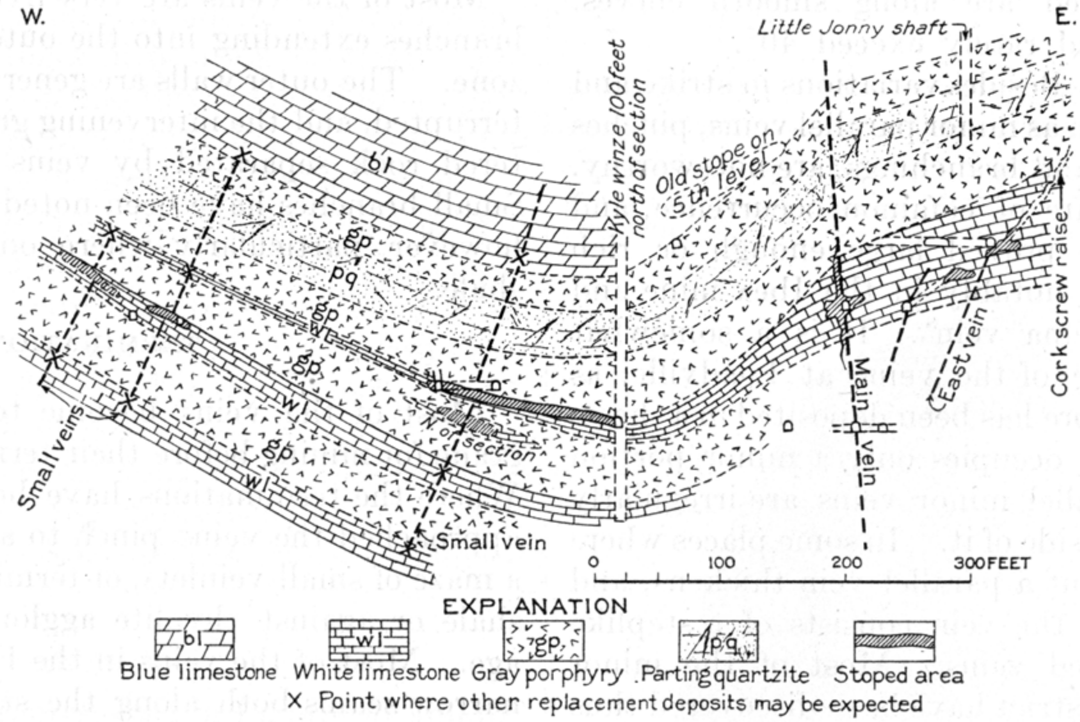

Figure 55. East-west section 20 feet north of Little Jonny shaft, showing relation of veins to blanket ore bodies in the Golden Eagle workings, Breece hill.

DIMENSIONS

The average length of the veins at Leadville, 700 to 800 feet, is short in comparison with the average length of veins in many mining districts. The lengths at Leadville mostly range from 200 to 1,000 feet. Exceptionally long veins include the Fortuna-Helena, in the Iowa Gulch area, reported to be 2,100 feet long; the Ibex No. 4, 2,700 feet (plate 57), and the Winnie-Luema, nearly 4,000 feet (plate 56). The widths range from a mere knife-edge at the terminations to more than 100 feet in the greatest swells. These unusually large swells, however, extend only for short distances, and a general average thickness of ore is not more than 3 feet. The workability of such narrow veins has been due largely to enrichment but in part to the easy removal of shattered waste material between the sides of the ore streak and the solid walls of the fissure zone. There is no definite basis for estimating the total depths of the major veins.

ORES OF THE VEINS

The veins are the result for the most part of replacement along shear zones and to a minor extent of cavity filling. Their principal original metallic mineral is pyrite, which is accompanied by minor quantities of chalcopyrite, zinc blende, galena, argentite and bismuthinite, and rarely by tetrahedrite and pyrargyrite. These primary sulphides are supplemented in the zone of sulphide enrichment by chalcocite, bornite, and locally visible gold and silver, one or more of which are generally essential to raise the ore to a profitable grade. The original gangue minerals are quartz and sericite, with minor quantities of siderite or manganosiderite, and locally barite. Rhodonite has been reported from veins in Iowa Gulch. In the zone of sulphide enrichment white clay-like material is abundant. In the oxidized zone the veins are changed to mixtures of brown and red iron oxide, black manganese oxide, cerusite, chrysocolla, horn silver, native gold, and clay-like material. Representative analyses of siliceous ores from veins or connected blankets are given on page 33 and accompany the descriptions of certain mines in chapter 13.

The ores of the veins may be divided on the basis of dominant mineral composition into three classes—(1) pyrite-chalcopyrite ore, with subordinate zinc blende, well developed in the Ibex, Big Four, and St. Louis groups; (2) highly siliceous ore, represented by the Resurrection group; (3) mixed siliceous sulphide ore, locally with prominent galena, represented by the Winnie-Luema vein. Although typical ores of these three classes are quite distinct from one another gradations are common and more than one class may be represented within a single vein. This is particularly true of the Winnie-Luema vein. According to commercial classification (page 67–68, Chapter 13) these veins include ore of all classes but very little mixed sulphide ore containing zinc in paying quantities has been shipped from them. Practically all the siliceous gold-silver, lead, and copper ores has come from them ore from small blanket ore bodies connected with them.

PYRITE-CHALCOPYRITE ORE

The pyrite-chalcopyrite ore, which is the most common variety, consists mainly of the two minerals from which it is named, with minor or inconspicuous quantities of quartz and altered wall rock. In places the two sulphides form solid masses filling the entire thickness of the vein. The chalcopyrite occurs in irregular interstitial grains among the larger and more abundant grains of pyrite and may be easily overlooked unless present in unusually great quantity. Vugs lined with the two minerals and rarely containing tetrahedrite are present here and there. The unaltered ore is hard unless softened by local films or streaks of highly sericitized rock. The ore most sought, however, has been altered to some degree and may appear as crumbly granular pyrite more or less tarnished or blackened by chalcocite. Where chalcocite is most conspicuous close inspection shows it to be mainly the product of a replacement of chalcopyrite. The chalcopyrite first becomes tarnished or coated by bornite, which in turn is replaced by chalcocite. Ore rich in chalcocite is likely to be rich also in silver or gold or both, but records of assays and smelter returns do not show any definite ratio between copper and gold or silver. Although quartz is a minor constituent, the ore shipped is distinctly more siliceous than the pyritic ore of the large blanket deposits in the western part of the district. It also contains more copper and gold.

A prominent sub-variety of this ore, which constitutes the largest shoots in the veins of the Ibex and Garbutt mines, consists mainly of pyrite cubes half an inch or more in diameter embedded in gray, fine-grained quartz or jasperoid. The texture and structural relations of the ore point to deposition by replacement. Oxidized portions of these ore shoots consist of honey-combed jasperoid with cubic cavities that are either empty (**Plate 58, D**) or partly filled with iron oxide, basic iron sulphate, or jarosite. The pyrite cubes have also been found partly or completely separated by practically pure sericite, and, in the sulphide enrichment zone, by masses of white clay-like material which has replaced sericite, shaly limestone, "Weber grits", or carbonate gangue.

The jasperoid matrix just described grades in many places into a cavernous variety that has resulted from the removal in solution of incompletely replaced rock or carbonate gangue. These caverns are lined with loosely compacted pyrite and quartz crystals. The pyrite and any chalcopyrite present are coated or considerably replaced by black, sooty chalcocite, which is accompanied by a little iron sulphate. The loose ore can be shoveled like gravel and has contributed greatly to the output of the Ibex mine.

HIGHLY SILICEOUS ORE

The highly siliceous ore in the Resurrection mine consists of dense quartz or jasperoid which has replaced sheeted zones in limestones and in which sulphides are usually scarce or absent. Galena and pyrite, however, are locally present in considerable quantity and their oxidation results in siliceous lead carbonate ore.

MIXED SILICEOUS SULPHIDE ORE

The mixed siliceous sulphide ore consists of pyrite chalcopyrite, zinc blende, and galena irregularly distributed through a gangue of quartz and silicified and sericitized wall rock. Small portions of ore in the Ella Beeler and Clear Grit group have a banded or crustified structure but are exceptional. The sulphides commonly form granular masses occupying the entire width of the vein or lenticular shoots within masses of gangue. Vugs lined with crystals of one or more sulphides are present here and there in the sulphide shoots. The general order of deposition of the sulphides was first pyrite, second zinc blende, and third chalcopyrite and galena. Quartz was deposited throughout the process but mainly before and with the pyrite and blende. Zinc blende and galena are prominent in some shoots and practically absent in others. Where they are abundant the ore is similar to the mixed zinc-iron-lead sulphide ore of the large blanket deposits in the western part of the district but is more siliceous and contains more copper and gold and locally more silver. The zinc blende, like chalcopyrite and pyrite, is in places coated with black films, probably of copper sulphide.

These ores, like other vein ores, have been considerably enriched with chalcocite and precious metals. The generally vertical or steeply dipping positions of the veins and the easy passage of water downward along them between their impervious walls of gouge have favored this kind of enrichment to relatively great depths, whereas conditions have not favored similar enrichment of the blanket ore bodies except in parts adjacent to and connected with mineralized fissures.

RELATION OF ORE BODIES TO CHARACTER OF WALL ROCK

As most of the major veins traverse rocks of several kinds, the influence of the physical and chemical properties of the different rocks on ore deposition is noteworthy. Mineralization in granite and porphyry has consisted chiefly of the replacement of broken material or sheeted rock within the fissure zone. The vein matter usually terminates abruptly on each side, against a selvage of gouge (finely ground sericitized rock); but the immediate wall rock is highly silicified for a few inches, beyond which for a considerable distance it is altered to a mixture of quartz, sericite, and thinly disseminated pyrite. As distance from the vein increases chlorite representing the original black minerals of the rock appears, and is accompanied by a minor amount of epidote. The alkali feldspar is only slightly altered, but plagioclase is considerably or completely altered to a mixture of sericite, epidote, and calcite. This partly altered rock grades into fresh rock. The zones of alteration are narrow in granite but are so extensive in the porphyry that it is doubtful if specimens quite free from mineralization can be found within the Leadville district.

Pyritic zones are also extensive in the Cambrian and Parting quartzites and “Weber grits” near the veins or related blankets. The pyrite fills interstices among the original quartz grains and is accompanied by microscopic sericite and inconspicuous secondary quartz. Sericite is abundantly developed at several places, however, near both veins and blankets, and evidently represents alteration of shaly beds.

The vein matter itself locally spreads from the fissure along bedding planes of the quartzite and “Weber grits”, and rarely it replaces calcareous beds. No replacement bodies of workable size connected with veins have been noted within the quartzites at Leadville, but in the Red Cliff or Gilman district, north of Leadville, an ore replacing a calcareous bed in Cambrian quartzite has been stoped as a local enlargement of the Bleak House vein. This vein was described in 1913 by Means,[3] who favored the view that the vein was later than and crosscut the replacement deposit but the evidence presented was not convincing. When the locality was visited by Loughlin in 1922 the vein itself, which had contained pyritic ore enriched in silver, had been worked out, and similar ore from adjacent parts of the replacement deposit had also been exhausted. The ore that remained in the walls of the stope was rather fine grained zinc or zinc-lead sulphide averaging 15 ounces to the ton in silver. There was no opportunity to study its relation to the pyritic silver ore.

Similar deposits due to the replacement of beds in the "Weber grits" have been noted along the Garbutt vein and some of the Ibex veins.

The stockworks have been developed where veins connect with shattered quartzite, "Weber grits", or porphyry at the intersections of fissures. They consist of networks of veinlets, which cement and to a minor degree replace the fragments of rock. The Antioch stockwork, worked by an open cut in the eighties is entirely in porphyry and has a roughly chimney-like shape. At the surface its north-south diameter is 215 feet and its east-west diameter 150 feet. It tapers downward, and the ratio of ore to rock fragments increases from top to bottom. The ore is entirely oxidized. The South Ibex stockwork is in "Weber grits" and a few intercalated sills of Gray porphyry. It has a roughly elliptical plan, with its longer axis parallel to the Ibex No. 4 vein. On the Ibex 500-foot level, it measures 130 by 120 feet; on the 900-foot level, 150 by 40 feet. These limits are determined by the contents of the ore rather than by any marked decrease in the ratio of ore to rock fragments. The two stockworks examined in the Cord mine are at the intersection of the Cord vein with the Tucson fault zone and have been productive on the northwest or hanging wall side of the Cord vein. The lower stockwork is in Cambrian quartzite at the ninth level, and the upper in Gray porphyry sill cutting White limestone at the sixth level. Ore of the same character has been reported in the intervening White limestone or transition shale, where shattering evidently permitted free circulation across the shale beds; but the ore mined in the limestone along the Cord vein has been take mostly from blanket replacement deposits.

The extent to which the character of the ore may be influenced by that of the wall rocks is strikingly illustrated by the No. 63 Ibex vein and its connected blankets. Where the walls are of porphyry, pyrite is the dominant mineral and forms relatively fine, even-grained masses, but where the ore body passes into "Weber grits" the amount of quartz gangue increases markedly and the pyrite consists of very coarse-grained aggregates and isolated crystals, mostly of cubic shape, which reach more than an inch and rarely 4 inches in diameter.

In limestones, particularly in the beds that alternate with shaly beds, nearly all the veins spread out into blanket ore bodies. Where the veins approach their upward terminations, as in the Nos. 3, 16, and 26 veins of the Ibex group, the blankets are unusually large and the fissures themselves terminate entirely; but where the veins are strongly developed the blankets extend out as branches at irregular intervals and the veins continue with undiminished intensity. The blankets in general have their longest dimensions parallel to the strike of the veins with which they are connected; but in the Winnie-Luema vein the northeastward trends of the blankets are determined by branch faults or fissures that seem to have guided the solutions and localized their action.

Very few of the veins pass through either shaly strata or limestones without the development of lateral shoots of ore; indeed, it would be a matter of great difficulty to find among the Ibex veins one without such auxiliary shoots attached to it at some portion of its course. These blanket bodies are much more abundant than can be appreciated from an examination of the mine maps or sections, because to pay for exploration, were left unexplored and are not recorded on the maps and sections.

[3] Means, A. H., Geology and ore deposits of Red Cliff, Colo.: Econ. Geology, vol.10, pp 1-27, 1915.

Blanket Ore Bodies

GEOGRAPHIC DISTRIBUTION

By far the greatest part of the total tonnage of ore from the Leadville district has come from the large bodies formed by the replacement of limestone, commonly termed blanket deposits. Besides these a few similar though much smaller deposits replacing quartzite and “Weber grits” have also been mined. These blanket ore bodies are widely distributed throughout the district, as shown in plate 45 (extra figures and plates), and have been worked in a few places to the east and south of the area there represented; but the largest are in the western half of the district. They commonly occur in groups, some merging into one another and others isolated.

In much of the intervening and surrounding areas the limestones have been either eroded, displaced by intrusive stocks of porphyry, or so deeply buried beneath glacial deposits or the Weber (?) formation that thorough prospecting has not been attempted. Elsewhere they have been found to be barren or of too low grade to pay for mining. The barren and unprospected areas are considered in chapter 14 (not in this report).

As the larger mining companies have kept excellent progress maps the positions and outlines of the larger blanket ore bodies are adequately represented in plate 45 (extra figures and plates); but maps of several of the smaller properties could not be obtained, and it has therefore been impossible to represent all the ore bodies. This statement applies particularly to the old properties in and between Stray Horse and Little Stray Horse gulches, and in less degree to the properties on Yankee Hill. This deficiency, however, does not seriously impair the value of plate 45 (extra figures and plates), as a basis for a general study of the distribution of the ore bodies. The most striking feature of their distribution is the roughly radial arrangement of the groups around the intrusive center of Gray porphyry at Breece Hill. Many of the single ore bodies also have a radial arrangement around this center. There are exceptions, however, to both rules as is to be expected from the fact, discussed elsewhere, that the location and grouping are controlled largely by other structural features, notably the reverse faults and normal faults and fissures formed subsequent to the intrusion of the porphyry sills.

RELATION TO COUNTRY ROCKS

The replacement ore bodies or blankets have been found in each of the sedimentary formations, but most of them are enclosed in the Blue or the White limestone. The Cambrian “transition shales” or “red cast beds”, which contain many thin beds of limestone, also contain several ore bodies of considerable size in areas of intense mineralization, and in these areas the quartzites also contain a few small ones. Blanket replacement deposits are also present here and there along veins in the Weber (?) formation. The principal function of the shales, however, and particularly of the porphyry sills, has been to serve as an impervious cover beneath which the ore forming solutions spread and replaced limestone.

Limestone.—The Blue limestone has contained the greatest number and the largest of the ore bodies so far mined, partly because the ore bodies in this formation were more easily discovered and worked and were more accessible to enrichment than those in lower strata. Many of the ore bodies in the White limestone and the underlying “red cast beds” lie beneath those in the Blue limestone and are therefore obscured in the mapping on plate 45 (extra figures and plates), but even with due allowance for this fact the difference in number and size is striking. In total production during the entire life of the district no other formation has excelled the Blue limestone in any considerable area, but the White limestone has been the most productive for several years in the Iron Hill areas and probably in the Carbonate Hill areas, and production from the Yak tunnel workings has largely come from ore bodies in the White limestone since 1913 or earlier. There are also fair chances of finding new ore bodies in certain undeveloped parts of the White limestone beneath ore bodies in Blue limestone. Drilling in the White limestone in the East Fryer Hill area in 1919 was disappointing. Mining in the White limestone in the Downtown area was also discontinued in 1923 but largely because of the high cost of operation and the rather depressed state of the metal market. Diamond drilling in other places has located ore of too low grade to encourage further development. These disappointments are offset by the large production from the deposits in White limestone in the Cord and Tucson mines in Iron Hill and the Wolftone and neighboring mines in Carbonate Hill, where ore deposition was intense along the Tucson-Maid fault zone. The White limestone and underlying "red cast beds" elsewhere along this zone, especially beneath ore shoots in Blue limestone, are well worthy of thorough prospecting. The White limestone, however, is less pure than the Blue limestone and is not covered by so thick and impervious a cover to dam back the ore-forming solutions, and therefore it should not be expected to contain extensive ore bodies as the Blue limestone away from centers of intense ore deposition. Solutions reaching the Blue limestone were obliged to travel along it slowly for long distances, whereas those which began to migrate along the White limestone were likely to escape upward and deposit their ore in the Blue limestone.

Quartzite—The Parting quartzite and the Cambrian quartzite beneath the "red cast beds" contain a few ore bodies. Ores in the Parting quartzite are known in the Maid, Greenback, and Wolftone mines and in the workings from White Cap and Cord winzes in Iron Hill. They are usually small and pyritic and either form connections between ore bodies in the limestones above and below or adjoin mineralized fissures. They are made up of stringers of ore along closely spaced intersecting fractures, with disseminated particles of sulphide between them, and do not usually form continuous masses of solid ore.

The Cambrian quartzite beneath the "red cast beds" rarely contains blanket ore bodies; the few that have been found are either thin beds replaced by pyrite, rarely more than 1 foot thick and usually connected with vertical fissures, or downward extensions of ore bodies in the "red cast beds" or "transition shales." An unusual ore body occurs in the Tucson mine about 60 feet below the top of the quartzite. It partly fills small caves dissolved along certain shattered beds and partly replaces the wall. It is connected with vertical mineralized fissures carrying the same minerals. The ore was unusually rich in silver, gold, and bismuth and contained considerable galena and zinc blende, with minor quantities of chalcopyrite, whereas ore in the quartzite usually consists almost entirely of pyrite.

Thin, flat beds of sulphides in the Cambrian quartzite have also been found in the Shanango and Maid mines. A large body of oxidized ore which was found in the Hibschle mine of the Downtown district lay mainly in the transition shales immediately beneath the White limestone, but extended downward into the Cambrian quartzite. Thin layers of sulphide are frequently penetrated by the diamond drill well within the Cambrian quartzite, but they are usually of too low grade to justify mining.

Weber(?) formation.—No blanket ores have ever been found within the black shales (the so-called "Weber shales") which lie at the base of the Weber (?) formation. A very few blanket replacement deposits of notable size have been found in the overlying "Weber grits"—for example, along the Garbutt vein [figure 29 (extra figures and plates), and plate 57]. A few lentils of limestone occur in the formation, and ore bodies have occasionally been found in them. Their exact stratigraphic position can not be definitely determined, but they appear to be well above the black shale member. Some ore has been found in one of them on Prospect Mountain, north of the Leadville district, at a geologic horizon that must be many hundreds of feet above the base of the formation. Lentils of impure limestone have also been encountered in the "Weber grits" on Breece Hill in the vicinity of the Ibex property, but they are not known to be ore bearing. It is possible that some of the upper-blanket ore bodies of the Ibex mine may replace lentils in the Weber (?) formation, but the excessively broken character of the intrusive bodies in this area makes the geologic horizon difficult to determine. It is not likely that ore bodies of size or consequence will be found in the Weber formation in the Leadville district, although in the Ten-mile district, to the north, these limestone lentils are among the main ore-bearing beds.

ORE HORIZONS OR "CONTACTS"

The blanket ore bodies in the Leadville district, as is to be expected of deposits formed by solutions, nearly all lie at horizons where a readily replaceable rock is overlain by a relatively unreplaceable and impermeable rock. The replaceable rock is everywhere or nearly everywhere calcareous; the overlying rock may be shale, quartzite, or other sediment, but that above most of the important blankets is a sheet of porphyry, and the number of horizons favorable for ore varies principally with the number of porphyry sheets. The rocks at favorable horizons are, of course, not everywhere mineralized; suitable structure and especially the presence of fissures through which the ore-bearing solutions may reach these horizons, are essential to the formation of large bed deposits. The horizons at which the blankets commonly occur are locally know as "contacts", and at any given place they are numbered in descending order, regardless of their stratigraphic position. At most places, however, the "first contact" is the horizon at which the main sheet of White porphyry overlies the Blue limestone. Although the limestone-porphyry contacts are on the whole the most productive, the localizing effects of sedimentary layers may conveniently be presented first.

The ores in the Blue limestone attain their greatest extent in its upper portion, immediately below either the overlying black shale or a porphyry mass that lies at or a little below the same horizon. From this horizon downward, where the limestone is not interrupted by additional intercalated intrusive porphyries, the ore bodies occur in somewhat diminishing number. Immediately above the Parting quartzite, and from that horizon upward for distances that differ in different localities, but with a possible maximum of 30 feet, the limestone is usually thinner bedded and interrupted by thin beds of shale alternating with quartzite beds.

Some ore bodies that occur within this shaly portion have replaced the thin limestone beds only, and others have replaced the thin limestone beds only, and others have replaced the shale and quartzite as well.

In the middle part of the Blue limestone ore bodies are found entirely enclosed in limestone, as in Rock Hill (**Plate 59**), but ore bodies are less common where intrusive sheets of porphyry are absent than where they are present and form impermeable barriers that favor concentration of the ore.

In the White limestone blanket deposits commonly occur either beneath porphyry sheets of in the shaly zone just below the Parting quartzite. Beneath the White limestone ore masses are also common in the 40 feet of "transition shales". At several places ore bodies are found in these shales, although they are absent from the purer limestone layers above. Their repeated preference for these shaly beds seems to be due more to the mechanical effect which the thin impervious, and comparatively resistant shales have had in stopping the upward passage of mineralizing waters and directing their circulation along the intercalated limestone beds than to any chemical cause. They have thus been formed in spite of the less replaceable nature of the shale layers and are likely to contain correspondingly high percentages of siliceous gangue. A few ore bodies appear to be entirely enclosed in White limestone, but it is probable that subordinate shaly layers have determined their position.

Porphyry sheets are numerous in some places and together with the shales already mentioned have produced as many as ten or eleven "contacts". These "contacts" in different parts of the district are shown in plate 59, which summarizes the pertinent structural data discussed in chapter 5 and represented in the sections on plates 14-18, 20, 21, and 28 (extra figures and plates),. The ore bodies along these contacts are described in some detail in Chapter 13. Some ore bodies, particularly in Iron Hill, illustrated by the Gold ore shoot (**Figure 56**) deviate from the immediate contact with porphyry and follow wandering courses within the limestone, locally along beds and locally at low angles to the beds. Irregular branches are connected by tortuous channels, which locally pinch and swell (**Figure 57**). Such of these irregular ore bodies as lie between two porphyry sills that are rather close together may not only reach down to the top of the lower sill but may even connect by stringers with the ore below it (figure 56). The deviations of the Gold ore shoot and neighboring shoots are approximately in line with the Tucson fault and may be related to it, but the geology as mapped by Blow[4] does not indicate any faulting, and the workings are inaccessible for restudy in the light of recent structural evidence.

[4] Blow, A. A., Am. Inst. Min. Eng. Trans., vol. 18, pp. 145-181, 1890.

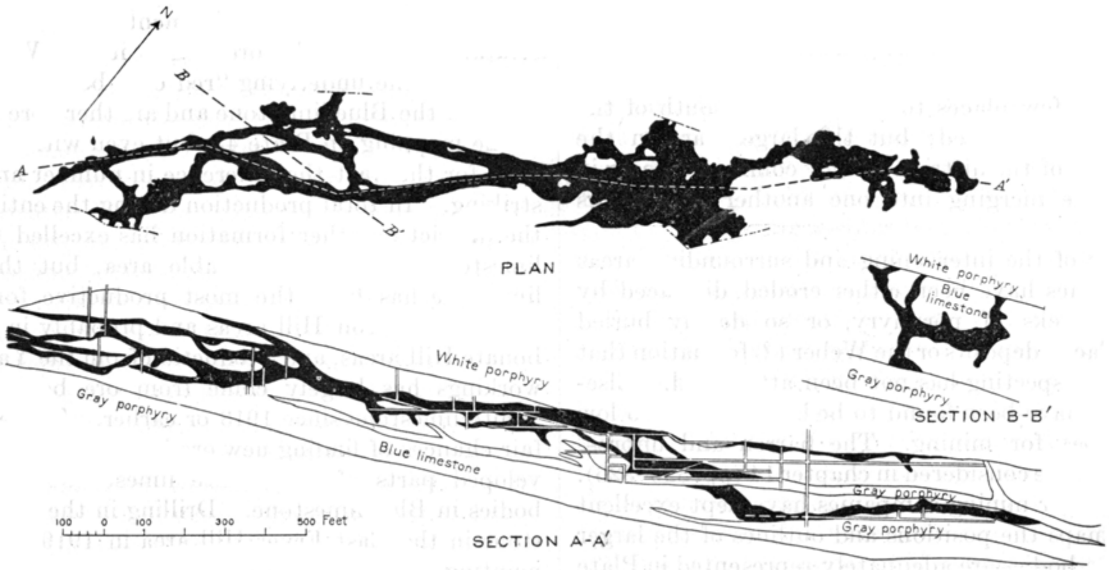

Figure 56. Plan and sections of the Gold ore shoot, Iron Hill. (After A. A. Blow)

A few ore bodies lie upon the upper surface of a porphyry sill, as at the fifth contact of the Old Mikado-Shanango group (plate 59). Such exceptions to the rule are presumably due to fracturing, which permitted solutions to pass upward through the porphyry only to be stopped a little higher by locally persistent shale beds, but the writers have had no opportunity to study any such occurrences.

Certain ore bodies in the Iron Hill and Fryer Hill areas are closely associated with dike-like offshoots from Gray porphyry sheets. These offshoots undoubtedly were of local importance as impervious barriers that restricted the movement of ore-forming solutions. Blow, who studied those in Iron Hill before their connection with sheets was established, concluded that the ore bodies were genetically related to them, particularly the Moyer and Imes dikes[5]; but subsequent developments have shown that ore bodies are quite as numerous and large in places free from dikes. It may also be noted that ore bodies are especially abundant in the vicinity of Gray porphyry intrusions regardless of shape, but this is due to the access afforded to the solutions by fracturing of the strata during the intrusion and does not imply that the Gray porphyry is the immediate source of the solutions.

[5] Idem, pp. 154-156.

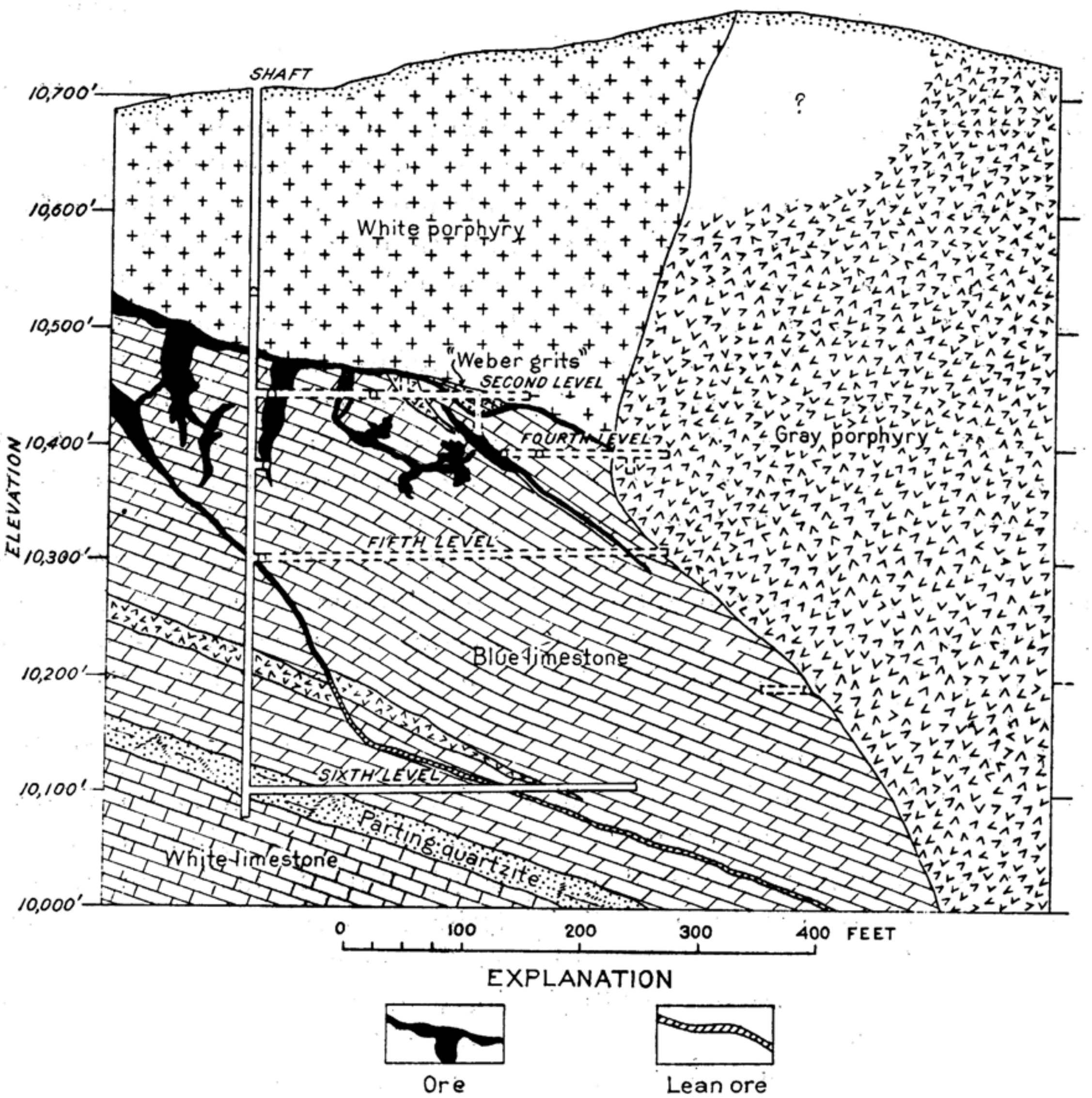

Figure 57. Section showing ore bodies in the Oro La Plata mine. By Phillip Argall.

RELATIVE RICHNESS OF ORES AT DIFFERENT "CONTACT"

The ores of the uppermost horizon, which throughout most of the district is the contact between White porphyry and Blue limestone, are nearer the surface and therefore more extensively oxidized than those at the contact between Gray porphyry and Blue limestone, and those in the White limestone are nearly everywhere sulphides. Considerable enrichment in silver has undoubtedly taken place in the thoroughly oxidized ores, and the presence of shaly matter in the White limestone renders the ores replacing it of lower grade on the whole than those replacing Blue limestone; but it is doubtful whether the ratio of metals in the ore minerals of this horizon is essentially different than that at other horizons. There is a temptation to imagine that the original ores of the "first contact" were richer in lead and silver. This may have been partly true. Shoots of galena low in zinc and pyrite may have been more numerous along the "first contact" than elsewhere, particularly in places furthest from the main channels of supply; but the oxidation products of these ores show that as a whole they were very similar to the mixed sulphide ores found below the oxidized zone at all the “contacts”. Such differences as have been noted in the sulphide ores are as pronounced in different parts of one horizon as in different horizons.

FORM AND TREND

The forms of these ore bodies vary greatly. Some replace single beds and are of considerable length and width but of small and rather uniform thickness. Others are thicker than they are wide, and in places narrow to mere borders of fractures (figure 57). Some have nearly parallel sides for considerable distances, and others have tongue-like branches and generally irregular outlines. Some split into two parts, side by side or one above the other. A few have nearly circular outlines. Many of the larger ore bodies enclose irregular masses of slightly mineralized or barren rock. A general idea of these variations may be gained from plates 18, 19, 22, 27, and 45 (extra figures and plates).

Although the outlines of the ore bodies are irregular in detail, most of the large ones in any restricted area trend in one or two prevailing directions. This is particularly true in the Iron Hill area, where the main ore bodies, whether single or composite, are roughly parallel and trend east-northeast. Other groups of roughly parallel ore bodies are in the vicinity of Fryer Hill and Graham Park and to the north of South Evans Gulch. Less marked parallelism may be noted at other places.

BOUNDARIES

As most of these ore bodies are bounded along their upper surfaces by sheets of porphyry or beds of shale or quartzite, their tops conform to the bedding, but their sides and bottoms are commonly irregular, In some places thin beds or slabs of limestone between porphyry or shale have been almost completely replaced. This is strikingly illustrated by the old replacement bodies of the Fairview and Fryer Hill area, which were the first ones examined by Emmons (plate 67, Chapter 13), and by a large ore body enclosed in White porphyry in the Moyer mine. The origin of these ore bodies was recognized only after unreplaced remnants of Blue limestone were exposed in the stopes.

Within the White limestone and underlying “transition shales” so many partings of difficulty replaceable shale intervene between beds of dolomitic limestone that numerous completely replaced layers of limestone occur, some only a few feet or inches thick but of considerable horizontal extent. Where mineralization has been very intense, even the more resistant shaly layers have been replaced by ore for certain distances, beyond which the ore body ends in a series of prongs or wedges separated by unreplaced rock.

In several places the ore bodies depart entirely from their contact with unreplaceable rocks, and their upper boundaries become as irregular as the lower. Stopes that have been formed by solution of limestone by underground streams.

The passage from ore to barren rock along these irregular boundaries is abrupt in some places and gradual in others. Abrupt transition is particularly characteristic within the Blue limestone. Where the transition is gradual the rock is much fractured or shattered, and the ore extends along the fractures, which decrease in number away from the main ore body. These shattered border zones are rarely more than 10 feet thick, and the fragments of rock in them are impregnated with ore and gangue minerals.

The relation of the form of ore bodies to the channels through which the ore was introduced is obscured in many places by oxidation, but in some places extensive ore deposits are associated with shattered zones that are terminated or interrupted by layers of shale or porphyry. Where fissures and sheeted zones are open and not interrupted the ore commonly forms narrow linings along them and rarely extends into the walls for any considerable distance. Where the fissures or shattered zones are interrupted the ore-forming solutions continued their progress along bedding planes and minor joints, but they were so impeded that there was opportunity to spread into and react with large volumes of rock.

DIMENSIONS

The intricate shapes of the replacement ore bodies render exact measurement of dimensions somewhat difficult, but the accompanying table will give an idea of the maximum dimensions of some of the larger ore bodies.

Many smaller blankets occur, but their tabulation would serve no useful purpose, as the table will show how large some of the ore masses are.

Approximate maximum dimensions, in feet, of some of the larger blanket ore bodies

Name	Length	Width	Thickness	Remarks
North Iron Shoot	3,100	520	60	Length includes a faulted portion west of the Iron fault.
South Iron Shoot	1,500	400	60	
Gold Ore Shoot	2,750	300	120	Faulted off at northeast end.
White Cap South shoot	1,100	200	50	Shoot originally supposed by Blow to be continuation of White Cap shoot
Moyer Main Shoot	2,050 NE 1,400 N.5˚W.	500	90	Second contact shoot, formed by the junction of two shoots of different trend. The lengths of both are given. Average thickness of about 50 feet.
Vivian-Hall-Rickard-Stone shoot	2,000	500	110	Shoot thick at north end but much thinner at south end
Rock shoot	800	300	30	
Reindeer-Bessie Wilgus shoot.	900	500	50	
Crescent-Catalpa-Morning Star-Wolftone-R.A.M. shoot	3,550	1,000	50	Probably a composite of several shoots
Small Hopes upper shoot	1,150	220	40	In small upper contact parting.
Mahala “second contact” shoot	1,150	200	55	
Greenback “third contact” shoot	440	300	200	An example of nearly equidimensional shoot. (Determined only by drills.)
Bangkok-Jaimie Lee shoot	1,220	Average 30	Unknown	An example of a long narrow shoot.
Pennsylvania shoot	900	≈300	≤ 6	An example of a siliceous gold shoot.
Little Ellen-New Years shoot	1,460	450	≤ 50	An example of a very broad but thin “first contact” shoot. Average thickness probably 5 feet.

ORIGINAL ORES

CLASSIFICATION

As oxidation has thoroughly changed the character of the ores in many of the blanket ore bodies, particularly in the Blue limestone, the ores must be considered under two general heads—sulphide ores and oxidized ores. The sulphide ores have been altered considerably near the surface of ground water by leaching, enrichment, or both; but the altered ores are very subordinate in quantity to the original sulphide ores are very subordinate in quantity to the original sulphide ores. The character of the original sulphide ores is of especial interest because of its bearing on the origin of the ores and the relations, already discussed at some length, of the blankets to the veins. The oxidized ores and the enriched sulphide ores, however, are more conveniently considered in Chapters 11 and 12 (not included in this report), which follow that on the genesis of the original ores.

The primary ores of the replacement bodies or blankets are usually of comparatively simple mineral composition. They contain a few common minerals in relatively large amounts, together with small though important quantities of less common species. They are in the main mixtures of pyrite, sphalerite, galena, and locally, subordinate chalcopyrite, with quartz (generally in the form of jasperoid) and variable though usually small amounts of manganosiderite or a related carbonate. In some localities the sulphides greatly preponderate; in others the quartz or jasperoid. In still other places one portion of an ore mass is more siliceous than another, both varieties occurring together in the same mine. The carbonates are present in many of the ores but entirely absent in others. In some places they occur in great quantity and are rather uniformly distributed through the ore bodies, but more commonly they form nearly pure masses enveloping the sulphide ore and distinguishable with difficulty from the enclosing limestone.

Added to these more abundant minerals are smaller quantities of argentite; of bismuthinite, including "kobellite" and "lillianite", which locally so preponderate as to form a separate class of bismuth-silver ores; and here and there of barite. Mingled with the ore are also residual masses of limestone, shale and porphyry, which have been usually partly to completely altered by mineralizing solutions.

The component minerals of the sulphide ores are mingled in very different proportions, and all gradations exist between equal mixtures and masses composed principally of one mineral. No entirely satisfactory classification that will include all of the possible mineral combinations can be devised, because of the varying proportions, but for purposes of description it is possible to adopt a grouping that will serve to distinguish the more abundant varieties, of which the others are merely to be regarded as mixtures. The larger divisions can be made on the basis of the relative quantities of gangue minerals and sulphides; the minor divisions on the basis of the relative abundance of the different metallic sulphides. In this manner we may arrive at the following grouping:

1) Massive sulphide ores, consisting of preponderating amounts of metallic sulphides:
   a) Pyritic or iron ores
   b) Galena or lead ores.
   c) Sphalerite or zinc ores.
   d) Chalcopyrite-bearing mixed sulphides or copper ores.
   e) Mixed sulphides.
   f) Argentite-bismuthinite, or silver-bismuth ores.
2) Carbonate sulphide ores, consisting of mixtures of sulphides and large amounts of manganosiderite.
3) Siliceous sulphide ores, consisting of mixtures of sulphides with large amounts of quartz or jasperoid:
   a) Pyritic gold ores.
   b) Chalcopyritic gold ores.

The first two of the above groups are merely variations of a single class, due to a relatively small or large amount of manganosiderite. The third group includes the siliceous ores of blankets directly connected with veins, which have already been considered, and a few similar ores that have not been proved to connect with veins.

The basic ores may be subdivided according to the relative preponderance of the different component sulphides, which are mingled together in all proportions. Ores that consist chiefly of one sulphide are best designated by the name of that sulphide, although from the smelter's standpoint pyritic ores with iron in excess may be termed "iron ores", and the others may be designated by the principal base metal present. The rarer varieties that contain the bismuth and silver sulphides in considerable quantity may be termed "silver bismuth ores". Ores with two ore more sulphides present in large amount are called "mixed sulphide ores". Few of the blanket bodies where unenriched contain commercial quantities of copper, so that division *d* is unimportant, though the corresponding division in the group of enriched ores is locally of considerable extent. As the transitions from one division to another are gradual, no definite limits to the divisions may be set unless they are the minimum quantities of different metals present for which the miner is paid.

In order that the character of the ores may be most readily understood each of the five main divisions and the different mixed sulphide ores are separately described.

Pyritic Ores

CHEMICAL AND MINERAL COMPOSITION

The pyritic iron ores when completely fresh and unaffected by enrichment are often extremely pure aggregates of pyrite with relatively small quantities of other sulphides. Some of them contain enough silver to be profitably mined, but many large masses are of value chiefly for their fluxing properties or as potential sources of sulfuric acid. Bodies of nearly pure pyrite are found in the mines of Iron Hill, Carbonate Hill, Graham Park, Breece Hill, and Evans Gulch and are present in greater or less number in nearly all portions of the district where the sulphides have been extensively exploited. In some places the relatively pure pyrite forms the entire sulphide body, as in certain stopes of the Maid, R.A.M., Greenback, Mahala, Tucson, Moyer, Wolftone, Ibex, and other properties. In other places the pyritic mass forms only a portion of the total mass and grades into relatively pure galena or sphalerite, or into mixed sulphides.

The pyritic ores, though in some places notably free from gangue, in others contained larger amounts of quartz than the other sulphides, and some of them are very siliceous. The more siliceous pyritic ores are comparatively high in gold. In some places, as in the El Paso ore body on East Fryer Hill, the ore is an intimate mixture of pyrite and siderite with few, if any other minerals present.

The analysis given below of one of the so-called "white iron" or pyrite bodies of the Henriett-Maid mine furnishes an excellent example of very pure pyritic ore.

Analysis of pyrite from Henriett-Maid mine, Leadville, Colo.
[R. C. Wells, analyst]

Fe	46.26	CaO	.004
S	53.25	MgO	.065
TiO_2	.11	$FeSO_4$	.33
SiO_2	.068	H_2O	.18
Cu	.078	CO_2	.08
Ag	.017		100.454
Zn	.005		
As	.007		

Specific gravity of specimen, 4.725; of powder, 4.964. Pore space, 4.5 per cent.

The calculated mineral composition is as follows: Pyrite, 99.27 per cent; chalcopyrite, 0.02 per cent; arsenopyrite, 0.02 per cent; sphalerite, 0.01 per cent; argentite, 0.02 per cent (or 5 ounces of silver to the ton). The arsenic indicates the source of the minute quantities of arsenic found in the flue dust of the smelters. The natural gangue, consisting of carbonate, quartz, and rutile (?), amounts to less than 0.5 per cent, and the ferrous sulphate was evidently produced during the grinding of the sample for analysis. Manganese was not determined but may be present and included in magnesia.

Besides large masses of such nearly pure pyrite as is represented by this analysis, there are many ore bodies composed mainly of a mixture of sulphides, which contain bands, or irregular masses of pure pyrite.

No. 1 is the analysis cited above, repeated in part for the sake of comparison. Nos. 2, 3, 4, 5, and 8 are essentially complete as regards metal content, and calculation of enough sulfur to accompany them in the common sulphide minerals of the ore brings totals close to 100 per cent. The manganese and a little iron, however, may have been present as manganosiderite which would imply a correspondingly less amount of sulfur and the addition of a little carbon dioxide. The small amount of silica or "insoluble" present represents quartz with more or less sericite. Nos. 6, 7, 9 and 10 presumably contained relatively high proportions of soluble gangue minerals, probably carbonates, and as no determinations of CO_2 or the alkaline earths were made the summation falls considerably short of 100 per cent. The small amount of manganese recorded in analysis 7 indicates that very little manganosiderite was present in the soluble gangue. Cadmium was not looked for, but minute quantities are doubtless present in the zinc blende.

Analysis of ores with dominant pyrite

	1	2	3	4	5	6	7	8	9	10
Fe	46.26	44.10	41.20	41.00	40.50	39.90	39.50	35.40	32.6	22.3
Pb	-------	-------	1.00	1.00	.80	1.00	.10	2.21	2.7	11.2
Zn	.005	3.20	5.00	5.50	9.00	4.50	7.15	14.24	8.3	.0
Cu	.078	-----	-----	-----	-----	-----	-----	-----	.1	.2
Ag	.017	.046	.30	.034	.027	.028	.033	.014	.029	.074
SiO_2	.068	[a]1.70	[a] 1.30	[a] 1.40	[a] 1.75	[a] 2.20	[a] 2.05	[a] 2.7	[a] 7.5	[a] 8.0
S	53.25	[b]51.24	[b] 49.43	[b] 51.52	[b] 48.75	[b] 47.60	[b] 44.00	44.76	41.1	26.7
Mn	-----	-----	.70	.40	.40	-----	.30	-----	-----	-----
		100.286	98.66	100.854	101.227	95.228	84.133	99.324	92.329	68.474
Au opt	Not Det	.16	.14	.10	.08	.09	.07	-----	.05	.04
Ag opt	5.00	14.80	9.50	10.90	8.30	9.10	10.35	4.5	9.20	23.7

[a] Insoluble [b]Calculated

1. Henriett-Maid mine, Carbonate Hill.

2-7. Iron Hill. Analyses furnished by courtesy of Iron Silver Mining Co.

8. Freeland, F. T., Am. Inst. Min. Eng. Trans., vol. 14, p. 189, 1886. Analysis by William R. Boggs, jr.

9-10. Analyses furnished by Ohio & Colorado Smelting Co.

Calculated mineral composition of certain ores

	1	8	9	10
Pyrite	99.21	64.01	66.87	45.28
Excess iron in carbonate (?)	-----	-----	-----	.61
Sphalerite (marmatite):				
ZnS	.01	21.19	12.36	None
FeS	-----	8.82	2.32	
Galena	None	2.55	3.10	12.92
Argentite	.01	.014	.04	.074
Chalcopyrite	.22	-----	.28	.57
Silica	.07	2.70	7.50	8.0
	99.52	99.284	92.47	67.454

These analyses also bring out in a rather striking manner the relation of the gold and silver to the sulphide minerals. As is shown elsewhere in greater detail, the gold in non-siliceous sulphide ore rises steadily with the increase in pyrite, and the silver content shows no relation to that of any other mineral in the ores. It has often been supposed that the silver is contained in the galena, but no such relation is apparent in these analyses.

TEXTURE AND STRUCTURE

By texture is meant the form and size of the mineral grains and their relation to one another, and by structure the larger features, such as banding and honeycombed structure, which involve the whole ore mass and are only in part dependent on the form and size of the grains.

The pyritic ores that are pure consist of pyrite grains, which vary greatly in size and do not possess definite crystalline boundaries. In some of the coarser grained varieties they show a slight tendency toward the development of crystal faces, but these are exceptional in the massive portions of the pyritic ore. In the finest-grained variety the crystal faces are so small that they can barely be distinguished with the naked eye and give the mass a peculiar velvety sheen.

The prevailing diameter of grain is perhaps 1 millimeter. The variations in the size of grain occur throughout the pyrite masses with little regularity. Extremely fine-grained masses are interrupted by those of very coarse grain, in some places abruptly and in others by gradual increase in the size of grain. Whatever may be the size of grain the pyrite masses are commonly intersected by minute veinlets, ranging from mere threads up to some more than a quarter of an inch in width, which are filled with relatively coarse-grained pyrite, accompanied in places by sphalerite, galena, and chalcopyrite.

The very fine-grained pyrite is usually massive and contains few, if any, cavities. The slightly coarse-grained material, however, abounds in irregular cavities, which give to it a well-marked cellular structure. Where these cavities have been protected from the access of surface waters they are generally empty and lined with well-developed glistening crystals of pyrite. The commoner crystal form is the pyritohedron, although the cube and octahedron are also sparingly developed. The pyrite crystals that project into these cavities are usually solid, but a few have a skeleton form like the galena crystals in plate 48, E (Chapter 8).

At the margins of the blanket masses where pyrite is the principal ore mineral, the change to the surrounding carbonate rock is gradual, and the gradation zone consists of carbonate rock containing isolated crystals of pyrite. (**Plate 58, C**.) These crystals of pyrite represent the earlier stages of replacement, and in some places in the fine-grained massive ore they can be seen surrounded by aggregates of irregular grains, just as in jasperoid formed by replacement of limestone quartz crystals are often found embedded in an aggregate of fine, irregular quartz grains.

In addition to the features just described many of the pyrite bodies show when viewed in mine workings a well-marked banding, which in some places is continuous with the bedding of replaced limestone but is more commonly of roughly spherical or ellipsoidal form. This banded structure is characterized by differences in size of grain and arrangement of the pyrite crystals, or by narrow cavities between successive layers. Similar banding is present in the mixed sulphide ore, where bands of zinc blende or galena alternate with bands of pyrite.

Zinc Blende Ores

CHEMICAL AND MINERAL COMPOSITION

The zinc blende or sphalerite ores, like the pyrite ores, are in some places almost entirely free from other sulphides; but the most purely sphaleritic ore grades through varieties in which zinc blende is dominant, into mixed sulphide ore.

The sphalerite, described in detail on page 10, Chapter 8, is nearly all of the dark ferruginous variety marmatite, popularly known as “blackjack”. Lighter-colored varieties, correspondingly low in iron, are present in small quantity in the ores of Iron Hill and South Iron Hill, but no chemical analyses of them are available.

Analysis of zinc sulphide ores with dominant zinc blende

	1	2	3	4	5	6	7	8	9	10
Zn	55.08	[a]52.80	[a]47.60	[a]45.10	41.00	39.65	37.70	25.45	24.30	23.40
Fe	4.00	12.10	14.80	17.80	14.00	17.80	18.70	7.70	19.30	27.60
Pb	6.71	-----	-----	-----	5.00	.70	.50	11.45	5.90	.80
Mn	-----	(b)	(b)	(b)	-----	-----	-----	.10	.10	.20
Ag	.32	-----	-----	-----	-----	-----	-----	-----	----	-----
Au	Trace	-----	-----	-----	-----	-----	-----	-----	-----	-----
S	32.44	34.7	35.70	36.40	-----	-----	-----	-----	-----	-----
SiO_2	.92	.20	.40	.20	2.00	1.50	2.00	7.70	17.40	2.40
	99.47	99.80	98.50	99.50	-----	-----	-----	-----	-----	-----
Au-opt	-----	-----	-----	-----	.02	.025	.02	.02	.01	.02
Ag-opt	94.50	-----	-----	-----	7.00	6.50	6.20	9.25	2.60	4.60

[a] Zinc includes 0.1 to 0.35 per cent cadmium
[b] Included in the iron; ranges from 1.3 to 3.7 per cent
1. Minnie mine, Iron Hill, Leadville. Analysis by W.R. Boggs, jr.; cited by Freeland, F. T., Am. Inst. Min. Eng. Trans., vol. 14, p. 189, 1885. This analysis is not recalculated
2. Adams mine, Carbonate Hill, Leadville. Analysis by A. W. Warwick.
3. Colonel Sellars mine, Iron Hill, Leadville. Analysis by A. W. Warwick.
4. Yak tunnel, Iron Hill, Leadville. Analysis by A. W. Warwick.
5. South Iron Hill. Average analysis of zinc ores for 1911. Furnished by courtesy of Empire Zinc. Co.

6-8, 10. Moyer mine, South Iron Hill. Analyses furnished by George O. Argall.
9. Tucson mine. Analysis furnished by George O. Argall.

Calculated mineral composition of certain zinc sulphide ores

	2	3	4	5	6	7	8	9	10
Sphalerite	[a]90.6	[a] 83.9	[a] 84.2	73.5	[b]71.0	[b] 67.5	[b] 45.8	[b] 43.7	[b] 42.4
Pyrite	9.0	14.3	15.0	13.3	22.1	24.6	6.1	31.5	49.6
Galena	----	-----	-----	5.7	.8	.6	13.2	6.8	.9
Argentite	NA	NA	NA	.0	.0	.0	.0	.0	.0
Insoluble	.2	.4	.2	2.0	1.5	2.0	7.7	17.4	2.4
	99.8	98.6	99.4	94.5	95.4	94.7	72.8	99.4	95.3

[a] ZnS.Fe(Mn)S.
[b] Calculated on the assumption of 5ZnS.FeS for marmatite. In analyses 8, 9 and 10 the Mn is included in the marmatite.

These analyses are arranged according to their zinc content and represent ores ranging from practically pure zinc blende (marmatite) to mixed sulphides. Nos. 8 and 9 may be conveniently classified as zinc-lead ore, and Nos. 9 and 10 average about as much in pyrite as in blende. As carbon dioxide was not determined it is not known to what extent iron and manganese are present as carbonates instead of sulphides; but it is inferred that in analyses in which the totals are appreciably below 100 the deficiency is due largely to carbon dioxide and magnesia and manganosiderite or dolomite and to moisture.

The low gold content is in keeping with the rather low percentage of pyrite, but the ratio of gold to pyrite is by no means uniform. The silver content as in the pyritic ores is independent of the percentages of the other metals and is calculated as argentite.

Except where sphalerite occurs as groups of large crystals lining cavities, it forms a granular aggregate in which no crystals have well-developed boundaries. Its texture, like that of the pyritic ore, varies widely; it grades from an exceedingly fine-grained aggregate with a velvety sheen and an almost black color to coarser-grained material in which the individual grains are one-eight of an inch or more in size. The coarser-grained ores show a more pronounced brownish tinge, especially where the grains have been slightly shattered or the ore crushed or abraded.

In the finest-grained ore the blende is relatively free from cavities and is dense non-porous material, but with increase in size of grain much of the ore becomes cellular and shows irregularly distributed cavities, similar to those in the pyritic ore, lined with marmatite crystals. In some places cavities are so numerous that the ore is composed of a loosely coherent mass of black blende crystals. As in the pyrite ore, most of the cavities are empty, but some contain coatings of carbonates and, where they are within reach of surface waters, also kaolin and calcite.

The sphalerite ores that are pure do not usually show distinct banding, but if the light is allowed to fall on a freshly broken surface at a small angle a series of parallel shadowy bands representing the original sedimentary banding is commonly visible. These bands can often be detected even in ores that are free from shale and consist entirely of sphalerite. White chert lenses are also of common occurrence and contrast strikingly with the dense black sphalerite.

Where considerable quantities of galena and pyrite are present in the sphaleritic ore, the galena and blende are intimately mixed, though most of the blend finished crystallizing before the galena. The pyrite, even in small quantities, especially in the finer-grained blende, is earlier than the blende and occurs as distinct cubic crystals embedded in the granular zinc blende. These pyrite crystals were evidently developed in the limestone as a first stage of replacement (plate 58, C) and the balance of the rock around them was then replaced by zinc blende. Where the relative amounts of the two minerals approach one another the characteristic banding or an evenly mingled arrangement is commonly present and the two minerals appear to have formed at the same time (see p. 37–39); but close inspection shows that in at least part of the banded ores the pyrite bands were introduced first and the zinc blende later filled the linear cavities between the pyrite bands as well as cracks across them.

The distribution of the zinc sulphide ores much resembles that of the pyrite. Some blanket masses are composed almost entirely of zinc blende. Others contain shoots of nearly pure blende that pass gradually or abruptly into mixed sulphides in which pyrite or galena or both are uniformly disseminated with the blende. Again, the zinc-blende ores may form alternating bands in the pyritic ores. Zinc ores can not be said to be characteristic of any one portion of the district to the exclusion of the others, for they occur in some quantity throughout the district. They are perhaps more abundant in the Carbonate Hill, Iron Hill, and Graham Park areas than elsewhere. They are distinctly subordinate to the pyritic ores but are believed to exceed the galena ores in total quantity.

Examined under the microscope the denser sphalerite ores are seen to consist chiefly of zinc blende, which is arranged in minute irregular grains of roughly rounded form. Sparsely but uniformly scattered among these grains are small quartz crystals in perfectly developed short, stout prisms, terminated by pyramids at both ends. They are set at all angles in the sphalerite matrix. Where the ore contains more gangue the grains of blende are more nearly rounded, though they have a crystalline outline, and are usually separated from one another by threadlike partings of aggregate of a light transparent mineral. Where the gangue is still more abundant the blende and this light colored aggregate form branching masses which penetrate one another in a very intricate mosaic. This light-colored aggregate consists of a mixture of carbonates, presumable of the manganosiderite group, and a small amount of mineral resembling chlorite which have been derived from the original shaly material of the replaced country rock. Barite is also present in small quantity. Scattered here and there through the blende are cubes or irregular patches of pyrite and varying amounts of galena. In addition to these sulphides there are a few irregular patches of a blackish mineral, which may be argentite. They are much less brilliant than the galena when seen in reflected light and in places form thin bands that surround the pyrite crystals or masses and separate them from the inclosing sphalerite. Unusually siliceous zinc sulphide ore consists of extremely jagged patches of blend scattered through a fine-grained clear mosaic of quartz. The quartz grains have irregular boundaries with one another but have crystal boundaries in contact with the sphalerite, which is evidently of later formation.

Galena Ores

MINERAL AND CHEMICAL COMPOSITION

Bodies of ore consisting exclusively of galena or of galena with very small admixtures of other sulphides are present in nearly all portions of the Leadville district but are much less common than either the highly sphaleritic or the highly pyritic ores. They are usually present as portions of bodies of mixed sulphides in which the lead content is locally higher than in the rest of the blanket mass, and they may pass gradually or abruptly into the mixed sulphides.

A natural supposition was current in the earlier days of development that the sulphide ores were to prove to consist more largely of galena than of other sulphides, as comparatively pure lead carbonate bodies were of common occurrence in the oxidized zone and were more extensively developed than the iron oxide masses because of the relatively greater profit to be gained from them. It now seems beyond question that the pure carbonate bodies are not the oxidized representatives of pure galena masses of equivalent dimensions but are generally the lead bearing remnants of a mixed sulphide body from which the zinc and to a lesser degree the iron has been removed by descending waters in the oxidized zone. Some lead carbonate shoots were undoubtedly originally solid galena masses before oxidation, but most of them probably differed but little from the ordinary mixed ores of the sulphide zone.

No analyses of nearly pure galena are available, as pure galena ores are much more rare than pure pyrite and sphalerite ores. An analysis of a specimen of lead ore from the seventh level of the Tucson mine was made by W. F. Hillebrand in the laboratory of the United States Geological Survey and illustrates the mineral composition of a common variety of lead sulphide ore.

Analysis and calculated mineral composition of lead ore from the seventh level of Tucson mine
[Analyst, W. F. Hillebrand, April 13, 1908]

Insoluble	5.25	Galena	51.27
Pb	44.40	Zinc blende:	
Zn	22.26	ZnS	33.22
Cu	.05	FeS	5.98
Sb	.01	MnS	.09
Sn	.01	Chalcopyrite	.18
Bi	Trace	Pyrite	.88
Fe	4.78	Carbonates:	
Mn	.13	$FeCO_3$	1.97
FeS_2	.88	$MnCO_3$	.11
CaO	.27	$MgCO_3$	.50
MgO	.24	$CaCO_3$	.50
S (calculated)	[a]20.63	Insoluble	5.25
	98.91		99.95
Cd, Te, As, Ni, Co	Not Found		

[a] Sulphur evidently calculated on the assumption that all of the iron and manganese were present as sulphide. If the prevailing ratio of 5ZnS:1FeS in zinc blende is assumed, a small excess of iron remains and may be calculated with MgO and CaO as carbonate. This adjustment and the arbitrary assignment of equal parts of Mn to zinc blende and carbonate gangue brings the calculated sulphur to 20.1 per cent, the calculated CO_2 to 1.28 per cent, and the total analysis to 99.66 per cent.

The microscope shows this ore to contain pyrite, sphalerite, galena, carbonate (probably manganosiderite), quartz, and a little finely divided material of light color, low refractive index, and low double refraction, which could not be definitely identified. Here and there a light-colored mineral (barite?) in minute radial groups may be observed. If it is barite its percentage in the analysis is included in "insoluble". The copper was determined from 45 grams of the powdered ore. Tests were made on 45 grams for cadmium, tellurium, arsenic, nickel, and cobalt, but no trace of these elements could be detected. The trace of bismuth is probably present as bismuthinite. The lime and magnesia are undoubtedly carbonates, as carbonates are recognizable under the microscope, and the manganese is probably present in part as carbonate and in part as a minor constituent of zinc blend (marmatite). The insoluble matter is almost entirely quartz but may contain a little barite and some of the aluminous material from shaly partings in the original rock. Some of it is probably sericite, but still more is in the light-colored aggregate whose nature could not be definitely determined with the microscope. No positive evidence is available as to the minerals containing antimony and tin.

As a basis of comparison, the following analyses are illustrative of the character of the ores with dominant galena from several parts of the Leadville district.

Analyses of ores with dominant galena

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Pb	72.65	55.00	50.86	46.90	46.20	44.40	43.50	43.10	42.10	40.30
Zn	5.66	-----	12.86	10.50	11.10	22.26	12.80	13.20	12.50	9.80
						Fe 4.78				
Fe	1.60	3.85	9.30	12.20	11.90	Fe in	12.00	10.40	12.60	19.40
						FeS_2 41				
Ag	.14	.019	.039	.034	.035	ND	.034	.031	.032	.028
Au	Trace	-----	Trace	.0009	.0006		.0006	.0006	.0006	.0009
S	15.66	[a]12.97	24.50	[a] 23.49	[a]25.20	21.77	[a]25.56	[a]23.85	[a]25.91	2.80
Insoluble	4.12	15.00	1.88	2.40	1.90	5.25	2.00	2.50	2.60	
	99.83	**86.84**	**99.439**	**95.52**	**96.36**	**98.73**	**95.89**	**93.08**	**95.74**	**72.33**
Gold-opt	-----	ND	-----	.03	.02	-----	.02	.02	.02	.03
Silver-opt	41.5	5.50	11.50	9.95	10.20	-----	9.80	9.05	9.20	8.30

[a] Calculated

1. Galena ore from Minnie mine, Iron Hill. Analysis by W. R. Boggs, jr. Cited by Freeland, F. T., Am. Inst. Min. Eng. Trans., vol. 14, p. 189, 1886.
2. From Little Chief mine, 1880. See U. S. Geol. Survey Mon. 12, p. 623, 1886.
3. Mixed sulphides with dominant galena from Minnie mine, Iron Hill. Analysis by W. R. Boggs, Jr., cited by Freeland, F. T., op. cit.

4-5, 7-10. From Moyer mine, Iron Hill. Average analyses of 50-ton lots. Furnished by George O. Argall.

6. Galena-sphalerite ore from Tucson mine, seventh level. Made in laboratory of the U. S. Geological Survey by W. F. Hillebrand. Same analysis given in detail on previous page. Repeated here for comparison.

If these analyses are recalculated on the same basis as the sphalerite and pyritic ores the following results are obtained:

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Galena	83.94	63.55	58.76	54.18	53.37	51.27	50.27	50.05	48.65
Zinc blende:									
ZnS	8.44	-----	19.16	15.65	16.54	33.22	19.08	19.67	18.63
FeS	.71	-----	1.13	2.82	2.99	5.98	3.45	3.55	3.36
MnS	-----	-----	-----	-----	-----	.09	-----	-----	-----
Pyrite	2.47	8.27	18.47	22.36	21.48	.88	21.08	17.49	22.48
Argentite	.16	.02	.02	.02	.02	Not Det	.02	.02	.02
Chalcopyrite	-----	-----	-----	-----	-----	.18	-----	-----	-----
Carbonates:									
$FeCO_3$	-----	-----	-----	-----	-----	1.97	-----	-----	-----
$MnCO_3$	-----	-----	-----	-----	-----	.11	-----	-----	-----
$MgCO_3$	-----	-----	-----	-----	-----	.50	-----	-----	-----
$CaCO_3$	-----	-----	-----	-----	-----	.50	-----	-----	-----
Insoluble	4.12	15.00	1.88	2.40	1.90	5.25	2.00	2.50	2.60
	99.84	**86.84**	**99.42**	**97.43**	**96.30**	**99.95**	**95.90**	**93.28**	**95.74**

In these recalculations the galena is to be considered as accurate, for the lead is present only as galena and the galena is pure PbS except for very small amounts of antimony which it may contain and which do not materially affect the calculation. Analysis 6, in which pyrite (Fe_2S) was separately determined, shows the composition of the blende to be 5ZnS.FeS. No. 10 has not been recalculated, as the assignment to pyrite of iron in excess of that ratio brings the total to 105 per cent. This iron is presumably present in both pyrite and carbonate. In analyses 1 and 3 a somewhat lower percentage of FeS than that commonly observed is assigned to the sphalerite but the formulas given are presumably accurate, as sulfur has been determined and the analyses sum up close to 100 per cent. The ores represented by other analyses presumably contained considerable amounts of soluble carbonates which were not determined.

SILVER CONTENT INDEPENDENT OF GALENA

The indefinite relation of the silver content to lead, zinc, and iron sulphides shown in the foregoing descriptions of ores may be emphasized because of the common supposition that silver and lead in ores of these classes are closely related.

In addition to the analyses given above, more than 120 assays of Leadville ore containing lead and silver have been collected and are represented diagrammatically in figure 58 in the order of increasing lead content. As nearly or quite all of the lead in the sulphide ores is present as galena, this diagram also represents the relation of silver to galena. No assays or analyses of nearly pure galena are available, but those represented in the diagram suffice to show the wide variation in the ratio of silver to lead.

The quantity of silver varies widely for any given percentage of lead, some of the highest percentages of silver being accompanied by low percentages of lead and vice versa. These assays represent ores in which there is little likelihood of enrichment. All the samples were obtained from stopes in which the secondary copper sulphides—the only visible indication of sulphide enrichment—were absent. None of the assays represent certain residual nuclei of galena found in the oxide ores and reported to be invariably enriched in silver.

The absence of correlation between galena and silver is further emphasized by the persistence of silver to the same general extent in pyritic sphaleritic ores that are entirely free from galena.

TEXTURE AND STRUCTURE

The galena, except where it occurs as linings of cavities, forms medium to coarse-grained masses whose grains have no crystal boundaries but interlock with one another. The diameters of the grains vary greatly, from a minimum of about 1 millimeter to a maximum of nearly 2 inches, even within a single small mass, and the uniformity of grain so commonly observed in both sphalerite and pyrite is lacking. The average diameter of the galena grains (one-fourth to one-eighth inch) is noticeably larger than those of the two other minerals. Galena that fills cavities in sulphide ore or in rock and has resulted from filling and not from replacement is invariably coarser grained, the grains reaching 1 inch or more in diameter. Where it incompletely fills cavities it forms brilliant crystals (plates 47, B, and 48, E).

"Steel galena", composed of grains less than 1 millimeter in diameter, is comparatively rare. The grains are fines where mingled with sphalerite.

Where galena and pyrite occur together, galena was the later to crystallize, for the pyrite occurs here and there and some cavities in galena ore are lined with pyrite cubes. In the lean ores, quartz crystals are enclosed in galena and were clearly the first to crystallize. Where sphalerite and galena occur together, the grains of both minerals are prevailingly so irregular that it is difficult to prove any difference in age; but close inspection shows that where any difference is suggested galena appears to have crystallized later than the blende. In short, galena is the latest of all the important primary ore and gangue minerals.

Copper Ores

CHEMICAL AND MINERAL COMPOSITION

The copper-bearing sulphide ores are less readily interpreted than the lead, zinc, or iron sulphide ores, as their primary content may not be easily distinguished from that due to downward sulphide enrichment. Even in the deeper levels of the mines in Carbonate, Iron, and

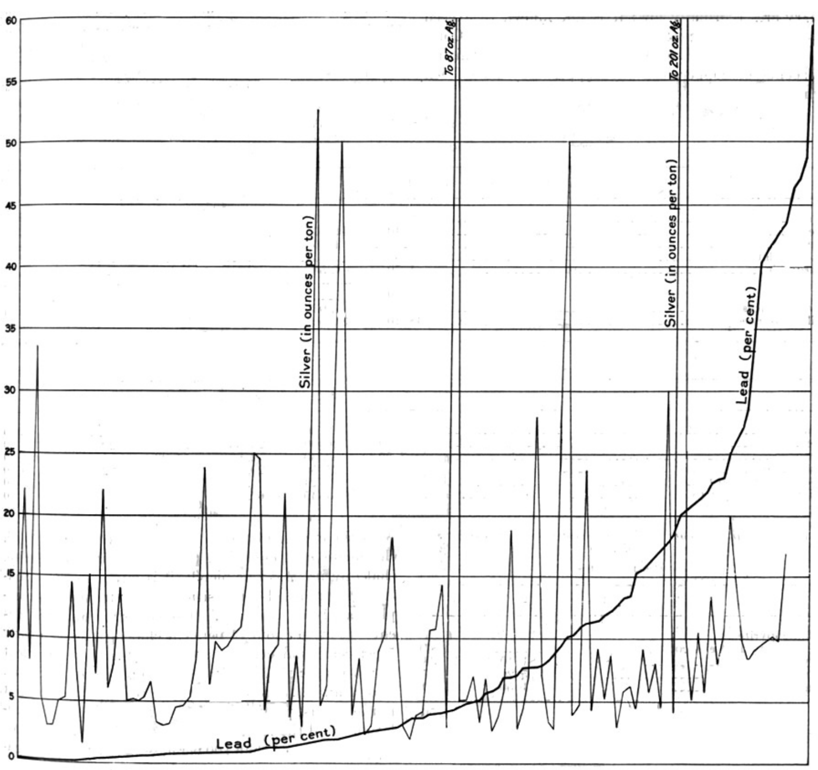

Figure 58. Diagram showing lack of relation between silver content of sulphide ores and percentage of galena in the ores.

Breece hills secondary chalcocite appears as a black powder in the vugs of the ores, and unless analyses and specimens are examined together the relative quantities of the minerals containing the copper can not be estimated even approximately. Many of the ores contain chalcopyrite, and probably all of them would show a small percentage of copper if complete analyses were available. The invariable presence of chalcopyrite even in the purest pyritic masses, which are wholly unaffected by alteration and as microscopic inclusions in zinc blende, establishes its primary origin beyond question. In a few blanket bodies as well as in several veins chalcopyrite is unusually abundant and as these occurrences are mostly within reach of downward-enriching waters their secondary origin is suggested; but no evidence has been found to prove that they are not local segregations of primary chalcopyrite. Chalcocite, on the other hand, occurs as sooty coatings of vugs, films on pyrite and zinc blende, and fillings of fractures in primary ore. So far as noted it has all been formed by processes of downward enrichment. It may therefore be stated that the primary ores all contain minute thinly disseminated grains of chalcopyrite, in most places too small for detection by commercial methods of analysis, and that locally the chalcopyrite may be sufficiently segregated to constitute a primary copper-bearing sulfide ore; that the existence of secondary chalcopyrite, though possible, has not been proved, and that chalcocite of undoubted secondary origin is present in most ores that contain copper in commercial quantity.

The percentage of copper in the undoubtedly primary ores is usually low; it is not known to exceed 3.5 percent and generally is very much lower. Commercial analyses of some ores show considerably higher contents of copper, but the copper may have been wholly or partly present as chalcocite.

The blanket ores in general are notably low in copper, as compared with the lode ores, which contain considerable though unevenly distributed quantities of chalcopyrite and which, owing to their nearly vertical positions, have afforded greater opportunities for downward enrichment with chalcocite.

The copper ores are in part very siliceous and may conveniently be divided into two classes according to silica content, as in the table below. No attempt is made in this table to distinguish the primary from the enriched ores. All the ores represented in the table came from South Iron Hill, but they illustrate fairly well the copper-bearing pyrite of the blanket ores.[6]

Partial analyses of copper-bearing sulfide ores

Ores low in silica

	1	2	3	4	5	6
Cu	3.90	3.80	3.80	3.25	2.90	2.30
Fe	44.40	41.90	37.50	42.40	42.80	38.00
Zn	-----	3.50	6.40	3.60	3.00	5.80
S (Calculated)	49.69	-----	-----	-----	-----	-----
Insoluble	1.70	1.50	2.10	1.60	1.70	1.90
	99.69	-----	-----	-----	-----	-----
Gold, ounces/ton	.035	.035	.03	.045	.035	.035
Silver, ounces/ton	48.10	31.50	11.85	19.50	15.50	8.35

Siliceous ores

	7	8	9	10	11	12
Cu	4.00	3.60	3.45	3.20	3.20	3.00
Fe	25.10	26.90	25.60	23.40	22.30	24.50
Zn	2.50	3.30	2.60	4.20	4.30	4.80
Insoluble	29.40	25.50	29.40	31.10	32.80	30.00
Gold, ounces/ton	.19	.24	.20	.13	.13	.10
Silver, ounces/ton	41.5	61.45	67.60	39.80	52.70	50.20

[6] Irving's manuscript did not specify the mines from which these samples were taken nor the analysts.

Calculated mineral composition of certain copper-bearing sulphide ores

Ores low in silica

	1	**2**	**6**
Chalcopyrite	11.20	10.28	6.61
Equivalent chalcocite	(4.90)	-----	(2.87)
Pyrite	85.65	81.10	77.38
ZnS	-----	5.26	8.67
Insoluble	1.70	1.50	1.90
	98.55	98.14	94.56

Siliceous ores

	7	**11**
Chalcopyrite	11.56	9.18
Equivalent chalcocite	-----	(3.98)
Pyrite	46.43	41.99
Sphalerite	3.70	6.43
Insoluble	29.40	32.80
	91.09	90.40

As the copper in these ores may be present in both chalcocite and chalcopyrite, and the iron in pyrite, chalcopyrite, and zinc blende, it is impossible to calculate their mineral composition closely from the incomplete analyses available. The copper in analysis 1 is equivalent to about 11 per cent chalcopyrite, or nearly 5 per cent chalcocite; that in analysis 6 is equivalent to 6.6 per cent chalcopyrite, or 2.9 per cent chalcocite. Nos. 1 and 2 represent nearly pure sulfide ore, but in the others, particularly in the siliceous group, calculation of all the metals as sulfides would yield totals considerably less than 100 per cent. Lead and manganese were not reported in these analyses and were evidently negligible.

There are no constant relations in these analyses between the precious metals and copper, though ores clearly enriched in copper usually contain more gold and silver than the corresponding primary ores. The gold and silver contents of the siliceous ores (Nos. 7 to 12) are distinctly higher than those of the ores low in silica, but the high percentages of precious metals may be due to enrichment.

The siliceous copper ores do not differ materially from those of a more basic character except for their higher percentage of quartz. They are mainly obtained from fissure-like extensions of the blankets and are further discussed under the vein ores, but they also occur as local modifications within blanket bodies. None of them were observed by the writer.

TEXTURE AND STRUCTURE

The chalcopyrite has four modes of occurrence—(1) as minute specks scattered through the dense pyrite; (2) as larger irregular masses filling vugs among crystals of pyrite; (3) as irregular patches occupying portions of minute veinlets in the solid masses of pyritic ore; (4) forming a large proportion of the ore mass.

The minute specks are sufficiently numerous in places to impart a slightly deeper yellowish ting to the pyrite, even though the percentage of copper is very low. They are too small for their relations to adjoining pyrite grains to be clearly determined.

In the second mode of occurrence the chalcopyrite partly encloses pyrite and is clearly later. In some places it is intimately mingled with dense black blende in such a way that the two appear contemporaneous, the sphalerite, like the chalcopyrite, partly enclosing those pyrite crystals which project into the open cavities. As all the blende in the ores is confidently believed to be primary, the same inference for this contemporaneous chalcopyrite appears justifiable.

In the minute veinlets the chalcopyrite is mingled with blende and galena and all three are clearly later than the pyrite though not the result of sulfide enrichment.

Chalcopyrite forming a large portion of the ore is comparatively rare but was observed in the Little Vinnie mine, on Breece Hill and in the Maid of Erin mine, on Carbonate Hill. In the Little Vinnie mine the chalcopyrite is reported to have been massive with many large cellular vugs. These vugs were filled with a mixture of pyrite cubes, manganosiderite, and a few well-developed crystals of marmatite. This occurrence of chalcopyrite older than pyrite and zinc blende is contrary to the usual relations just described. This ore carries 68 ounces of silver to the ton but no noteworthy amount of gold.

In the Henriett-Maid mine a banded solid mass of chalcopyrite, zinc blende, and pyrite was found. It was much altered, containing sulfates both of copper and of iron in the cavities, and was rendered iridescent by coatings of bornite on all the cavities and fractures so that at first glance it may be mistaken for solid bornite. Chalcopyrite was the only original copper mineral present. A polished specimen of this ore is represented by **Plate 58, A, B**.

In this specimen the chalcopyrite occurs partly as layers and partly as fracture fillings. Thick layers are present at the top and bottom, and the fracture fillings extend from them, cutting rather sharply across the layers of blende but spreading along and partly replacing the layers of pyrite. This relation represents a late phase of primary deposition, just as the sulfides as a whole represent a later stage than the manganosiderite, and is similar to the relation of zinc blend to pyrite and of galena to both pyrite and blend shown in **Plate 60, B**.

Mixed Sulphide Ores

CHEMICAL AND MINERAL COMPOSITION

The mixed sulfides are the commonest ores of the blanket ore bodies and occur in all parts of the Leadville district. They have been developed in greatest quantity in North and South Iron Hill, East Carbonate Hill, and Graham Park and in considerable quantity in Breece Hill, Little Ellen Hill, Fryer Hill, and East Fryer Hill. They consist of mixtures of pyrite, sphalerite, and galena with usually subordinate quantities of quartz and manganosiderite or ferruginous dolomite, together with residual shaly material and sericite from the alteration of included shale or adjacent porphyry. In some places they contain notable quantities of chalcopyrite. They differ in no essential particular from the purely arbitrary types with dominant iron, lead, or zinc sulfides hitherto described, into which they pass by imperceptible stages, but they offer some characteristic features of structure and paragenesis which can not be noted in the purer types and in which are of great genetic importance.

Only a few commercial analyses of the mixed sulfides are available, but these show the range of metal contents and approximate mineral constituents. The source of the samples represented by the analyses was not recorded.

Partial analyses of mixed sulfide ores.

	1	2	3	4	5	6	7	8
Fe	17.80	16.80	16.60	16.0	15.40	15.30	15.20	14.50
Pb	17.80	22.60	10.70	15.0	21.40	23.10	23.00	27.40
Zn	23.40	21.50	24.50	24.00	24.60	24.00	24.50	23.05
Mn	.50	.50	-----	-----	.50	.60	.70	.60
Ag	.104	.045	.186	.038	.036	.36	.027	.034
Insoluble	1.45	1.20	3.40	-----	2.00	2.80	1.75	2.10
Gold, oz./ton	.03	.05	Trace	-----	.05	.02	.05	.03
Silver, oz./ton	30.40	13.50	54.30	11.00	10.50	10.35	7.95	9.95

Approximate mineral composition of mixed sulfide ores

	1	2	3	4	5	6	7	8
Pyrite	29.65	28.20	26.66	25.56	24.28	24.06	23.66	22.70
Galena	20.56	26.11	12.35	17.34	24.73	26.68	26.56	31.67
Zinc blende (marmatite):								
ZnS	34.87	32.04	36.52	35.77	36.66	35.77	36.52	34.35
FeS	6.29	5.78	6.59	6.45	6.61	6.45	6.59	6.20
MnS	.79	.79	-----	-----	.79	.95	1.10	.95
Argentite	.06	.03	.11	.03	.02	.02	.01	.02
Insoluble	1.45	1.20	3.40	(a)	2.00	2.80	1.75	2.10
	93.67	94.15	85.63	85.15	95.09	96.73	96.19	97.99

[a] Not determined

If galena rises much above 25 per cent and can be profitably concentrated, the ore is likely to be classified commercially as lead ore, especially if the zinc blende, which has not been readily separated from the pyrite by processes in use up to 1926, is not in excess over the pyrite. Mixed sulfides consisting mainly of pyrite and blende, with pyrite in excess, with less than 5 per cent lead, and with too little gold and silver to pay for shipment, have not been profitably treated, and large quantities of them have accumulated on the mine dumps awaiting a profitable process of treatment. New processes applied to these ores in 1926 have yielded encouraging results.

TEXTURE AND STRUCTURE

The texture and structure of the mixed sulfides offer features of unusual interest. There are three well-marked varieties of structures, which may best be separately described—massive structure, cellular structure, and banded or layered structure.

Massive structure is exhibited by non-porous granular aggregates of the different sulphides, which show no especial regularity in the relative size, and distribution of the grains. Such aggregates are similar to the massive varieties already described and generally pass gradually into lead, zinc, or iron sulfide.

The ore having cellular structure is filled with irregular cavities, invariably lined with crystals of one or all of the component sulfides, together with carbonates and, locally, quartz. In these cellular mixtures some of the cavities are rather large, but more commonly they are only a fraction of an inch in diameter and are scattered throughout the ore mass without regularity. In some ores the cavities may be so numerous that the ore becomes a porous aggregate of nearly complete crystals of the different sulfides only slightly held together.

There are two kinds of banded or layered structure. One is due to preservation of the banded character or bedding of the original rock which the ore has replaced. This structure is less commonly perceptible in the mixed sulfides than in the purer varieties but may be seen on close inspection along large faces of ore. On freshly broken faces of ore a series of parallel shadowy bands appear. After the face is covered with the dust that collects on the walls of stopes, the banding is brought out by the adherence of the dust to certain layers of the ore. The other kind of layering or banding is generally independent of bedding but closely related to fracturing and permeability.

The parallel layers when seen in broken ore appear in part nearly or quite free from curvature (**Plates 60, D; 63, A, B**) and in part markedly and completely curved (**Plates 60, A, B, C; 61, C, D**). Less commonly they consist of different sets of layers in unconformable contact. (plate 54, a, B) In places they are fractured or faulted and re-cemented by sulfide minerals. (**Plates 61, A, B; 62, A, B)** The layers where well exposed in the stopes are seen to have an ellipsoidal, spherical, or several-sided form. The ore that is marked by roughly circular bands on the walls of stopes has been called "ring ore". The "rings" have a maximum diameter of 10 feet or more. They consist for the most part of alternating layers of pyrite and zinc blende, but layers of galena are prominent in places, and similar layers of chalcopyrite have been found in the Henriett-Maid mine. (plate 58, A, B)

The relations of these concentric bodies to the enclosing limestone leave no doubt that they are replacement deposits formed by reaction between the limestone and solutions which spread from fractures and open bedding planes into the rock. The process can be analogous to that which accounts for Liesegang's rings. These rings were regarded by Ostwald[7] in 1897 as due to reaction between a solution diffusing from a central point and a substance contained in the medium through which diffusion took place. Reaction progressed until the solution became supersaturated with one of the products of reaction. Deposition of this product then took place, forming the first ring, and continued until the solution became under-saturated. Reaction was then resumed as the solution continued to diffuse, and in due time a second ring was formed. Repetition of the process continued as long and far as the solution could diffuse. Owing to progressive depletion of the original reacting constituent of the solution, a greater and greater distance

[7] Ostwald, Wilhelm, Zeitschr. phys. Chemie, vol. 23, p. 365, 1897.

had to be covered before super-saturation with the product of reaction could take place, and the successive rings were deposited farther and farther apart.

Experiments on rhythmic banding have been continued by Liesegang and others. The medium used in the earliest and most of the later experiments was gelatin containing some compound which could react with the diffusing solution; but it has been shown that other material, such as sand and diatomaceous earth containing pores or interstices of capillary size, may also serve as a medium. Liesegang[8] in 1913 published a general account of processes and laws of diffusion, discussing experimental results obtained by himself and others, and results of certain geologic processes, including the replacement of limestone. In 1914 Dreaper[9] published the results of some instructive experiments on diffusion through diatomaceous earth, and in 1917 Stansfield[10], besides reviewing the most important contributions to the subject, showed how the thickness and distribution of the rings were dependent on relative concentrations and rates of diffusion. Ostwald's explanation that the rings were due to rhythmic attainment of super-saturation has been questioned, particularly by Hatschek,[11] but it is strongly supported by Stansfield and others cited by him.[12]

Experimental work thus far has differed from natural rhythmic replacement of carbonate rocks, in that the reacting substances have diffused in an inert medium, whereas the carbonate rock is both reagent and medium. The small quantity of organic matter, particularly in the Blue limestone, may have contributed to the reaction but the important factors were the carbonate minerals themselves and ability of the solutions to permeate along boundaries between grains and microscopic cracks. Variations, shape, and size of the layers are attributed to variations in permeability and composition of the carbonate rock and to differences in concentration of the invading solution.

The simplest case imaginable occurs where solutions spread to both sides of a fracture produced ore with layers parallel to the fracture (**Figure 59, A**). Where the opening along which the solutions arrived was a pipe-like enlargement of a fracture, the layers formed concentrically around the "pipe" (**Figure 59, B**). If two or more "pipes" were sufficiently close together, the layers from each grew together into complicated forms resembling intricate contortions of shaly or schistose rock.[13] The great masses of layered ore, however, are more complicated and may consist of a number of spherical, elliptical, or irregular units. Each unit is bounded by intersecting fractures along which the solutions moved and represents a replaced block of limestone. The dimensions of the units depend upon the distribution of the fractures and the uniform or variable permeability of the limestone block. Typical variations are shown diagrammatically in **Figure 59, C**. If the rock was uniformly permeable the layers of ore are regular; if the rock was more permeable at one point than another the layers of ore extend farther from the fracture and are broader in the more permeable part.

Short fractures branching from the main fractures give rise to similar irregularities. These irregularities, as seen in small specimens or in smooth walls of stopes, resemble the contortions that are common in disturbed shaly strata; but in large blocks of ore, where the irregular layers can be seen in their entirety, these layers are so closely associated with absolutely undisturbed layers that they can not be explained as due to any form of compression. Where disturbance has undoubtedly taken place, either through uneven settling of the newly formed layered ore or through earth movements, the layers are fractured or faulted. Fracturing or faulting is much more likely to take place than folding, particularly in ore that consists largely of the hard, brittle mineral pyrite.

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[8] Liesegang, R. E., Geologische Diffusionen, 1913, Pp. 138, 148-149, 145-155 are of particular interest in connection with rhythmic replacement of limestone. Reviewed by Adolph Knopf (Econ. Geology, vol. 8, pp. 803-806, 1913).

[9] Dreaper, W. P., Precipitation and stratification in the absence of gels, and their bearing on the formation of mineral deposits: Inst. Mining Met. (London) Bull. vol. 23, 1914, pp. 381-391.

[10] Stansfield, J., Retarded diffusion and rhythmic precipitation: Am. Jour. Sci., 4th ser., vol. 43, pp. 1-26, 1917.

[11] Hatschek, E., Zeitschr. Chemie Ind. Kolloide, vol. 10, p. 124, 1912.

[12] Stansfield, J., op. cit., pp. 3-6.

[13] Liesegang, R., op. cit., p. 138. Knopf, Adolph, Geology of the Seward Peninsula tin deposits: U. S. Geol. Survey Bull. 358, p. 46, 1908.

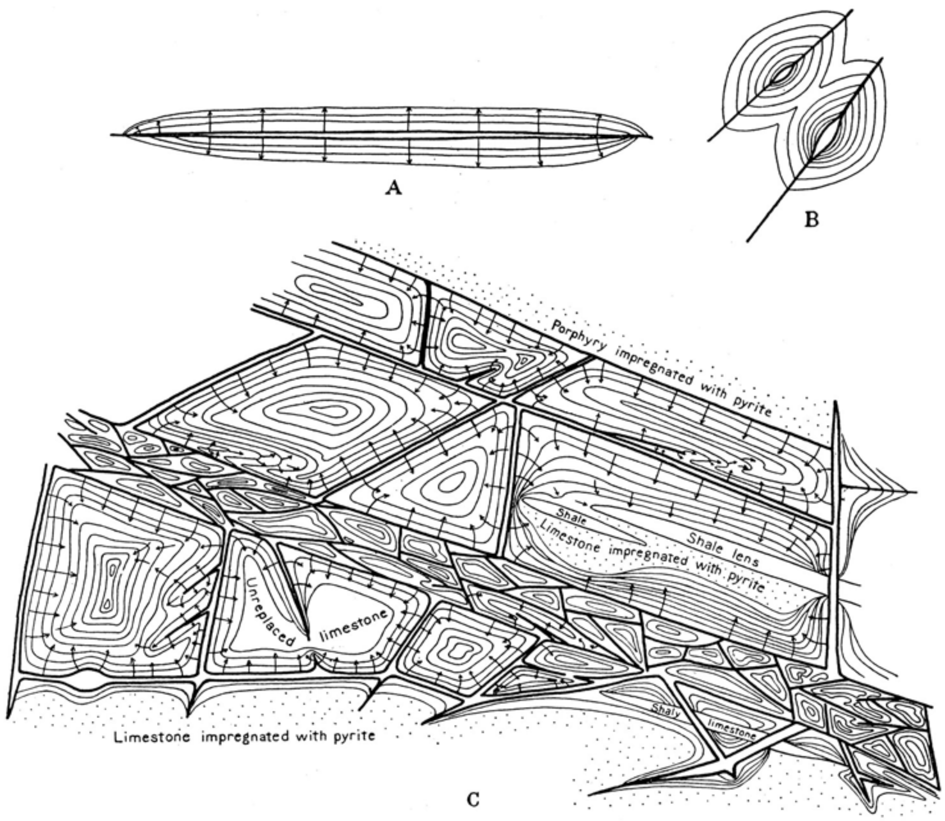

Figure 59. Diagram illustrating the development of concentrically banded ore by the replacement of limestone.

The unconformable relation shown in plate 54, A, B, is interpreted as the result of interference between two groups of layers growing from different fractures. The specimen represented is too small to show this relation in as much detail as would be desirable. Group *a* represents deposition in uniformly permeable rock, replacement progressing upward with respect to the specimen. Group *b* represents deposition where the solutions could permeate horizontally more easily than vertically. Group *a* had developed in broad layers nearly to its upper limit, where progress, presumably because of a less permeable layer of rock, was much slower and resulted in closely spaced narrow layers. At the same time group *b* had developed in an opposite direction until it approached or reached the upper limit of group *a*, where its downward progress was arrested; but it was still able to move to the right, parallel to the top of group *a*, against which its layers terminated abruptly. After deposition of group *b* was completed the ore was fractured across the layers of both groups and re-cemented.

Where only two ore minerals are present they appear at first glance to have been deposited in rhythmic alternation—a layer of pyrite followed by one of blende and by another of pyrite; but the relative thicknesses of the different mineral layers vary considerably, as shown in several of the accompanying illustrations (plates 54, A, B; 60-**63**), and the rhythmic relations could not have been perfect. Moreover, where a third mineral such as galena, is prominent in some parts of a layered mass and not in others the apparent rhythmic relations are further disturbed. Close inspection of the ore, however, shows that the layers of zinc blende or galena are connected with veinlets of the same mineral that cut across the layers of pyrite (plates 60, B—D; 61, A—C; 62, A, B). Lumps of ore considerable size may be found in which no such veinlets are present, but the veinlets in general appear to be sufficiently numerous to warrant the conclusion that the layers of zinc blende, galena, and rarely chalcopyrite were deposited between earlier formed layers of pyrite from solutions that extended along fractures and spread along the voids between the pyrite layers. The common occurrence of pure banded cellular pyrite has already been noted. It was originally more prevalent, but in places has been permeated by zinc, lead, or copper sulfide solutions and converted into the layered mixed sulfide ore.

In some places the layered pyrite was not only cracked but slightly to thoroughly shattered before the deposition of later sulfides in the irregular voids, with corresponding complexity in the texture mixed sulfide ore (plates 60, A; 61, B; 62, A). In a few places the small remnants of pyrite may be so evenly and thickly distributed among the zinc blende or other sulfide aggregates as strongly to suggest simultaneous deposition; but if such a mixture can be traced for a short distance it will be found to grade into the more normal banded ore or to connect with veinlets of essentially pure zinc blende.

The pyrite was not everywhere deposited in simple bands but locally formed short rod-like or columnar aggregates transverse to a rather obscure banding. Such aggregates as are seen today are in part cellular and in part mixed with zinc blende (plates 61, D, and 63, B) in a manner to suggest that the two minerals grew simultaneously. The writer (Loughlin) has seen very little ore of this variety, but what he has seen proves to be connected with veinlets of zinc blende and is interpreted as a mass of cellular pyrite whose cells were later filled with zinc blende.

In some places pyrite during the first stage of ore deposition may not have completely replaced the limestone, and the zinc blende of the later stage not only filled voids but also completed the replacement. Such conditions would give an excess of zinc blende, which would enclose isolated crystals or small aggregates of pyrite. Other local variations in physical conditions could multiply the variations in texture of mixed sulfide ores, but it is believed that all, if closely studied and traced to contacts with the more ordinary varieties can be interpreted as due to successive stages of deposition—first, pyrite; second, zinc blende alone or in great excess over other sulfides; third, either galena or chalcopyrite alone or in excess over other sulfides. The writer has found banded ore containing pyrite, blende, and galena in which the minerals were clearly deposited in three successive stages. The layers of blende were connected with veinlets of blende that crosscut the pyrite layers, and the layers of galena were connected with veinlets of galena that cut not only the layers of the other two minerals but the veinlets of blende as well. Layers of chalcopyrite connected with veinlets that crosscut blende and pyrite and appear to replace part of the pyrite are shown in plate 58, A, B. The presence of both galena and chalcopyrite in the same mass of layered ore has not been noted.

These successive stages of deposition agree with the relative order of crystallization in the other varieties of sulfide ore. They also help to explain the segregation of relatively pure masses of blende and galena. The solutions of the second or third stage must have moved where opportunity allowed. If they could not escape from the places where the rock had already been replaced by pyrite they filled voids in the pyrite; if they could escape and reach a mass of replaceable rock they formed the relatively pure shoots of blende or galena.

To judge from the relative quantities of sulfide minerals in the Leadville district the original ore-forming solutions contained, besides silica and other non-metals, iron in great abundance, considerable zinc, less lead, and very little copper, besides minute quantities of other metals. The principal gangue minerals, quartz and manganosiderite, were deposited for the most part by the replacement of dolomite or limestone before the sulfides except for a small amount of pyrite. When conditions permitted the deposition of sulfides in large quantity pyrite was the most concentrated and the least soluble constituent of the solution. Its deposition was caused by reaction with the carbonate rocks, but the volume of rock dissolved was greater than the volume of pyrite deposited. As the solutions permeated the rock from the feeding fractures solution took place until equilibrium between solution and rock had been reached or slightly exceeded and pyrite was deposited. Deposition continued until the solution became under-saturated again, and solution of carbonate rock was resumed until pyrite was forced once more to precipitate. Solution and deposition alternated more or less rhythmically while the solution advanced into the rock until an un-replaceable barrier was reached or the supply of pyrite was exhausted.

Whether a eutectic point between pyrite and zinc blende can exist in so complex a solution is not known. If one does, it is evidently reached only when the ratio of pyrite to zinc blende is very low. The nearly pure masses of zinc blende all contain pyrite, some of which may have been deposited at the same time as the blende and some of which may represent the first (pyritic) stage of sulfide deposition. The second stage took place when the solution had become super-saturated with zinc blende. All layers of zinc blende were deposited simultaneously, or as soon as the voids between pyrite layers became filled with saturated solution. There was no rhythmic alternation between solution and deposition, except where remnants of un-replaced carbonate rock were reached, and even there banding was not very conspicuous, as replacement of carbonate rock by blende was not marked by any great decrease in volume.

The relations between blende and galena and between pyrite and galena were similar to those between pyrite and blende. Blende was nearly all deposited before deposition of galena began. If a eutectic or triple point existed it was after the solution had lost nearly all of its zinc and iron.

The relations between pyrite and chalcopyrite were also similar to those between pyrite and galena. If simultaneous deposition took place it was only after the solution had been almost depleted of iron in excess of that needed to form chalcopyrite. The relations between zinc blende and chalcopyrite were similar. So far as the layered ore is concerned the chalcopyrite was formed during a later stage than the blende, but much of the blende contains microscopic inclusions of chalcopyrite, which must have been deposited with it. The outer parts of blende crystals in vugs partly enclose chalcopyrite in such a manner as to suggest that the growth of the two minerals overlapped. From this relation as contrasted with that between blende and galena it may be inferred that sulfide solutions containing considerable copper, iron, and lead would deposit chalcopyrite first but would begin to deposit galena also before the deposition of chalcopyrite approached completion. No evidence was found that would suggest the shattering of earlier formed sulfides by crystal pressure of those formed later nor was any conspicuous amount of replacement of earlier by later sulfides noted.

ORES CONTAINING BISMUTH

Ores with high contents of bismuth and silver and usually with high content of gold have been found only in small quantity. The most noteworthy occurrences have been in the Lilian, Ballard, and Tucson mines, but assays show that bismuth is present in several other mines, principally in oxidized ore. The only original bismuth mineral thus far identified is the sulfide bismuthinite in a microscopic intergrowth with argentite and galena. This intergrowth was formerly called “lillianite” or “schapbachite”. (See p. 32, Chapter 8) It was first found in the Lilian mine, but the writers have had no opportunity to study it there. In the Tucson mine it coated crustified ore which lined cavities in Cambrian quartzite, as described in detail in chapters 8 and 13 (p. 32, Chapter 8, p. 26, Chapter 13). In the Ballard mine nuclei of the same intergrowth were found in the centers of lenticular bunches of yellow ocherous oxidized gold ore. This ocherous ore was also accompanied by thin lenses of bluish to whitish bismutite.

The ores containing bismuth have not been systematically worked for that metal and little information beyond the descriptions of the component minerals is available concerning them. Exploration has, however, proved the presence of bismuth in appreciable quantities, particularly in the oxidized ores of Breece Hill and also of Iron and Carbonate hills. In most of the samples assayed the bismuth content was less than 1 per cent, but in exceptional samples it was as high as 9 per cent. The samples consisted mostly of yellow earthy material and evidently contained the yellow oxide, bismite, but some of the exceptionally rich samples were described as “blue clay” and evidently contained the basic carbonate, bismutite.

The content of gold, silver, and lead in these oxidized samples was strikingly low, in contrast to the sulfide ore, and showed no relation to bismuth. Gold in most of the samples amounted to 0.02 ounce to the ton or less, and silver, with few exceptions, amounted to less than 5 ounces to the ton. An exceptionally rich sample contained 0.4 ounce of gold and 76.5 ounces of silver to the ton and 0.13 per cent of bismuth.

RELATION OF VEINS TO BLANKET ORE BODIES

The preceding discussion has set forth in some degree the manner in which minor blanket ore bodies connect with the veins either as lateral offshoots or as upward terminations. The ores that have been mined from these connecting blanket masses are nearly all similar to those within the veins and different from the ores that form the large blankets in the western part of the district; but gradations between the two kinds of blanket ores have been established at a few places.

For a long time, however, no apparent connection between the two kinds of blanket ore had been found or appreciated, and there was an inclination to regard them as distinct in origin. They were so regarded by Moore[14] and, tentatively by Irving, but evidence brought to light after Irving's last visit to the district favors the view that all; the ores were formed at essentially the same time. As the present writer (Loughlin), however, has not been able to examine places cited by others as affording evidence against this view, he does not regard the question as finally answered and leaves the reader to draw conclusions from the following summary of the evidence on both sides.

The available analyses (p. 23–35) show that the main blanket ores in the western part of the district, whether oxidized or not, are nearly all relatively high in silver and low in gold. Where completely or partly oxidized they have been enriched in silver but not in gold or copper. There are notable exceptions, however, some of which serve as connecting links between the silver ores of the blankets and the gold-copper ores of the veins. The "gold ore shoot" in Iron Hill,[15] which was unusually high in gold, though no visible gold was found in it, was remarkable for lying between shoots of the ordinary silver-lead oxidized ore. It has not been accessible in recent years but its position and the details of its outline [plate 26, section M—M' (extra plates and figures), and figure 56] suggests that it may be more directly connected than the other shoots with the Tucson fault, which served as a channel for ascension of the original ore-forming solutions. This suggested relation is similar to the proved relations between gold-copper ores and zinc-lead ores in the Tucson mine [figures 18 and 20 (extra plates and figures)]. There typical sphalerite-galena ore replacing White limestone extended to the fault, where it graded into pyrite-chalcopyrite ore enriched by chalcocite, gold, and silver in a siliceous gangue. The pyritic copper ore evidently favored a siliceous environment—either quartzite, Gray porphyry, or gouge derived from them—but it did not extend far into the limestone before it gave way to the sphalerite-galena ore. The ore bodies of the Tucson mine are described on pages 25–27 (Chapter 13).

The Cord vein [figures 21–23 (extra plates and figures)] presents the strongest evidence of direct connection between the two kinds of ore. At the lower levels it lies between walls of Cambrian quartzite and is typical siliceous pyritic or, containing irregularly distributed gold and copper. Its highest-grade ore is in part clearly enriched by chalcocite but in part without visible sign of enrichment. Similar ore is found in Gray porphyry sills and also in the Parting quartzite; but where the vein crosses beds of White limestone it spreads out and forms blankets of sphalerite-galena-pyrite ore, which have their longest axes along the vein. There is no evidence that the vein differs in age from the connected blankets. These ore bodies are described on pages 25–27 (Chapter 13).

Similar evidence may have been exposed in and near the Wolftone mine along the Tucson-Maid reverse fault. Veins of rich ore containing copper have been worked there and apparently were connected with large replacement bodies of ordinary zinc-iron-lead sulfide ore, but no adequate account of the relations has been preserved. The connection of blanket ore bodies with the mineralized Tucson-Maid fault has been shown by Spurr.[16]

On the seventh level of the Greenback mine a vertical vein in a branch of the Tucson fault between Cambrian quartzite and upturned beds of the overlying "transition shales" contained ore that resembled

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[14] Moore, C. J., Recent developments at Leadville, Colo. (discussion of paper by G. M. Butler entitled "A Leadville fissure vein"): Econ. Geology, vol. 7, pp. 590-592, 1912.

[15] Blow, A. A., The geology and ore deposits of Iron Hill, Leadville, Colo.: Am. Inst. Min. Eng. Trans., vol. 18, p. 168, 1890.

[16] Spurr, J.E., The ore magmas, vol. 1, p. 353, 1923.

the ore of the Winnie-Luema vein in the kind and distribution of its minerals. It was visibly enriched in copper, but no assay records of it were obtained.

It lay directly below the large blankets in White and Blue limestone that formed the principal ore bodies of the mine. The ore between the lower blanket and the accessible part of the vein was said to have been considerably enriched in silver. Much of the ore in these blankets was low-grade pyrite with local shoots of zinc-lead ore. The predominance of pyrite so near the vein is in harmony with the general evidence of the distribution of the ores, but the condition of the workings, when visited in 1919, prevented a thorough study of the ore bodies.

The absence of zinc-lead ore in the blankets connected with veins in the eastern part of the district has been cited as evidence that these blankets are not to be correlated with the large blankets in the western part; but zinc-lead ore was observed in the Golden Eagle workings and in the 20—a vein of the Ibex mine, in Breece Hill. The veins in the Golden Eagle workings (figure 55) are mostly too small to be productive themselves, although their mineral composition is typical of the enriched pyritic veins; but they serve as leads to small blanket bodies that replace thin bedded shaly White limestone between rather closely spaced sheets of porphyry. The smallest of these replacement deposits are mere bulges along the narrow veins and do not differ from the veins in mineral composition unless in having a greater percentage of quartz. The larger blankets are also of similar composition for a short distance from the veins, but farther away they change almost abruptly into massive sphalerite-galena ore carrying a few ounces of silver to the ton and very little gold. The effect of siliceous rock on the ore solutions was evidently not overcome until a considerable quantity of carbonate rock had been replaced.

Careful scrutiny of the junctions of veins and blankets in the Golden Eagle workings proved that the minerals in both were deposited at the same time. Irving's observations on the 20 –a vein of the Ibex mine are especially significant. This vein was found on the tenth level and was followed upward nearly to the seventh level, where it terminated in a blanket. The vein consisted of coarse-grained pyrite and chalcopyrite enriched by chalcocite. The blanket, on the contrary, was very low in copper minerals but contained 25 to 35 per cent of zinc blende. Complete analyses of the two varieties of ore are not available.

The miners in Breece Hill, producing gold ore that may contain also considerable copper and silver, stop mining when this ore passes into the sphalerite-galena ore, which evidently does not pay for the cost of mining and treating. This sphalerite-galena ore is essentially identical in character with the zinc-iron-lead sulfide ores of Iron and Carbonate hills, but the ore shoots are smaller. The fact, therefore, that the principal ores mined from the blankets connected with veins in the Breece Hill area are the gold and gold-copper ores does not prove that there are no zinc-iron-lead ores present.

The absence of extensive blanket bodies connected with the larger veins is attributed to physical conditions. A comparatively thin layer of gouge along the vein wall serves as an effective seal to keep the solutions within the fissure. The absence of replacement bodies in the White limestone along the veins in the Luema mine [figures 104 and 105 (chapter 13)] may be due to this cause, although it must be admitted that the limestone has not been intensively prospected for replacement bodies that have been fed through minor fractures connected with the main vein. The White limestone is so shaly in the Breece Hill area that it is not particularly favorable for extensive replacement, and it is split into so many thin layers by porphyry sills that the formation of thick blankets is further prevented.

There have been few opportunities to study blankets along the veins in Blue limestone. The positions of blanket stopes in the Blue limestone of the Ibex mine, however (plate 57), strongly indicate their connection with veins. The oxidized ore mined from them was lead carbonate, some of which was rich in gold. The Little Johnny stopes near the Ibex No. 1 shaft have been famous for the gold mined from them in the early days, and shoots of zinc carbonate ore directly connected with some of these stopes have been mined since. One feature of this zinc ore is the presence of aurichalcite, the basic carbonate of zinc and copper. There thus appears to have been much zinc and lead as well as gold and copper in the original ores of these blankets.

Two facts very difficult to reconcile are the direct connection of blankets of siliceous gold ore with the southern part of the Winnie-Luema vein and the lack of connection between the old stope of lead carbonate and the northern part of the vein. It is possible but can not be proved that here, as in certain other similar stopes, the mining of the siliceous ore was stopped where the zinc blende became dominant. The old lead carbonate stope was not accessible when the Luema mine was studied in 1913. A minor vein of mixed sulfide ore [figure 104 (chapter 13)] was followed toward the blanket stope but became too poor for working or pinched out before the stope was closely approached. The stope extended nearly to the vein but is not known to have reached it at any point. The immediate source of the ore in the blanket body has not been found, and the occurrence lends little support to either view regarding the relative ages of the lode ores and the large blanket deposits of zinc-iron-lead ore.

G. M. Butler[17] in discussing the deposition of the ores in the Luema mine suggested that the blanket deposit could have been fed through narrow fissures connected with the main vein, and he was at first inclined to regard the blanket and the main vein as contemporaneous, but Moore[18] contended that they were of different ages and cited places where blanket bodies had been cut through and locally enriched by later veins. According to information furnished by Moore to Irving, the Ella Beeler east vein, in the Iowa Gulch area, cuts directly across a blanket ore body at the top of the White limestone, and the ores are distinct and show no connection with each other; but no description of the intersection or of the composition of the ores is furnished, and there is some question as to whether the siliceous pyritic ore along the vein is so different from the zinc-lead ore (or lead carbonate ore?) in the blanket as to afford a presumption that the vein actually cut the blanket.

The preceding paragraphs may be summarized as follows: Several veins and connected blankets in the eastern part of the district have been proved to be contemporaneous, and in some of them the siliceous pyritic gold and gold-copper ore in and near the veins have been found to pass into and not cut across zinc blende or mixed sulfide in the blankets. The Cord vein and its connected blankets afford similar proof in the western part of the district, and the transition between siliceous gold-copper ore and zinc-lead sulfide ore in the Tucson mine is also proved. At other places in both parts of the district the same relations are suggested, but records are inadequate for proof.

The comparatively small size of the blankets in the eastern part and the great number of veins near them favor the inference that both are contemporaneous, but the great number of large blankets and the scarcity of veins in the western part are not so easily explained. The scarcity of exposed connections between these blankets and veins is partly due to methods of development, particularly of the "first contact" by inclines along thoroughly oxidized ore bodies, partly to the fact that small veins cut beneath the ore bodies, partly to the fact that small veins cut beneath the ore bodies have been overlooked or have offered no incentive for exploration because of their small size. Exploration has been sufficient in places, however, to demonstrate the absence of persistent veins beneath some of the large blanket ore bodies.

No veins have been found associated with the blankets between sills of White porphyry at Fryer Hill. These blankets, however, were thoroughly oxidized and the presence of underlying veins was greatly obscured. Furthermore, during Emmons's first survey very little work had been done beneath those ore bodies, and in later years any evidence that may have existed has been concealed by timbering and waste filling. Recent explorations in the White limestone of East Fryer Hill disclosed one fissure along which the limestone was impregnated by a little quartz and pyrite, but no persistent vein was found, and it is concluded that the ore-forming solutions, whatever their source must have traveled for considerable distances along bedding planes or "contacts".

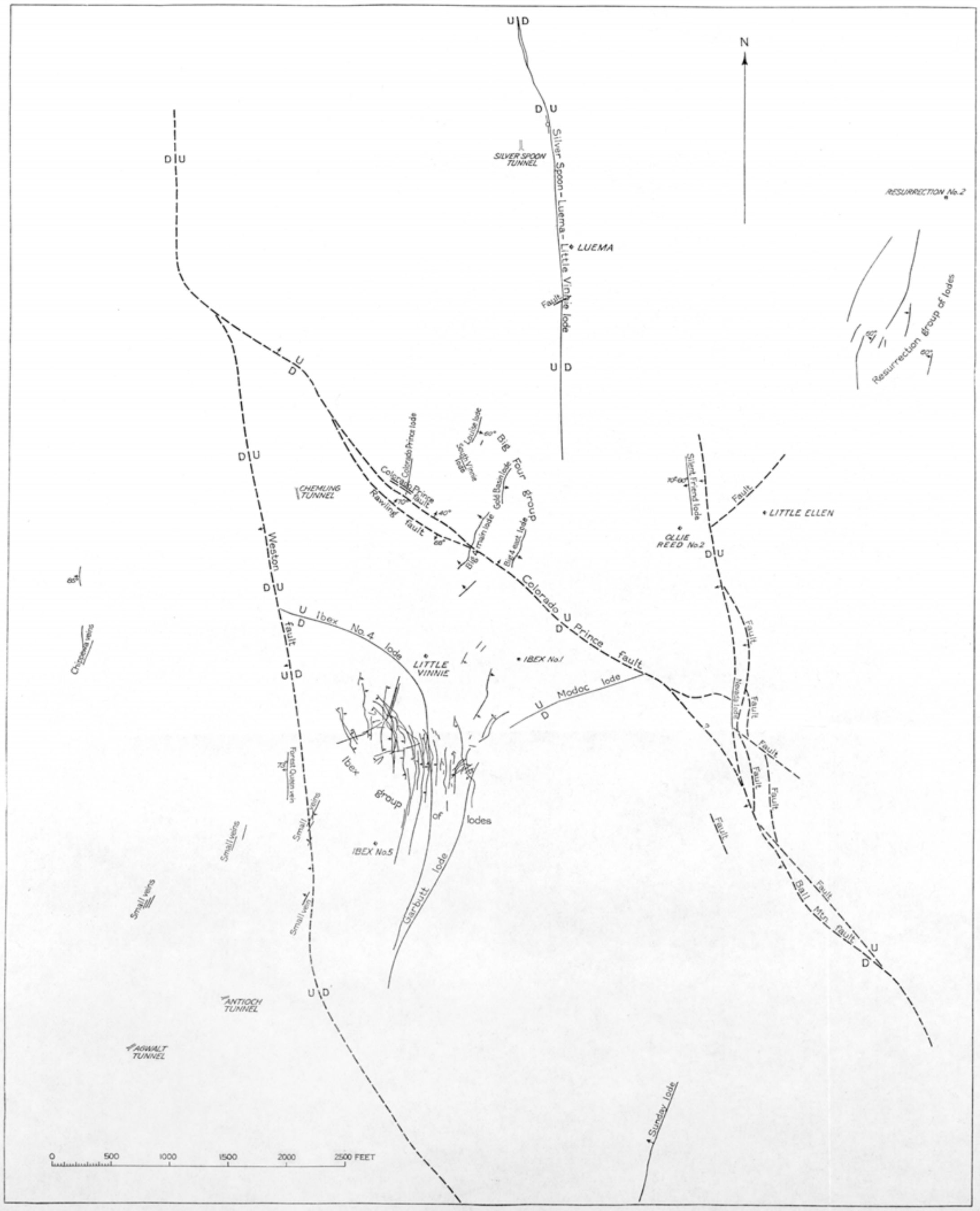
Similar remarks apply to other large ore bodies, particularly in the oxidized zone, and Emmons, who had searched for mineralized fissures beneath them but who died before the significant evidence of the Cord and Tucson mines was disclosed, was justified to a considerable degree in discrediting the controlling effect of fissures on the distribution of ore bodies. The elongate shapes and parallel arrangement of the ore bodies, however, strongly indicate that fissures or shattered zones served as channels for circulation of the ore-forming solutions beneath impervious cappings. These fissures, as shown in chapter 5, were intrusions and subsequent to the period of folding and reverse faulting. The

[17] Butler, G. M., A Leadville fissure vein: Econ. Geology, vol. 7, pp. 315-323, 1912; Colorado School of Mines Quart., vol. 8, pp. 1-8, 1913.

[18] Moore, C. J., Econ. Geology, vol. 7, pp. 590-592, 1912.

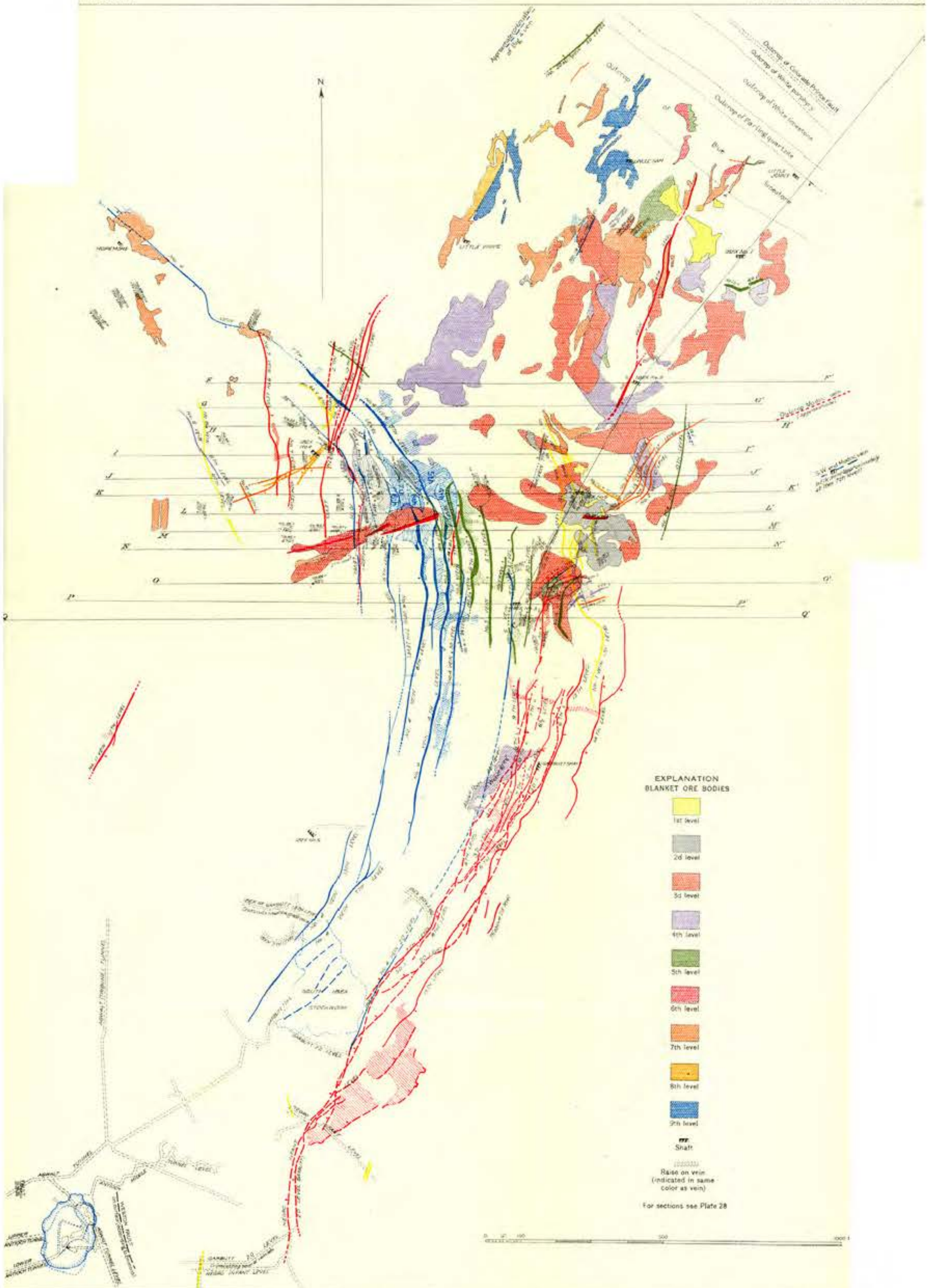
different degrees to which different rocks yielded to these stresses account for the presence in the Blue limestone (dolomite) of fractures that do not continue into or through the adjacent porphyry sills or the shaly beds at the top and base of the Parting quartzite. Only the major faults and fissures were continuous through all the formations, and it was only where they were sufficiently closed or deflected by the more flexible rocks that conditions were favorable for replacement of the limestones. At such places the ore-forming solutions could be deflected along bedding planes or along local fractures or shattered zones between shale beds pr porphyry sills until they were stopped by some barrier, and the resulting ore body might be a considerable distance from the trunk fissure through which the solutions rose. To trace the courses followed by the solutions would be no simple matter even if mine workings had been driven for that purpose, and to trace them in the workings that exist is impossible.

As the viscous porphyry intrusions were deflected for long distances from the trunk conduits, it is quite conceivable that the more fluid ore-forming solutions were deflected even farther. They clearly rose through trunk fissures like the Cord vein and through the fissured ground along the Tucson-Maid fault. Portions of them were doubtless deflected from these trunk channels at different horizons and followed available channels at those horizons in directions quite different from those of the trunk channels. Thus the ore bodies of the Carbonate Hill area are believed to have been mostly if not wholly deposited by solutions that rose along the Tucson-Maid fault zone and by more or less devious paths reached the “contacts,” which they followed eastward to Graham Park and westward to the Downtown area. They may even have followed the “first contact” northward through the Small Hopes ground to Fryer Hill; but it would not be surprising if another local source of supply were found somewhere beneath Fryer Hill and beneath the pyritic ore in the mines of East Fryer Hill, similar to those in the New Mikado and Penrose mines (p. 2 and 8, Chapter 13), which supplemented those from the Tucson-Maid fault zone.



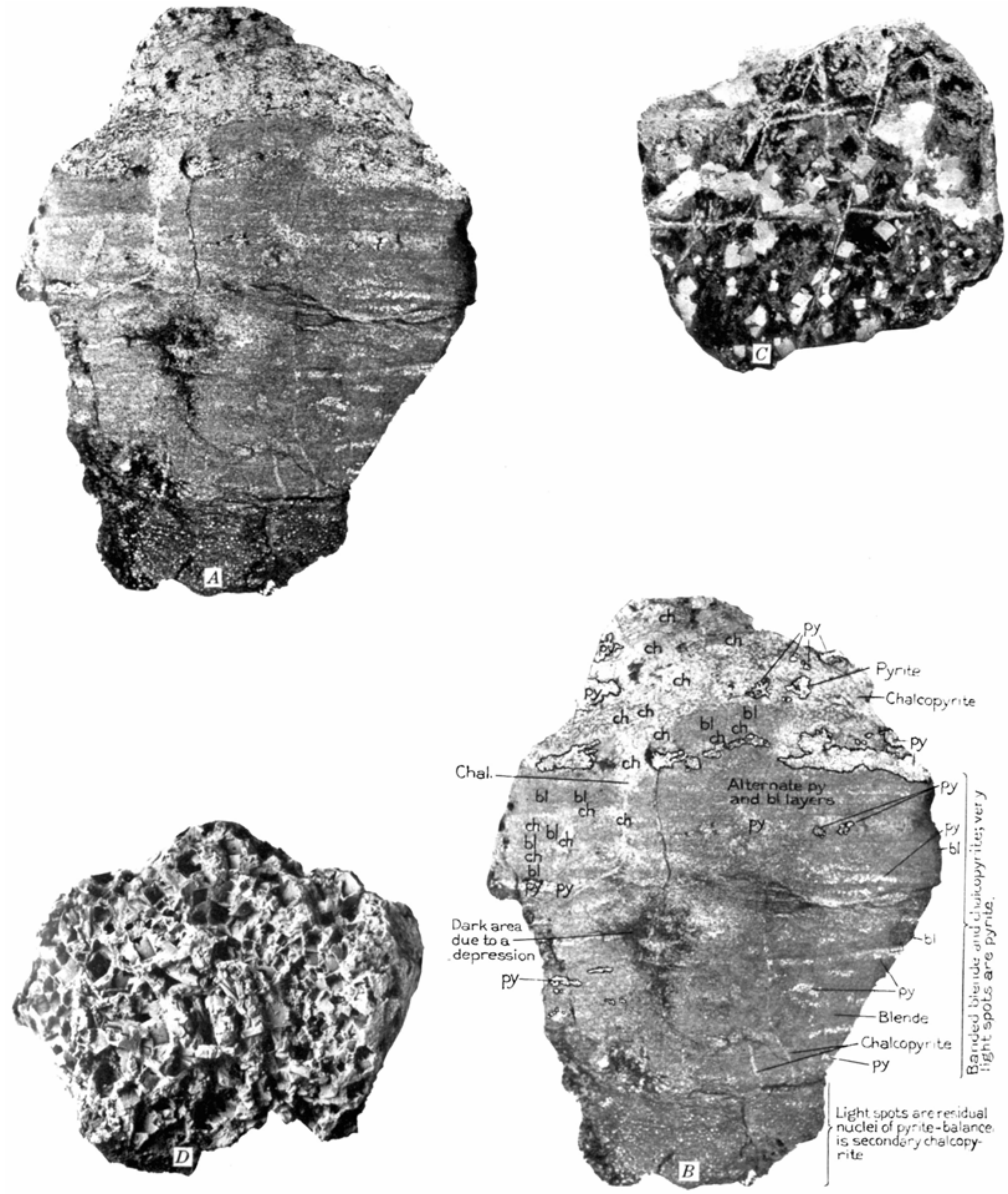
PLAN SHOWING THE PRINCIPAL VEINS AND FAULTS IN THE EASTERN PART OF THE LEADVILLE DISTRICT

PLATE 56



MAP SHOWING VEIN AND BLANKET ORE BODIES IN IBEX AND ADJOINING MINES

PLATE 57



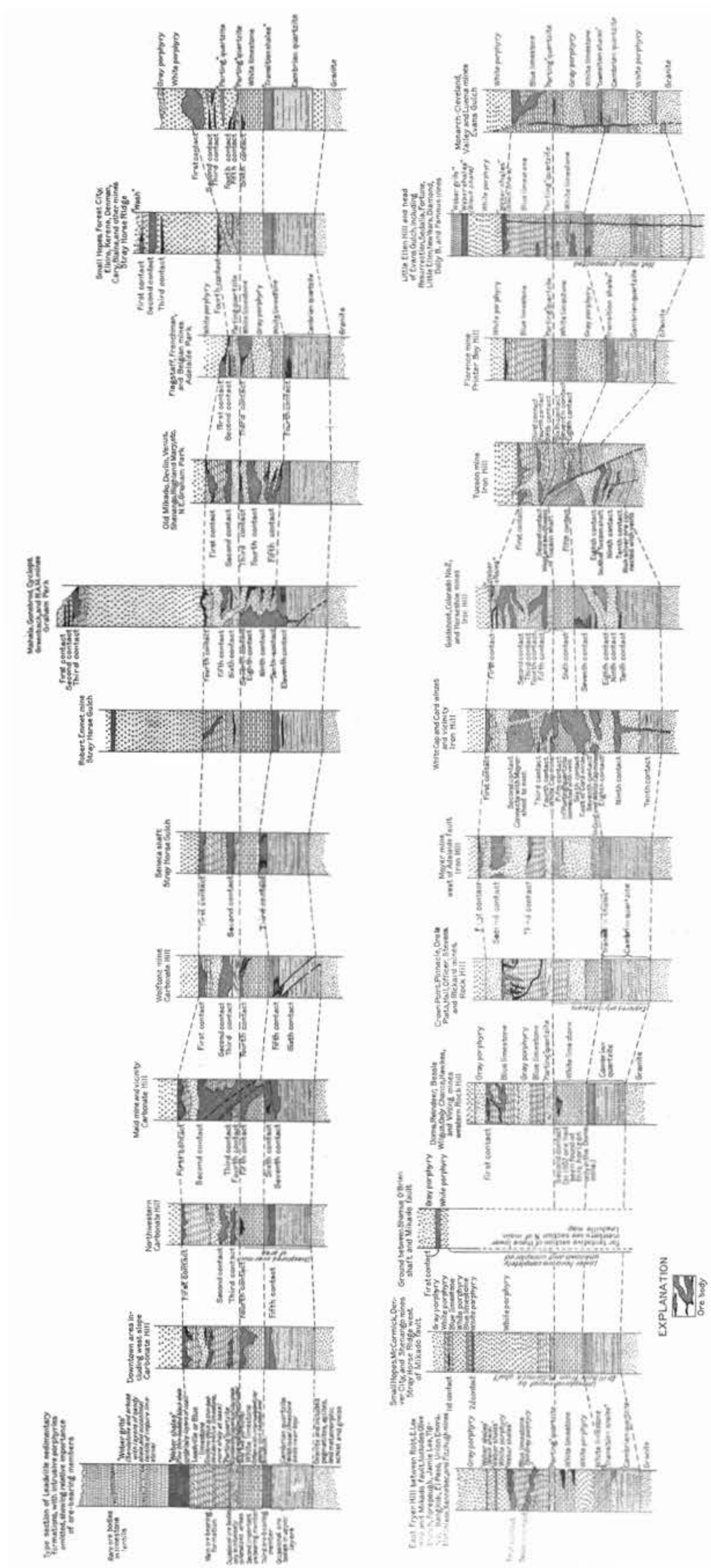
P L A T E 58

A, B. POLISHED SPECIMEN OF MASSIVE CHALCOPYRITE-SPHALERITE ORE

Natural size. Py, Pyrite; bl, sphalerite; ch, chalcopyrite. Boundaries of some pyrite aggregates are emphasized by black lines. Ore consisted at first of alternating layers of pyrite and sphalerite. Chalcopyrite was later introduced along the layers and cross fractures and appears to have partly replaced the layers of pyrite but not those of sphalerite. Thick layers of chalcopyrite with inclosed grains and aggregates of pyrite form the upper and lower parts of the specimen.

C. PYRITE CRYSTALS IN LIMESTONE AT THE MARGIN OF A MASSIVE REPLACEMENT BODY OF PYRITE

D. JASPEROID HONEYCOMED WITH CUBIC CAVITIES LEFT BY THE LEACHING OUT OF PYRITE CRYSTALS, FROM OXIDIZED LODE ORE, IBEX MINE



COLUMNAR SECTIONS SHOWING POSITION AND RELATIVE SIZE OF BLANKET ORE BODIES IN DIFFERENT PARTS OF THE LEADVILLE DISTRICT, COLO.

PLATE 59

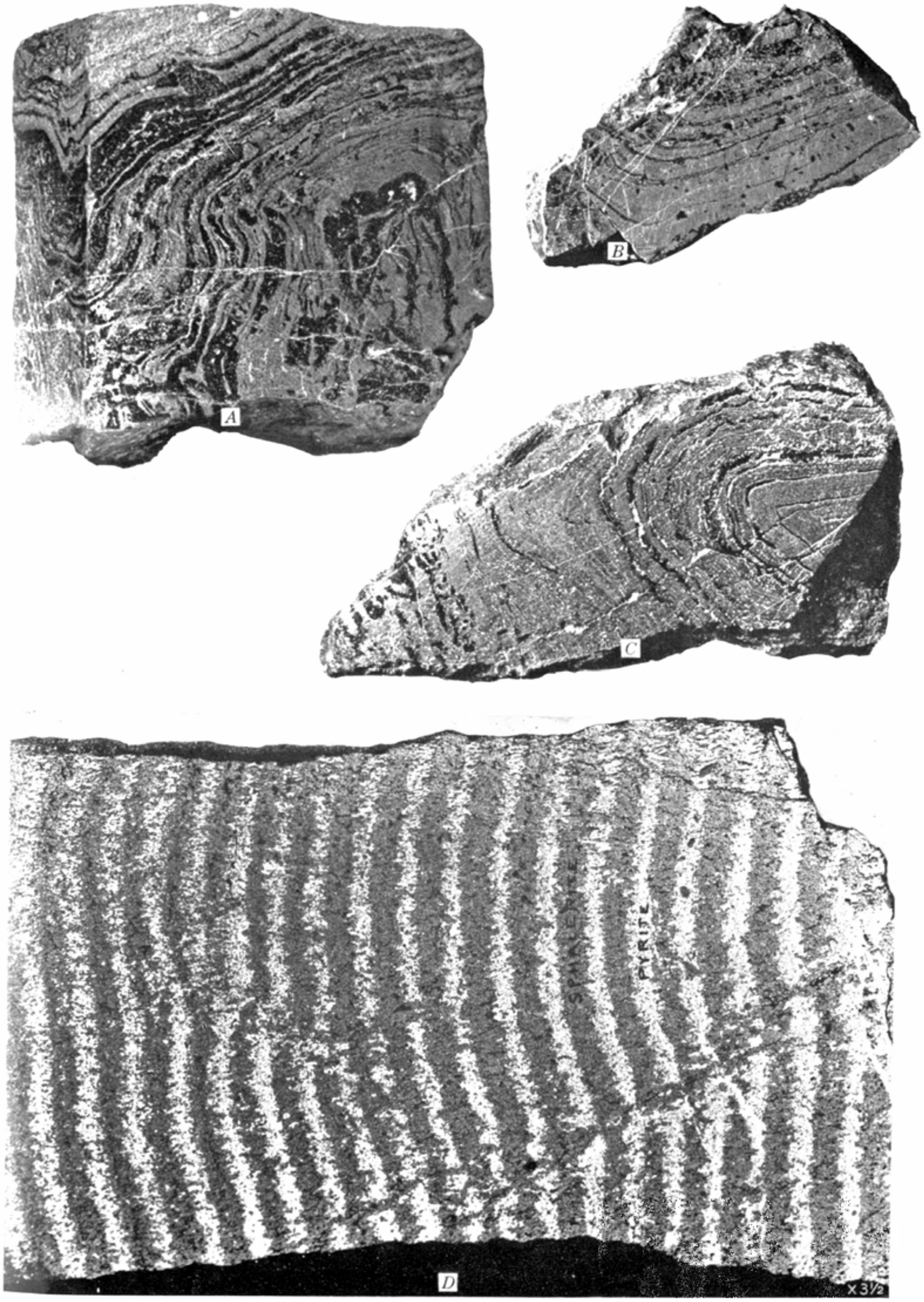


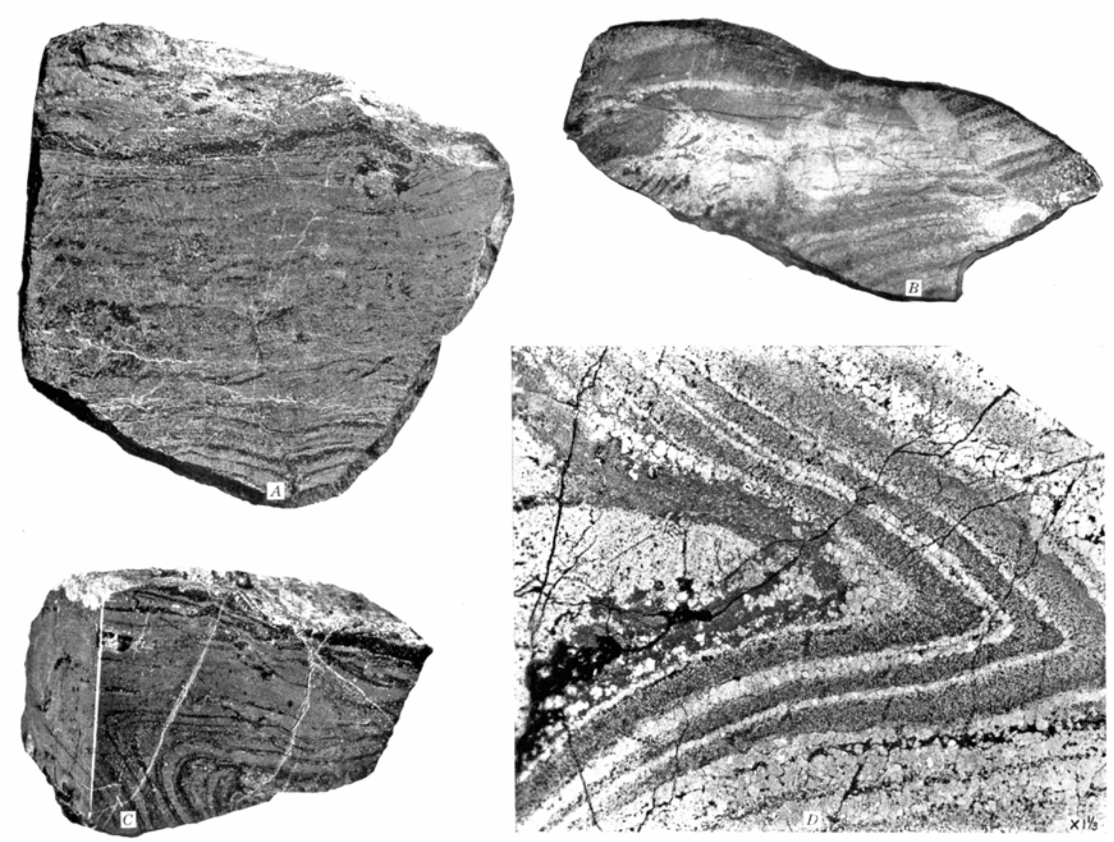
PLATE 60

A. IRREGULAR CONCENTRIC BANDING IN FINE-GRAINED PYRITE-SPHALERITE MIXTURE

B. PYRITE-SPHALERITE BANDING SHOWING FRACTURES ACROSS PYRITE BANDS FILLED WITH SPHALERITE, ALSO ISOLATED MASSES OF SPHALERITE IN THE MIDST OF PYRITE LAYERS

C. CONCENTRIC BANDING OF SPHALERITE-PYRITE ORE

D. BANDING OF PYRITE-SPHALERITE MIXTURE FROM SOUTH MOYER MINE



P L A T E 6 1

A. BANDING IN PYRITE-SPHALERITE ORE

B. MINIATURE FAULTING IN BANDED PYRITE-SPHALERITE ORE

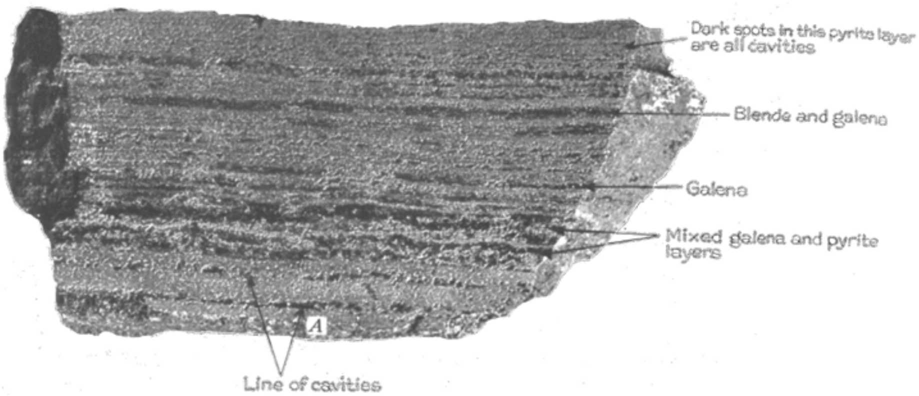
C. BANDED IN PYRITE-SPHALERITE ORE, WITH TWO FACES POLISHED TO SHOW CONCENTRIC BANDING

D. CONCENTRIC BANDING IN COARSE-GRAINED PYRITE-SPHALERITE MIXTURE

PLATE 62

A. MINIATURE FAULTING IN FINE-GRAINED BANDED PYRITE-SPHALERITE ORE

B. MINIATURE FAULTING IN BANDED ORE



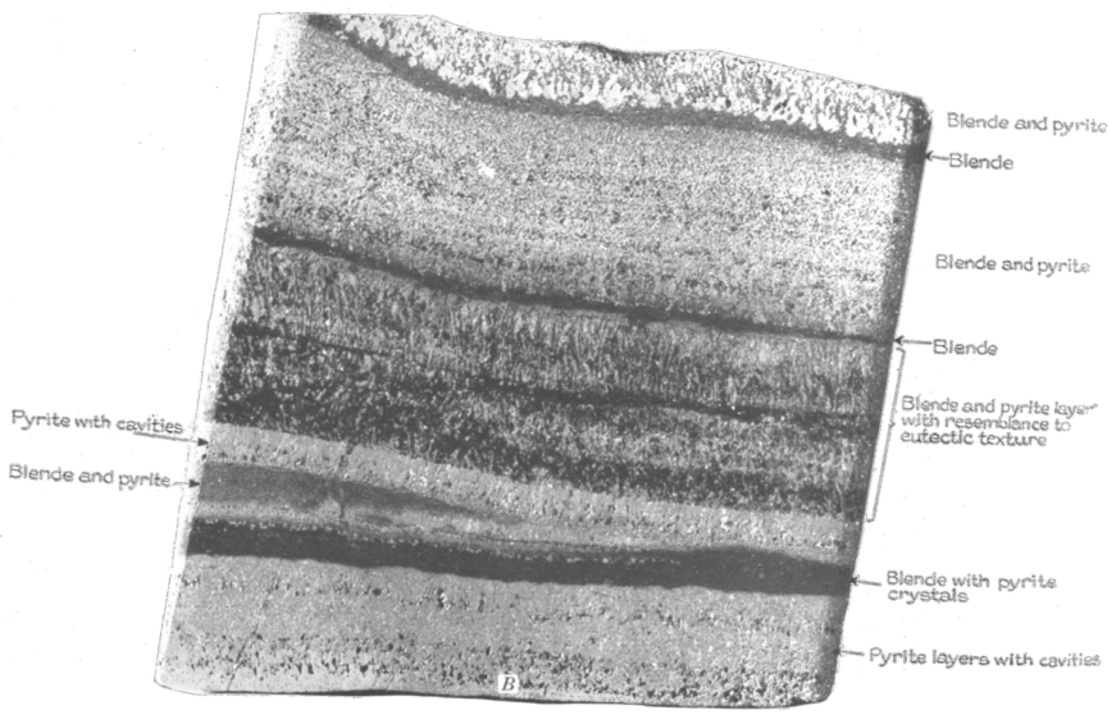


PLATE 63

A. BANDED STRUCTURE IN GALENA-SPHALERITE MIXTURE REPLACING WHITE LIMESTONE BEDS

B. COARSER VARIETY OF BANDING THAN THAT SHOWN IN *A*

CHAPTER 13

LOCAL DESCRIPTIONS

Data for local descriptions of ore bodies are in general incomplete, principally because of the inaccessibility of workings that were opened and closed between the earlier and later geologic surveys. Some ore bodies or groups of ore bodies can be described in considerable detail, but others can not be described at all. The following descriptions present such data as are available and will give, it is hoped a fairly representative if only partial picture of the deposits. They are arranged from west to east and conform to the groups of ore bodies represented on plate 45 (extra figures and plates).

CARBONATE HILL GROUP

The Carbonate Hill group includes the ore bodies in the Downtown, Carbonate Hill and Graham Park areas and is represented by columns B to I, inclusive, of plate 59 (Chapter 9). Were records of old workings more complete, they might show that the Adelaide group is really part of the Carbonate Hill group, separated from the rest by the Iron fault.

Downtown Area

Ore bodies in the Downtown area have been mined at five contacts, shown in column B of plate 59 (Chapter 9) and in plate 18 (extra figures and plates). The most work has been done at the first, beneath the White porphyry, and the second, beneath the Gray porphyry sheet in Blue limestone. The others are just above and below the Parting quartzite and in the "transition shales" above the Cambrian quartzite. When seen by Emmons and Irving in 1902 the two upper contacts had been extensively explored, and most of the ore had been mined from them. After the un-watering of the Penrose shaft in 1916 a large quantity of oxidized zinc, lead and manganese-iron ore was mined by the Downtown Mines Co. south of the Coronado shaft and west of the Midas shaft in the lower part of the Blue limestone and in the White limestone, and a small quantity in the underlying "transition shales," but in 1924 these operations were suspended. Elsewhere there has been no production from the Downtown area since 1907, except for a small tonnage of manganese-oxide ore from the first contact in 1918.

The first contact follows uniformly the upper surface of the Blue limestone, which is shown by scattered fragments of black chert to be present in its full thickness beneath the White porphyry. The contact surface is marked by many irregularities and undulations, some of which are due to irregularities in the original intrusive contact and some to the distortion to which both ore bodies and porphyries have been subjected by faulting. In a small portion of the area (plate 18, section XII) between the Penrose and Coronado shafts, the Gray porphyry rises to the under surface of the White porphyry, and there is locally no "first contact." In other places the single Gray porphyry sheet that forms the "second contact" divides into several branches, increasing the number of ore contacts. Throughout the Downtown area the ores of the first and second contacts depart less than elsewhere from their characteristic position immediately below the porphyry sheets, although exceedingly irregular protrusions extend downward into the limestone from their lower surfaces.

The first-contact ores have been found in greater amount in the southern portion of the area and the second-contact ores in the northern and eastern portions. The absence of the first contact in the northeastern part of the area is due in some places to the approach of the Gray porphyry to the White porphyry, as just explained, and in others, perhaps, to erosion, as shown on sections I, II, III, VI, V, VI of plate 18.

The only noteworthy vein seen in the Downtown area is one connected with an oxidized replacement body that has been mined 12 feet above the third level of the Penrose mine, southwest of the shaft. This replacement body directly underlies a sheet of Gray porphyry and extends for 280 feet in a northeasterly direction with an average width of 20 feet and average thickness of 5 feet. The vein, which connects with the northwest side of the replacement body (**Figure 84**), has an average thickness of 1 foot and extends to and below the fourth level but has not been followed deeper. The ore mined from the replacement body consisted chiefly of iron and manganese oxides and silica with considerable lead and 100 to 200 ounces of silver to the ton. The vein also was found to be highly siliceous and to contain considerable horn silver, but it could not be profitably worked. A few other small veins have been reported beneath replacement bodies in the Downtown area, but they are on the whole scarce and inconspicuous.

Third-contact ore, lying directly on the Parting quartzite, has been found on the bench between the Pendery and Niles faults in the Wildcat, Bison, and Catalpa mines (plate 18, section IV), where the Gray porphyry approaches within 60 feet of the Parting quartzite and the second-contact and third-contact ores come together. Third-contact ore has also been mined by the Downtown Mines Co. (plate 18, sections V and XII), as already stated.

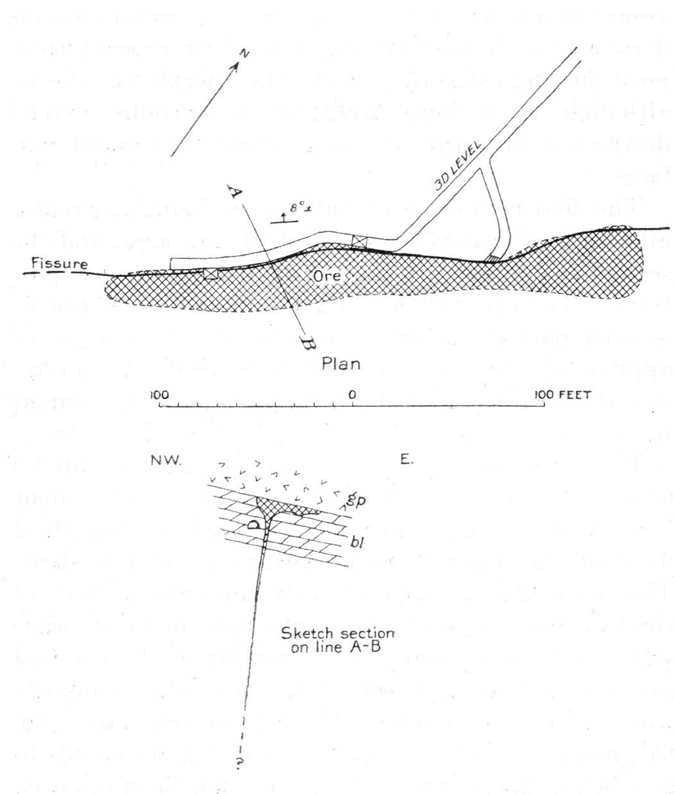


Figure 84. Plan and section of oxidized ore body, with feeding fissure extending downward from it, Penrose mine. Gp, Gray porphyry; bl, Blue limestone.

The presence of a fourth contact, beneath the Parting quartzite, had been demonstrated by 1902 in the Lazy Bill, Midas, Sixth Street, and Coronado mines. In drill holes Nos. 7 and 1 of the Coronado mine and No. 2 of the Sixth Street mine (plate 18, section XII) this fourth-contact ore was found to extend completely through the White limestone down to the Cambrian quartzite. During 1918 to 1923 the fourth-contact ore of the Coronado was mined by the Downtown Mines Co. In the Hibschle and Walcott mines (plate 18, section III) a large body of ore was found on a fifth contact; it lay mainly in the "transition shales" at the top of the Cambrian quartzite but extended for a short distance into the quartzite itself. This ore body was in line with the northwestward projection of the Tucson-Maid reverse fault. Upthrow along the Pendery fault brought it sufficiently near the surface to permit complete oxidation.

All the ores mined on the first three contacts in the Downtown district were oxidized, and the fourth-contact ores found in drill holes and in recent workings of the Coronado mine below the Parting quartzite were partly oxidized sulfides. The first-contact ore bodies were, on the whole, the richest in silver, the ores of the second and third contacts had a slightly lower tenor in this metal, and the fourth-contact ores were prevailingly of low grade. How much of this difference was due to oxidation and how much to differences in the original silver content could not be determined from the available data.

A fairly good conception of the thicknesses of the various blanket masses may be gained from a comparison of sections I to XII, plate 18. The ore bodies on the first contact were in general relatively thinner than those on the second. The maximum thickness for the second-contact ore, 150 feet, was attained by the Coronado-Sixth Street body immediately above the Sixth Street drill hole No. 2 (section XII). Over most of the area the ore bodies of both contacts ranged in general from 6 to 30 feet in thickness, with a thickening here and there to 60 feet and in a few places to nearly 100 feet. The disseminated ore bodies in White limestone in the Sixth Street and Coronado mines were apparently much thicker and may have occupied the entire thickness of the White limestone; but recent developments in the Coronado showed that only parts of them could be profitably worked. In the Midas and Penrose they were thinner, being, respectively, 80 and 30 feet thick. The ore bodies on all contacts were much more variable in thickness than is indicated on the generalized sections of the Downtown map.

Carbonate Hill

The number of contacts and the position and number of intrusive bodies of Gray porphyry are the same throughout the Carbonate Hill area as in the Downtown area, but the degree to which mineralization has affected the different horizons differs. In the western part of the area, just west of the Pendery fault zone, the ore horizons are similar to those in the Downtown district, as shown in section C, plate 59 (Chapter 9); those in and near the Maid of Erin mine, where workings have penetrated completely through the sedimentary rocks into granite, are represented by section D.

On the northern slope of the hill, from the Niles fault southeastward to the Maid of Erin mine, the principal ore bodies were found on the second third fourth and fifth contacts in the vicinity of the Tucson-Maid reverse fault. A vein 4 feet in width was found on the 900-foot level, at the north end of the Maid-Combination shaft station, and was followed in the Lower quartzite for 42 feet upward from the level. It was filled with loosely compacted ore, chiefly pyrite, but showed no galena or zinc blende; it had a high silver content (300 ounces to the ton) and 15 tons of ore was mined from it. This vein was not followed far enough to connect with the ore bodies above, but there can be little question that a connection exists. On the third level of the Henriett-Maid mine another vein was found connected with the shoot that extends southeastward through the Mahala mine. This vein was reported to trend southeastward beneath the middle of the ore body. It was not followed downward. Both of these veins were near the Tucson-Maid fault, whose existence was not suspected when they were examined.

Farther north, on the 450-foot level of the Shenango mine, a pyrite vein a few inches thick was found in the Holden winze. It crosscut the Cambrian “transition shales” and connected flat replacement ore bodies along different beds within the shale horizon.

In the Halfway, Lower Henriett, New Waterloo, and Harker No. 1 mines an immense body of ore occupied the combined second and third contacts between the Gray porphyry above and the Parting quartzite below and was followed downward to the southeast by an incline from the Harker No. 1 shaft to the Maid-Combination workings. This ore extended down through the Parting quartzite in the White limestone and extended into and beyond the workings of the Henriett-Maid. None of these workings have ever been accessible to the writer (Loughlin), so that no details other than the simple statement of the horizon of occurrence and the outlines of the ore body shown on **Plate 66** can be given. In the workings of the Maid of Erin mine little could be learned of the first or White porphyry contact, as the workings above the Gray porphyry were inaccessible at the time of the writer’s visits. First-contact ore may therefore extend farther east than is indicated on the map.

In the Henriett, Maid of Erin, Seneca, Surprise, Vanderbilt, Clontarf, and Wolftone mines ore not only appeared at the same contacts as in the northwest Iron Hill region but more additional horizons were found than at any other mine west of the Iron fault. An immense shoot of ore extended southeast by east from a point 50 feet west of the Seneca shaft to and beyond the Wolftone shaft, total distance of about 1,200 feet. It lay in the transition shales at the top of the Lower quartzite and at its widest point showed a width of 330 feet.

Within a roughly circular area, approximately 200 feet in diameter, just north of the Maid-Combination shaft, the ore bodies on all contacts were so thick that with the single interruption of the Gray porphyry sheet in the Blue limestone they formed a practically solid mass from the White porphyry roof to and into the Cambrian quartzite.

The ores of the first contact, long inaccessible, in the Maid of Erin mine appear to have been less extensively developed than those on the lower contacts, but this may have been due to lack of records on the older maps. One of the most extensive ore bodies of the mine lay at the fifth contact, beneath the Parting quartzite. Other less continuous bodies of great horizontal extent occur beneath the second contact. An extremely large ore body on the sixth contact, immediately above the Cambrian quartzite, extended from a point north of the Seneca shaft into the lower workings of the Wolftone mine. This ore body at several places extended for some distance into the Cambrian quartzite. The ore bodies of the Maid and adjacent mines, which lie in one of the most thoroughly mineralized and most productive areas in the Leadville district, are shown on plate 66. Too few observations were possible in these workings to permit further description of the details of occurrence. The ore bodies in the Maid of Erin workings are oxidized down to the base of the Parting quartzite, where the lead carbonate ores pass rather abruptly into s; but the zinc carbonate ores have been extensively mined in the underlying White limestone and locally beneath pyritic ore (plate 66).

Stray Horse Depression

Obtainable information on the mine workings beneath Stray Horse and Little Stray Horse gulches and the intervening Stray Horse Ridge is meager and unsatisfactory. It is roughly represented in columns F and G of plate 59 (Chapter 9).

Graham Park

General features.—The ground between Graham Park on the south and Stray Horse Gulch on the north has been remarkably productive. The ore shoots extend from the workings of the Maid mine on the west to the Mikado fault on the east, and most of them occur at great depth. Within this tract the principal shafts are the Wolftone, Standard, Mahala No. 1, Mahala No. 3, Greenback, R. A. M., Cumberland, Rialto (Pyrenees), Hunkidori, Gonabrod, Cyclops, and Agassiz. Ore is found at more horizons than in any other area in the district except Iron Hill and East Breece Hill (Ibex). In the Wolftone workings on the west there are six ore horizons, but the number increases toward the east until in the R. A. M. mine there are as many as eleven. They are represented by sections D and H, plate 59 (Chapter 9). They are in part clearly related to the Tucson-Maid fault, and in part to a pre-mineral fissure zone closely parallel to the Mikado fault, as shown in the descriptions on page 8.

The horizons in the Blue limestone form two series. One lies above the main White porphyry intrusion and is continuous with the upper beds –which were so productive in the Small Hopes mine and adjacent territory to the north; the other lies below the main White porphyry intrusion and forms an eastward continuation of the ore horizons developed in the Maid, Big Chief, and Castle View workings.

The part of the Blue limestone above the White porphyry is in most places thin and is divided locally by minor sheets of White and Gray porphyry into two or more portions. Some of these portions are connected where the porphyry sheets wedge out; others form superposed lenses entirely enclosed in porphyry. Toward the south the amount of Blue limestone below the main White porphyry sheet increases until in the Mab, Satellite, and Blind Tom shafts the entire formation is below the White porphyry. The southern limit of the ore horizons above the main sheet of White porphyry is at the Greenback and Mahala shafts. In the basin-shaped area filled with “lake beds” just west of the Mikado fault the beds at these uppermost horizons have been removed by erosion, as shown in the Rialto and Cumberland shafts.

The ore on these upper contacts if for the most part directly beneath a porphyry roof, but in several places a layer of limestone intervenes between the ore and the porphyry. At one place in the upper workings of the R. A. M. mine the “lake beds” are in immediate contact with the ore [See section E—E’, plate 20; (extra figures and plates] Ore has completely replaced these limestone members only where they are very thin. Most of the ore bodies terminate downward, and some both downward and upward, against limestone. All the ore mined in the upper contacts was oxidized. The horizons below the main porphyry sheet have been the most productive.

Certain blanket bodies and veins in the Greenback mine.—In the Greenback and Mahala mines the ore bodies are in many places so thick that the entire space between the Gray porphyry and the Parting quartzite is occupied by ore. This is true of the large ore body on the second contact beneath the Gray porphyry, which extends from the southern workings of the Wolftone mine southeastward through the Mahala into the Greenback workings. [plate 19; (extra figures and plates)] In part of the Mahala and Greenback mines its maximum thickness is about 60 feet. For the greater portion of its length it lies in contact with the Gray porphyry and the Parting quartzite is occupied by ore. This is true of the large ore body on the second contact beneath the Gray porphyry, which extends from the southern workings of the Wolftone mine southeastward through the Mahala into the Greenback workings. [plate 19; (extra figures and plates)] In part of the Mahala and Greenback mines, its maximum thickness is about 60 feet. For the greater portion of its length it lies in contact with the Gray porphyry roof. It is closely related to the Tucson-Maid fault, along which it extends down into the Parting quartzite. Farther east in the Greenback mine there is another blanket body of northward trend at the same horizon, equally thick but less extensive. Beneath the north end of this body some ore within the Parting quartzite was also mined, notably at the intersection of two vertical veinlets. One of these veinlets strikes east. The other strikes north and has been followed directly above a large blanket body in White limestone, and there is no doubt that this blanket is connected with that in the Blue limestone by the two veinlets. Recent work in the Greenback has shown the ore body in White limestone, mostly low-grade pyrite with marginal shoots of blende-galena ore, to be practically continuous down into the Cambrian quartzite, where it forms a vein in probable branch of the Tucson-Maid fault.

The vein is exposed on the seventh level of the Greenback mine, 330 feet south of the shaft [plate 40; (extra figures and plates)]. At its junction with the main drift it is 16 to 20 feet thick. It strikes about N. 65-70º W. and dips 63º S. between a footwall of Cambrian quartzite and a hanging wall of shale. The quartzite dips at a low angle for a long distance but steepens close to the fault. The shaly beds are nearly vertical from the fault to the south end of the drift, a distance of 100 feet.

The ore in the vein consists of lenticular bands of sulfide, some rich in zinc blende and others in pyrite, dipping steeply southward and alternating irregularly with bands of clayey gangue. The pyrite bands are blackened by chalcocite. The vein has been mined for the full width of the drift and upward in raise for 52 feet. There ore is continuous to the sixth level, 50 feet above, and is said to contain streaks very rich in silver, evidently due to enrichment.

On the seventh level 110 feet west of the main drift a small stope has been opened where the same vein or one closely parallel to it has replaced White limestone at or near its contact with the underlying “transition shales”. The ore is of the same banded character but contains more galena and is accompanied by considerable manganosiderite. The bands dip steeply northward and the width of the ore body is 30 feet. This stope is very near the projected position of the Tucson-Maid fault.

The workings when visited in 1919 were not sufficiently open for the exact relations between these two exposures on the seventh level to be determined. They are lens-shaped shoots in step-like arrangement and may be connected by a fault which is followed by and may be connected by a fault which is followed by the crosscut and which crosses the strata at a low angle. The shaly beds between the two exposures are partly replaced by pyrite.

Another veinlet is exposed in Cambrian quartzite on the seventh level and extends northward from the large vein. It is almost directly under the northward trending veinlet above the fifth level and the major axes of the two large blanket ore bodies. Although its only exposure is 150 feet below the lower blanket, its presence adds to the evidence of a system of northward mineralized fractures parallel to the longer dimensions of the blankets in this vicinity.

Veins in the Wolftone mine.—Irving reports three closely spaced sulfide veins in Cambrian quartzite connecting upward with an ore body in the "transition shales" on the eighth level of the Wolftone mine, 15 feet from the shaft. The veins are nearly vertical, 8 to 12 inches thick, and of northerly trend. The ore body with which they connect is about 75 feet thick. They are near the Tucson-Maid fault, but their exact position was not recorded.

On the eighth level 200 feet east of the shaft a small pyritic vein with a considerable silver content trends northeast and dips 74º NW along a crushed zone in Cambrian quartzite [figure 26; (extra figures and plates)] It has been followed upward for 16 feet, but there is no record of its passage into the overlying "transition shales". About 380 feet southeast of the shaft a vein connecting with extensive replacement bodies has been followed down the Tucson-Maid fault in a 10 foot winze and is said to have contained enriched pyritic ore with considerable copper content. A connected vein, followed upward along a northeast auxiliary fissure to the seventh level, joins a blanket ore body before reaching that level.

On the first level of the Wolftone mine 150 feet northeast of the shaft a veinlet of galena 3 to 4 inches thick has been found connecting a sulfide ore body beneath the Gray porphyry with an oxidized ore body beneath the White porphyry. The difference in composition between this minor connecting veinlet and the pyritic veinlets at lower levels in or close by the Tucson-Maid fault below is noteworthy. A search in the limestone beneath the large ore body on the second level east and north of the shaft has failed to disclose any veins, and their absence implies that at that place the ore-forming solutions had moved along the base of the porphyry for a long distance from the fissures through which they rose.

Veinlets in the Mikado mine—In the new Mikado workings, on the fifth and sixth levels, small sulfide veins in Gray porphyry have been found close to and about parallel to the Mikado fault. They doubtless connect upward with the large shoots of zinc sulfide and mixed in Blue limestone and indicate a pre-mineral fissure zone that served as a feeder for the large replacement bodies. This fissure zone has not been explored below the White limestone and is probably cut off by the Mikado fault, which has a somewhat lower westward dip than the mineralized fissure zone. The two are so nearly parallel that the suggestion has been made that the Mikado fault itself was an ore channel. Considerable ore has been mined within the Mikado fault, but it has all been dragged from the replacement ore bodies (plate 20, section A—A' (extra figures and plates)]). No veins have been found underlying the large shoots that extend from the Mikado and R. A. M. mines to the Wolftone mine. It is therefore inferred that the solutions which formed these shoots rose mostly along the Tucson-Maid fault zone, to a less degree along the pre-mineral fissure zone in the Mikado mine and perhaps others not yet discovered. On reaching the Blue limestone, they spread for long distances along the strata beneath the porphyry sills.

Limits of oxidation and enrichment—Nearly all the ore mined below the first or White porphyry contact has been sulfide. In the more westerly shafts, however, where the lower horizons were nearer the surface, oxidation has extended below the Parting quartzite. Thus the oxidized ore body that lies immediately beneath the Parting quartzite in the Upper Henriett mine changes to sulfide as it enters the Maid mine. East of this point the lower limit of the oxidized ore dips toward the east less steeply than the country rock and hence gradually rises through the several horizons, reaching the lower part of the first-contact ore in the Wolftone mine and White porphyry itself in the Greenback and Rialto mines. In the R. A. M. oxidized ores of lead, iron, and manganese occurred in insignificant amount beneath the White porphyry. Oxidized zinc ores extend in places below the general level of oxidation and have been found beneath ore, as shown in Chapter 11 (not in this report).

The sulfide ore immediately beneath the oxidized zone contains a considerable portion of zinc blend. The ore at the lowermost horizons, however, especially in the Cambrian quartzite in the Wolftone mine and in the White limestone in the Greenback and Mahala mines, consists almost entirely of pyrite, accompanied by little zinc blende and extremely small quantities of copper and precious metals, except where locally enriched, as shown on page 258 (Chapter 12; (not in this report). The marginal shoots of zinc-lead ore in the Greenback and Mahala have already been noted. Where the ores in White limestone rise in a westerly direction into the workings of the Maid of Erin mine they have a generally higher silver content than where they are more deeply buried and farther removed from the lower limit of oxidation. It is probable that their greater richness toward the west is due to relatively thorough enrichment.

Mikado Wedge

The wedge-shaped block of ground between the Mikado and Iron faults may be considered in two parts—a productive southern part, which forms the upthrown continuation of the productive territory on the west, and a comparatively unproductive northern part, which extends from Hawkeye and Del Monte shafts to the northern limits of the Leadville district.

In the productive part the ore has been obtained chiefly from the Snowstorm, Indiana, Highland Mary Nos. 1 and 2, Shenango, Old Mikado, Devlin, Venus, and Hermes mines. The ore horizons in this part are represented by column I of plate 59 (Chapter 9). The beds that have been so productive above the main White porphyry sheet in the downthrown territory west of the Mikado fault have here been completely eroded. Five contacts remain, although in places the fifth contact is divided into a number of minor contacts separated by irregular branches of the Gray porphyry intrusive mass.

The contacts are (1) beneath the White porphyry or beneath a Gray porphyry body which in places lies immediately beneath the overlying White porphyry; (2) in the Blue limestone immediately above the Parting quartzite; (3) at the top of the White limestone immediately beneath the Parting quartzite, locally filling the entire space between the Parting quartzite and a sheet of Gray porphyry that cuts the White limestone; (4) beneath this Gray porphyry sheet, in the upper third of the White limestone; (5) in the lower beds of the White limestone and underlying shales, irregularly distributed along the contacts of a second Gray porphyry sheet. The ore of the fifth contact locally extends down to the Lower quartzite, and in a few places, as in the Boulder drift of the Shenango mine; layers of sulfide replace beds of the Lower quartzite itself.

The larger portion of the rich ore taken from this territory came from the Mikado mine. A considerable body, completely oxidized, was found on the first or upper contact, but by far the greater production of the mine came from ore at the lower horizons, immediately above and beneath the Parting quartzite. Oxidation was complete down to the Parting quartzite, but its lower limit was exceedingly irregular and extended downward along cracks and water channels into the Cambrian quartzite members of the sedimentary series. The oxidized ore contained large quantities of silver chloride and lead carbonate, and the sulfide ores were enriched in places. For the most part, however, sulfide enrichment seemed to have operated only to a minor degree, as many of the sulfide bodies were of comparatively low grade. A large body of sulfide ore north of the shaft on the fourth level of the Mikado mine in the White limestone was in places 200 feet wide and 40 feet thick and carried only 2 to 4 ounces in silver to the ton.

It is noteworthy that the lower limit of oxidation in this mine is at a geologic horizon but slightly lower than that in the R. A. M. mine, west of the Mikado fault, although the rocks in the

R. A. M. mine have been down-faulted for a vertical distance of more than 700 feet. In other words, the Mikado fault has apparently acted as a dam separating the hydrostatic basin on the east from a lower hydrostatic basin on the west. The ground water, as indicated by the depth of oxidation seems to have been at an altitude of 10,340 feet east of the fault and of 9,270 feet west of the fault. In the chapter dealing with the oxidation of the ores other instances are cited of this condition, which in many places has characteristically affected the oxidation process in the Leadville district.

It is probable that the difference in the grade of the ores in this locality at the different horizons is due more to the action of enrichment upon the upper ore bodies than to original distinctions in the mineralogic and other characters of the material. It is certainly true that the un-enriched sulfide ores remaining in this area of comparatively low value; but abundant good ore has been extracted from the upper parts of the ore bodies and the oxidized ores immediately above them in the Mikado, Shenango, Highland Mary, and adjoining mines.

The extensive mineralization at the horizons beneath the Parting quartzite may be related to the pre-mineral fissure zone exposed in the New Mikado mine, just west of the Mikado fault. It may also be related to the extensive mineralization of White limestone in the Adelaide group, east of the Iron fault, but there has been no opportunity to study any of the deposits in White limestone east of the Mikado fault.

In the northern and less productive portion of the **V**-shaped area less exploration has been carried on and much of it represents the mines that were in operation at the time the Leadville monograph was written. In this area there is a large mass of oxidized “vein matter” and included ore above the Parting quartzite in the Blue limestone. It has been opened up in the Chieftain tunnel and in the Cordelia Edmonson, Birdie Tribble, Bobtail, First Chance, Hawkeye, Dania, J. B. Grant, Scooper Nos. 1 and 2, Hard Cash, and Fairplay shafts. In some places the ore is in contact with the overlying porphyry, and in others it is well down in the body of the Blue limestone. Much of it lies directly underneath the “wash” and has been so found in the Birdie Tribble, Bobtail, First Chance, and Cordelia Edmonson workings. The Hard Cash and Fairplay shafts have penetrated below the Parting quartzite, but none of the other workings have reached the lower horizons. No ore is reported from the Hard Cash shaft below the Parting quartzite. (**Figure 85**) In the Fairplay shaft a small fault running parallel to the Iron fault and forming, indeed, a part of the Iron fault zone, has brought the lower quartzite up in the shaft. A singular body of ore occurs in this shaft, consisting of oxidized iron ore and lead carbonates deposited through the entire thickness of the Lower quartzite and extending from the upper surface of this formation down to the point where the shaft passes from the quartzite to the granite on the east side of the fault (**Figure 86)**.

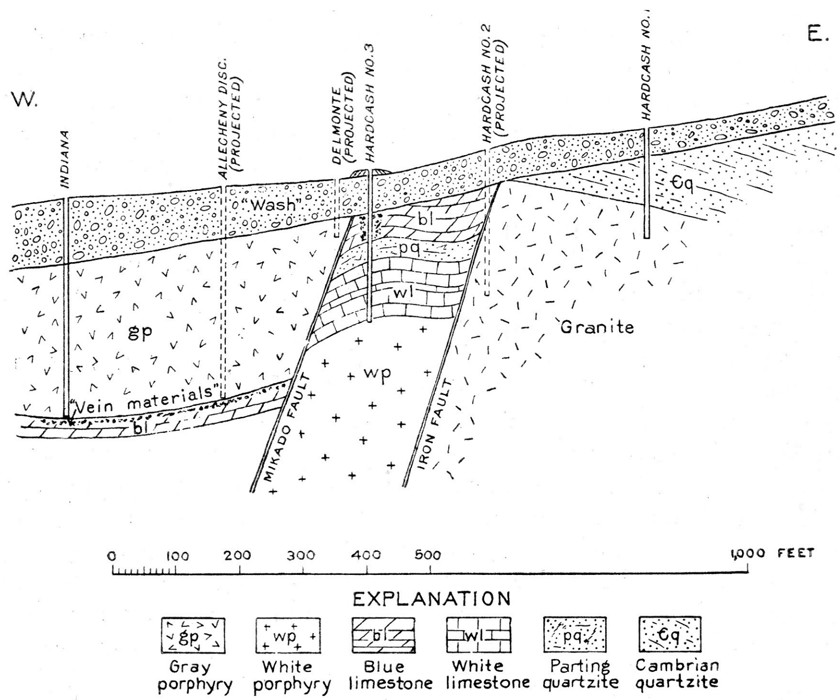


Figure 85. Section through Indiana and Hard Cash shafts, showing probable structure and ore horizons between Mikado and Iron faults.

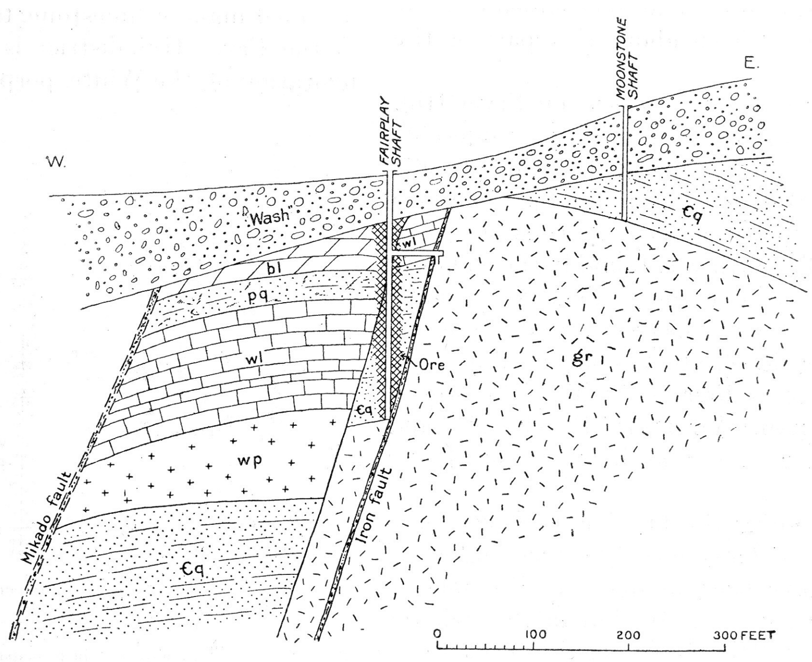


Figure 86. Probable structure and ore horizons in Fairplay shaft and body of iron and lead in the Cambrian or Lower quartzite. Wl, White limestone; bl, Blue limestone; pq, Parting quartzite; wp, White porphyry; €q, Cambrian quartzite; gr, granite.

Still farther north are the Abe Lincoln, Little Hoosier, and Elkhorn mines, from none of which has any production of note been obtained. The Little Hoosier and Abe Lincoln never penetrated the porphyry overlying the Blue limestone. The Elkhorn shaft, 860 feet in depth, penetrated the entire series of rocks, including 50 feet of Cambrian quartzite, but revealed no ore bodies of any magnitude. Another shaft 1,000 feet north of the Abe Lincoln penetrated the overlying porphyry and found “vein material” 5 feet thick in the Blue limestone beneath.

FRYER HILL GROUP

The Fryer Hill group of ore bodies includes those beneath the three low knolls Fairview Hill, Fryer Hill, and East Fryer Hill. Beneath Fairview and Fryer hills, which were collectively termed Fryer Hill in Emmons’ original report, occur the famous Fryer Hill ore shoots. The group as a whole extends from the All Right shaft on the west to the Jamie Lee, Olive Branch, El Paso, and Cullen shafts on the east. In the early days it was one of the most profitable of the Leadville district. The ore shoots between Fairview and Fryer hills, represented on **Plate 67**, are simply richer and more profitable portions of a body of low-grade “vein matter” which replaced almost the entire mass of limestone that intervened between the White porphyry sheets.

Boundaries

The ore shoots of this group are bounded on the north by an area of comparatively unproductive territory that has been opened by the Prize, Buffalo, Katie, Pride, and Otis shafts, from none of which, to the writer’s knowledge, was any considerable quantity of ore produced. The westernmost ore body in the group is in the Jason workings. South of this mine is the barren Poverty Flat. On the south, the Fryer Hill group is in a general way connected with the Carbonate Hill group, either continuously or through scattered ore bodies.

Ore “Contacts”

FAIRVIEW AND FRYER HILLS

The horizons of ore occurrence on Fairview and Fryer hills have a general similarity [plate 59, section L (Chapter 9)]. The upper contacts in this region were extensively explored in early days, and the best descriptions of them were those by Emmons[1] and Rolker[2]. The deposits at lower horizons, however, have been penetrated only by vertical shafts, and at the time of Irving’s last visit they were comparatively unprospected. There is, therefore, little to be added to what Emmons has already written about this part of the district.

Ore has been found at six contacts on Fryer Hill, only the uppermost of which is of any considerable importance [plate 59, column L (Chapter 9), and plate 67, sections A—A' and B—B']. The four upper contacts are along Blue limestone enclosed between sheets of White porphyry. The fifth was found in the Pandora No. 3 shaft and the sixth in the Climax No. 3 shaft, but neither, so far as known, has been productive.

The famous Fryer Hill ore bodies of early days were found in the syncline of Fairview Hill. The ores of the Matchless, Dunkin, Virginius, Pittsburgh, and Robert E. Lee occur in the anticline under Fryer Hill.

The large shoots along the first contact are separated by local dikes of Gray porphyry trending west-northwest, which have been mapped by Emmons as extending downward indefinitely; but in the light of developments in Iron Hill it is possible that these dikes also may be upward offshoots from the Gray porphyry sill that has been intruded into the White porphyry below the first contact. Another small Gray porphyry sill has also been injected between the

[1] Emmons, S. F., U. S. Geol. Survey Mon. 12, pp. 445-492, 1886.
[2] Rolker, C. M., Am. Inst. Min. Eng. Trans., vol. 14, pp. 273-292, 1886.

uppermost White porphyry and the limestone and forms the roof of the first contact in the vicinity of the Little Chief shafts Nos. 1 and 4. The limestone of the first contact ranges from 10 to 100 feet in thickness, as shown in the sections of plate 67.

Throughout the Fryer Hill area the mineralization was unusually intense, and practically the entire mass of limestone on the first contact has been replaced by ore and "vein material". Only here and there have irregular remnants of limestone—many of them entirely enclosed in ore—been left un-mineralized. The ore shoots as represented on plate 45 (extra figures and plates) show only those portions that could be profitably mined at the time the Leadville monograph was written. Since then considerable lower-grade ore has been mined, and small shoots of high-grade silver-lead ore as well as a few small shoots of zinc carbonate ore have been extracted by lessees.

To the east and south of Fryer Hill the first contact continues but is underlain by a much thicker layer of White porphyry in the Small Hopes and adjoining mines.

The bodies of limestone at the second and third contacts, also one or two other subordinate contacts, are thin, mostly lenticular masses, 10 to 12 feet or rarely over 20 feet thick. They have not yielded ore except in the Vulture No. 2 mine, where the included mass attained a thickness of 59 feet, and in the Pandora and Kit Carson mines.

As the ore nearly everywhere replaces the entire included mass of limestone, the form of the ore bodies in the Fryer Hill district is determined by the configuration of the White porphyry contacts above and below. The few remnants of unreplaced limestone are in part adjacent to the dikes of Gray porphyry that cut the White porphyry[3] and in part wholly enclosed in White porphyry.

In 1901, when the last visits were paid to this portion of the district (by Emmons or Irving), the contacts below the Parting quartzite had been but little explored, and, so far as known, they have not been explored more recently. The following shafts are shown by the records of S. F. Emmons to have penetrated the White limestone horizon.

Buckeye Shaft; sunk to Lower quartzite. No ore reported. (No record since 1880.)

New Chrysolite shaft and drill hole a short distance southwest of Roberts shaft; sunk to granite. No ore reported.

New Discovery shaft No. 6; sunk 20 feet in White limestone. No ore bodies reported. (No record since 1886.)

New Discovery shaft No. 1; sunk to lower White Porphyry below first contact. Drill hole in Lower quartzite in east drift. No ore reported below Parting quartzite. (No record since 1900.)

Dunkin Nos. 1,2, and 3 shafts; sunk 20 feet in White limestone. Some ore below Parting quartzite reported. (No record since 1886.)

Matchless No. 6 shaft and drill hole; sunk into White limestone. No ore bodies reported. (No record since 1895.)

Except for these shafts but little exploration had been conducted, up to 1901, in the White limestone. The unsatisfactory results of the work done, however, may be inferred from the fact that the rocks below the Parting quartzite, though penetrated, were not extensively explored, a neglect which is the more remarkable because the richness of the ore bodies above might well have raised the hopes of the miners for valuable ore bodies below. All the ore on Fairview and Fryer hills from the White porphyry contacts was oxidized, although numerous and in places very rich residual masses of galena were found scattered through it.

[3] This feature has been emphasized by C. M. Rolker (op. cit., p. 290) as having a peculiarly important significance in connection with ore genesis. To the writer (Irving) it appears merely as an accidental feature of the ore formation of no special importance.

EAST FRYER HILL

East of Fryer Hill there is a considerable area of productive territory bounded on the east by the Mikado fault, on the west by a line through the Harvard No. 2 and Little Sliver shafts, on the north by a line through the Price and Morris shafts, and on the south by a line through the Robert Emmet and Shenango shafts. The ore horizons differ somewhat in different portions of this area, as shown by plate 59 (Chapter 9), sections K, M, N, and O.

There are four contacts in the Blue limestone in this area. The first is above the uppermost White porphyry and directly under the "wash"; the second and third are at depths of 40 and 70 feet, respectively, below successive minor sheets of about 40 feet of White porphyry; the fourth, 200 feet below the third, is under the main White porphyry sheet. The fourth contact has been cut in the Cary, Elkins, McCormick and Denver City mines but has been productive only in the Denver City. The White limestone has been cut, so far as known, only by the McCormick shaft, where it was not found to be productive, although large ore bodies have been found in it in the Graham Park area, to the south (**Figure 87**). The first three contacts are oxidized and resemble the main contact of Fryer Hill in their undulating character. The main shoot, called the Small Hopes shoot, is at the second contact, and its positions in different shafts are shown in figure 87. Much of the ore mined from this shoot was very rich, and the quantity extracted from less than 1 acre is reported to have yielded more than $6,000,000. Elsewhere at this horizon the ore was not so rich but compared favorably with ore in other parts of the district. The high grade of the ore was probably due to enrichment in the oxidized zone.

Available data on contacts a little to the east of the Small Hopes shoot is shown in **Figure 88**. The principal production has been from the top of the main sheet of White porphyry through the Shamus O'Brien, McCormick, and Shenango shafts.

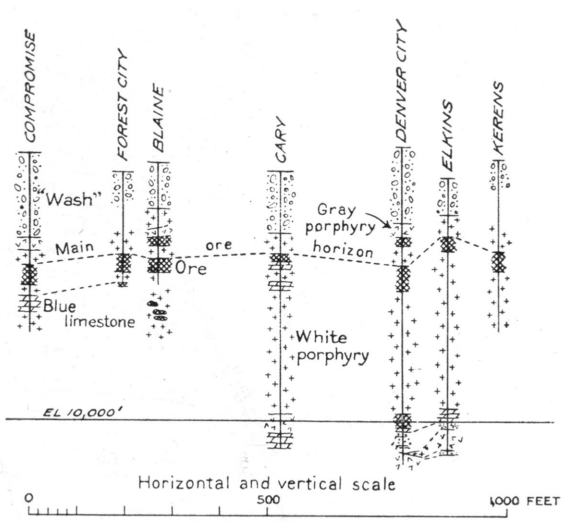


Figure 87. Sections of some of the principle shafts of the Small Hopes mine showing main ore-bearing contact above main White porphyry sheet. Shafts are all projected on a vertical plan striking N. 15° E.

In the area west of the Mikado fault, between the Shamus O'Brien and Raven shafts on the south and the Morris and Harvard shafts on the north, ore has been found at two horizons, which have been extensively explored. One is below the uppermost thin sheet of White porphyry at the top of the Blue limestone and the other is within the Blue limestone. Just east of the Mikado fault in the Kennebec mine ore has been mined at two horizons in the upper part of the White limestone, one a little below the Parting quartzite and one at the top of the lower sill of White porphyry. The ore horizons at the different shafts are shown in figure 35 (extra figures and plates).

The greater portion of the ore from the area has been obtained from the upper portion of the Blue limestone at or near its contact either with overlying black "Weber shales", White porphyry, or Gray porphyry. The ore departs from the immediate contact in many places—for example, in the Tip Top, Harvard No. 2, and Bangkok shafts—but for the most part it is at the immediate contact.

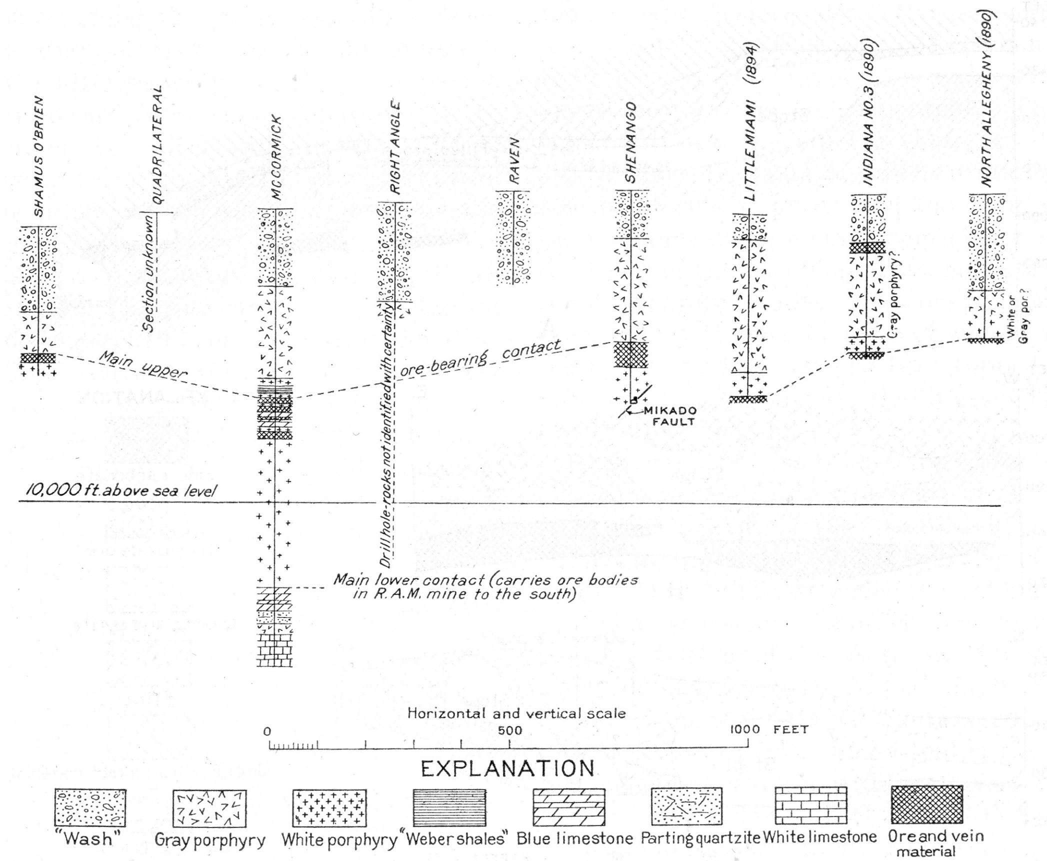


Figure 88. Shafts in area between Small Hopes ore shoot and Mikado fault, showing persistence of upper Forest City contacts above main White porphyry to Mikado fault

The "second contact" has been most extensively developed in the Forepaugh, Olive Branch, and El Paso mines.

These ore bodies in Blue limestone were extensively mined in 1893—1896 by the Union Leasing & Mining Co., which produced 37,740 tons of ore having average silver content of 76 ounces to the ton and a range of 17 to 260 ounces, according to Norman M. Estey.[4] The ore shipped was reported to be principally siliceous , but considerable iron and manganese oxide and low-grade zinc carbonate around the stopes prove that much oxidation had taken place. Iron was the principal base metal, and in some shipments it may have exceeded silica. Lead and zinc were generally low, but some shipments of sulfide ore contained as much as 25 to 30 per cent of zinc.

Operations were confined to the Blue limestone owing to the large amount of ground water, which was evidently lowered from its natural level of 10,205 feet sufficiently to drain the second contact. When operations were stopped by the general miners' strike in 1896 the mines were flooded. The Fryer Hill Mines Co. later drained them again and did a little development work, including the sinking of the Harvard No. 2 shaft, but shipped no ore.

In 1917 and 1918 the mines were reopened by the United States Smelting, Refining & Mining Exploration Co., and ore was mined around the old stopes while prospecting by the diamond drill was being done in the White limestone. The ore around the old stopes comprised five classes—iron-manganese oxide, zinc carbonate, pyrite, siliceous pyritic silver ore, and zinc-silver sulfide ore.[5] The common relations of the ores and gangue, except massive pyrite, are

[4] Unpublished record dated January 13, 1915.

[5] According to company records, including a report by C. A. Allen, dated Jan. 26, 1917.

shown in **Figure 89**. The stopes represent the ore mined by the Union Leasing & Mining Co., and doubtless the zinc-silver ore recently mined. Flint forms a persistent floor and in places along the second contact extends down to the Parting quartzite. In the zone of partial oxidation iron oxide irregularly overlies the pyritic ore and passes upward into “contact matter,” an indefinite mixture of clay, silica, and iron oxide. Zinc carbonate is associated in small quantity with the iron oxide, but the principal deposits of it underlie the flint. Although comparatively rich samples were found at scattered points, the ores shipped in 1917-18 were of low grade. The zinc carbonate ore shipped contained from 14.8 to 19.7 per cent of zinc and as much as 0.6 ounce of silver to the ton. It came largely from the big stope just north of the Tip Top shaft and also from stopes near the Joe Davis and Olive Branch shafts. Large quantities of similar material containing 10 or 12 per cent of zinc were left unmined, as the minimum content accepted by the local zinc oxide plant was 14 per cent.

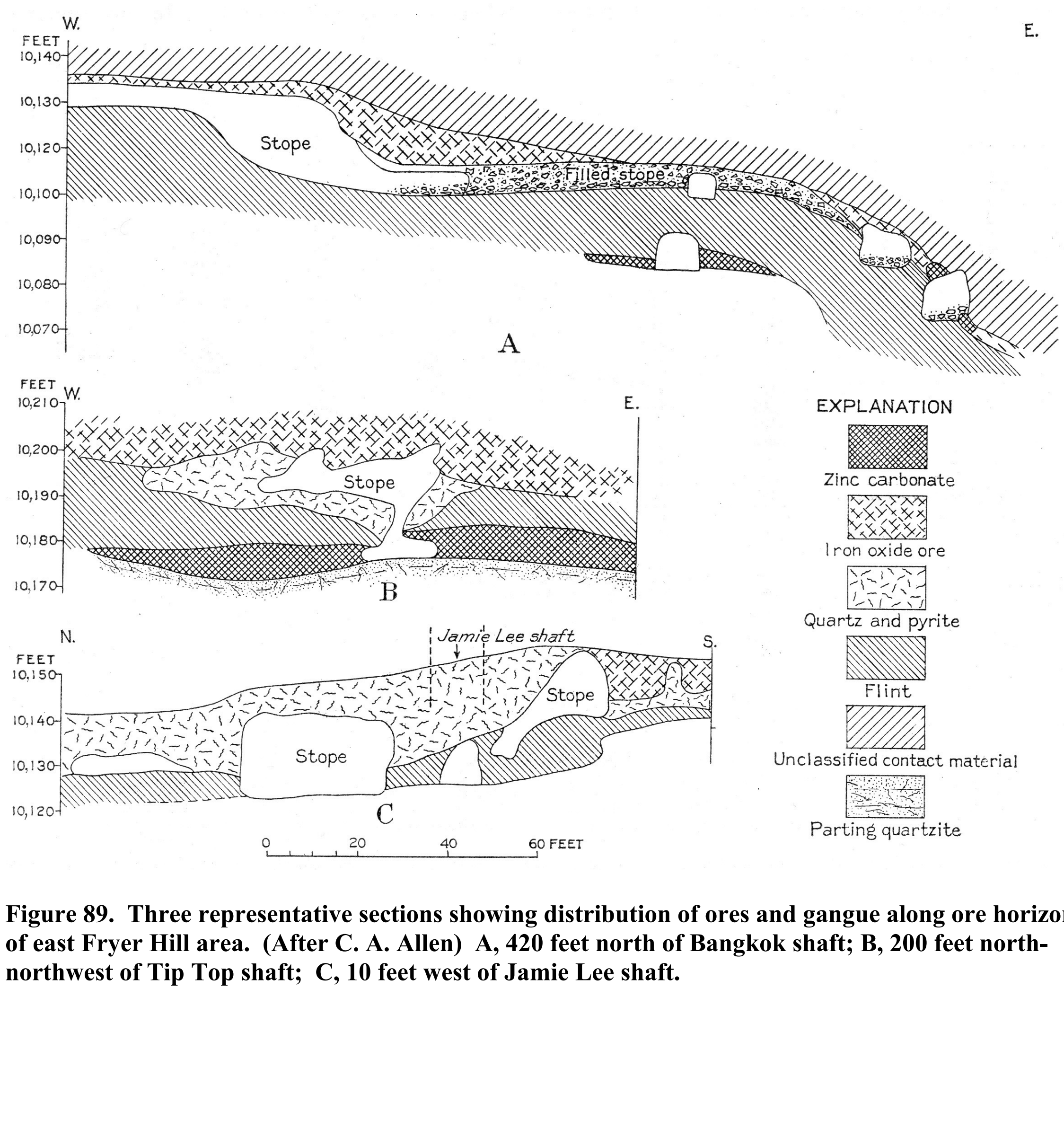


Figure 89. Three representative sections showing distribution of ores and gangue along ore horizons of east Fryer Hill area. (After C. A. Allen) A, 420 feet north of Bangkok shaft; B, 200 feet north-northwest of Tip Top shaft; C, 10 feet west of Jamie Lee shaft.

Representative smelter analyses of ores shipped from East Fryer Hill, 1917-18

	Silver (oz./ton)	Zinc (per cent)	Iron (per cent)	Manganese (per cent)	Silica (per cent)	Sulfur (per cent)
Iron Oxide Ore	6.9	-	28.9	5.4	35.1	-
	8.4	-	43.2	-	3.2	-
	9.1	10.2	25.4	5.0	23.0	-
Zinc-Silver-	8.7	18.0	-	-	11.1	-
	10.2	19.0	-	-	10.5	-
	11.5	14.2	-	-	9.0	-
	16.1	12.5	-	-	-	-
	22.0	20.4	-	-	-	-
	22.7	9.5	-	-	-	-
Iron-Silver-	7.3	2.5	43.5	-	4.3	46.0
	7.3	-	44.2	-	2.2	46.5
	14.3	12.0	44.8	2.8	2.5	-
	15.9	-	45.2	-	5.1	-
Pyrite	1.8	5.3	-	-	-	46.2
	3.0	-	-	-	2.0	47.0
	1.8	3.4	-	-	-	47.2
	1.6	3.3	-	-	-	48.0
	3.0	5.1	-	-	-	49.7

Shipments of ores represented by the first three groups in the above table were made while the price of silver was high, but when it dropped as low as 80 cents an ounce, late in 1917, much of the ore was of a little too low grade to pay for mining. Ore with 20 ounces or more silver to the ton occurred only in small streaks and bunches. The pyritic silver ore came mainly from a body 100 feet southwest of the Jamie Lee shaft, and small quantities of high-grade (35-ounce) ore were mined by lessees near the Little Silver and Forepaugh shafts. The sulfide ores represented above were low in silica, in contrast to the reported character of the ore formerly shipped (p. 13). The pyrite ore, shipped for the manufacture of sulfuric acid, differed from the pyritic silver ore in its very low content of silver and perhaps of silica also. Pyrite containing 45 per cent of sulfur was then worth $3.50 a ton f. o. b. mine, and a penalty or bonus of 15 cents a unit was applied to ore with lower or higher content. This ore was at first mined near the Tip Top shaft, but it graded into pyritic zinc ore, some of which contained too much zinc to be sold as pyrite and too little for zinc ore. Later shipments were made from a body about 400 feet southeast of the Tip Top shaft, north of an eastward-trending porphyry dike. This ore body was 8 to 9 feet thick and contained 3 ounces of silver to the ton and 2 per cent of silica. It had been topped by old workings, a fact which suggests that it graded into ore with higher silver content.

Explorations in the White limestone included the extension of the Jamie Lee shaft to a depth of 843 feet—the horizon of the "transition shales" below the White limestone—and the driving of several drill holes. One of these extended to the Cambrian quartzite below the shaft; another was driven eastward from the bottom of the shaft for 302 feet, with the intention of locating the Mikado fault, but was abandoned when it entered dolomite sand. A hole was driven westward from the bottom of the shaft for 250 feet, and another southward for 100 feet without promising results, although both extended beneath ore in the Blue limestone. Drifts from the Jamie Lee shaft also passed directly under the old stopes without disclosing mineralization. The only evidence of mineralization in the White limestone in this vicinity was a fissure 10 feet southeast of the shaft, striking N. 60º E. and dipping 53º NW, along which a little quartz and fine-grained s impregnated the limestone.[6] Two drill holes, 80 and 260 feet south-southwest of the Tip Top shaft, reached the Cambrian quartzite and were reported to pass through 70 feet of Gray porphyry just above the quartzite; but no transition shale was recognized, although such shale is present near by, and the rock reported as porphyry may be largely the shale. A few stringers, presumably of pyrite and quartz, were found in the bottom 1½ feet of rock along its contact with the quartzite. The absence of ore in the White limestone here is in contrast with its presence in the Kennebec mine, just east of the Mikado fault.

The work done has failed to disclose any important course along which the ore-forming solutions could have risen, as they did in the Iron and Carbonate Hill areas. The considerable quantities of pyrite accompanied by quartz and manganosiderite southwest and south of the Jamie Lee shaft and 400 feet southeast of the Tip Top shaft imply that the solutions began to deposit their contents at these places and then deposited the mixed sulfides, which contain considerable zinc blend, but the course followed by the solutions was mainly along the bedding.

Most of the fractures noted by Allen in the walls of old stopes trend northeastward, whereas the ore channels trend in various directions but mostly northward. The ore channels lie along local undulations or "rolls" in the strata, where the limestone had doubtless been fractured more than elsewhere. Allen concluded that the intersections of northeastward-trending fissures with the axis of a "roll" were especially favorable places for ore deposition.

IRON HILL GROUP

In the Iron Hill and Rock Hill area, one of the two most productive areas in the district, sills of Gray porphyry are numerous, and ore has been found in one place or another at 10 contacts. The upper contacts when only partly developed were first described by Emmons and when more thoroughly developed by Freeland[7] and Blow,[8] but they had become inaccessible before the resurvey of the district was begun. The representations of ore bodies on plates 22, 45 (extra figures and plates), and 59 (Chapter 9) are based on these descriptions and more recent data and give a generally adequate idea of the location and extent of ore deposition, although certain ore bodies have doubtless been omitted from lack of information. Ores in the Cord and Tucson mines are described in some detail.

"First Contact"

The "first contact," between the White porphyry and the first sheet of Gray porphyry below, has been thoroughly explored (**Figures 90-95**). It is especially well developed in the workings of the Iron-Silver Mining Co., extending from the North Iron incline southward to the Doyle workings and eastward as far as the Louisville and Rubie shafts and Cord Winze. Southward from these points the uppermost sheet of Gray porphyry is in contact with the White porphyry, and the first contact is eliminated.

North of the Smuggler [along section H—H', plate 24 (extra figures and plates)] and eastward throughout the workings of the North Moyer mine, the sheet of Gray porphyry has separated from the White porphyry and the first contact is again present. In some places, as in the workings of the Accident shaft, shown on section K—K', plate 25 (extra figures and plates), the upper sheet of Gray porphyry thins out entirely and the same ore body lies partly beneath the Gray porphyry and partly beneath the White porphyry.

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[6] Allen, C. A., unpublished report.

[7] Freeland, F. T., The deposits of South Iron Hill, Leadville, Colo.: Am. Inst. Min. Eng. Trans., vol. 14, pp. 181-195, 1886.

[8] Blow, A. A., The geology and ore deposits of Iron Hill, Leadville, Colo.: Am. Inst. Min. Eng. Trans., vol. 18, pp. 145-181, 1890.

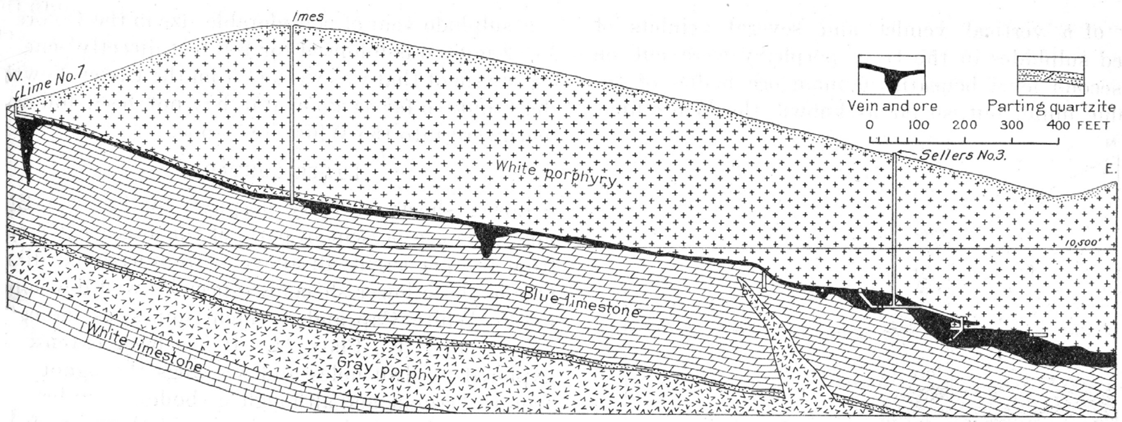


Figure 90. Section through Imes and Sellers No. 3 shafts. (After Freeland)

The North Iron shoot and the South Iron shoot lie for the most part immediately beneath the White porphyry. The Gold ore shoot and the Rubie Channel shoot, as shown in section M—M', plate 26 (extra figures and plates), lie mostly away from the contact. Their northeastern parts have greater vertical than horizontal parts have greater vertical than horizontal dimensions and extend down along fissures to the Gray porphyry [section K—K', plate 25 (extra figures and plates)]. The same is true of the Imes shoot (figure 90). The White Cap and Smuggler shoots taper downward along fissures and pinch out before reaching the Gray porphyry.

In the workings of the Moyer mine, which lie west of the Adelaide fault, the upper ore horizon or "first contact" between the White porphyry and the first sheet of Gray porphyry is comparatively barren, but farther east, across the Adelaide and Mike faults, the ore bodies near the North Mike shaft and Habendum raise are probably at the "first contact."

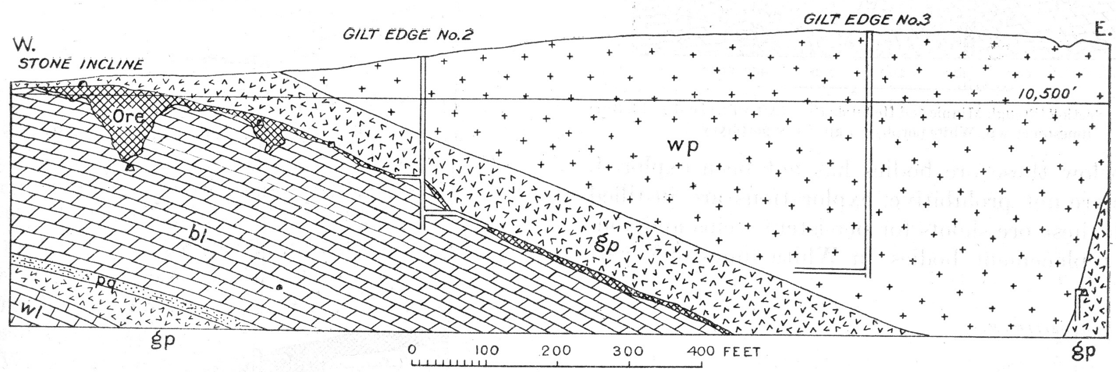


Figure 91. Section through Gilt Edge shafts Nos. 2 and 3. (After Freeland) wp, White porphyry; gp, Gray porphyry; bl. Blue limestone; pq, Parting quartzite; wl, White limestone

"Second Contact"

In the southern part of Iron Hill and the adjacent part of Rock Hill as much ore has been produced from the "second contact" as from the first. On this "second contact" is a large irregular shoot which nearly parallels the Moyer fault. In the Moyer mine this shoot turns northward and parallels the Adelaide fault. The northward-trending part is known as the Moyer shoot. Near the A. Y. No. 3 shaft the shoot turns southward and extends under Rock Hill. This shoot is V-shaped and in places more than 40 feet in vertical diameter. In the vicinity of the Accident shaft this “second contact” shoot is interrupted by a steeply plunging mass of Gray porphyry, and a short distance to the northeast it joins the “first contact” shoot, which is cut off by the Adelaide fault.

The vertical dimensions of neighboring shoots in the Rock Hill area, like those of the Imes, Rubie, and other shoots in the South Iron Hill area, are greater than their horizontal widths, and these ore bodies also taper downward along fissures, or reach the Gray porphyry. From some of them mineralized fissures have been followed downward through the underlying Gray porphyry, but no work, so far as known, has been done to prove their persistence to deeper levels. For example, a sulfide ore body beneath Gray porphyry in the Moyer mine replaced Blue limestone on one side only of a vertical veinlet, and several veinlets of mixed sulfides in the Gray porphyry were cut on the second level beneath the main ore bodies of the Minnie mine; but, so far as known, the White limestone below these ore bodies has not been explored. If costs are not prohibitive, explorations are justified beneath these ore shoots for persistent veins and connected replacement bodies in White limestone, particularly along the expected intersections of the veins with the Tucson-Maid fault zone and the little-known reverse fault G west of it, which is considered in Chapter 5 (not in this report).

A sulfide vein of considerable size in the Colorado No. 2 mine was followed for 100 feet directly beneath the ore shoot that was worked from the Ulster-Newton shaft, but, so far as known, it has not been followed downward into the White limestone.

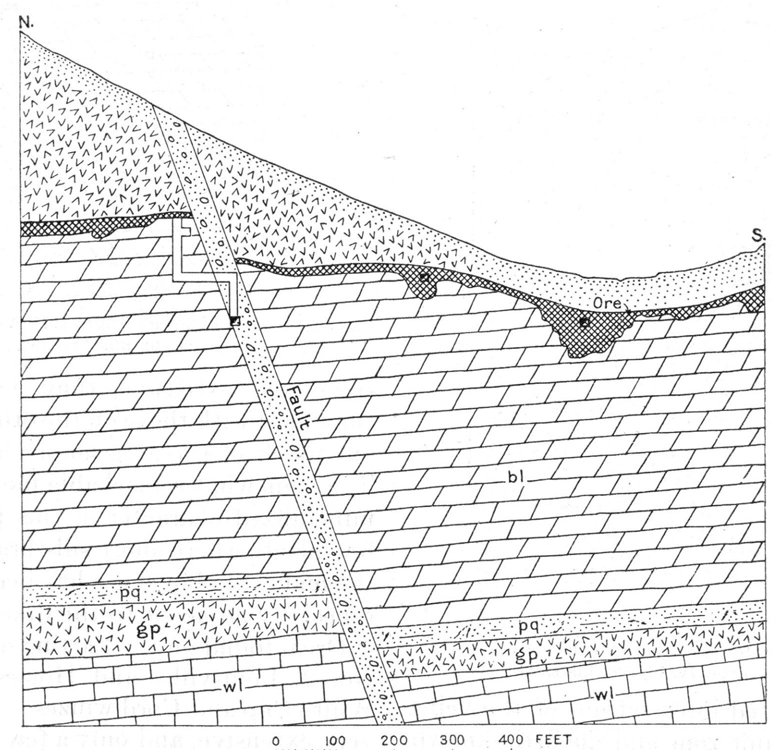


Figure 92. Section across California gulch west of Forfeit shaft and Stone incline. (After Freeland) bl, Blue limestone; pq, Parting quartzite; gp, Gray porphyry; wl, White limestone

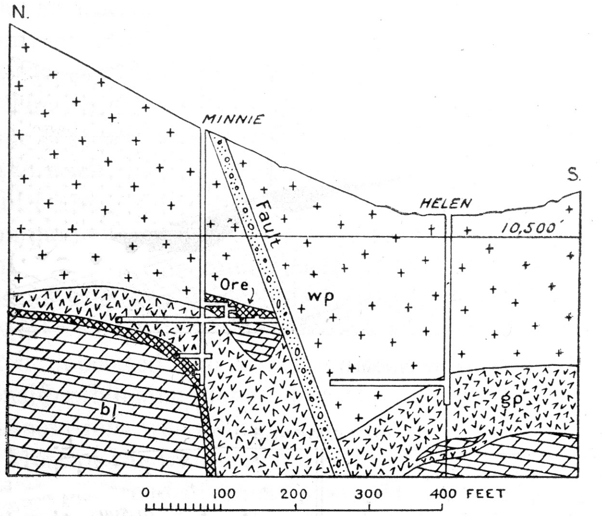


Figure 93. Section through Minnie and Helen shafts. (After Freeland) bl, Blue limestone; wp, White porphyry; gp, Gray porphyry

Lower Contacts

Lower sheets of Gray porphyry within the Blue limestone are present in parts of the area as offshoots from the persistent sill above or from irregular dikes. One of these lower sheets is especially well developed in the White Cap and Accident mines, as indicated on section F—F', plate 24 (extra figures and plates). It has been extensively explored by drill holes and workings throughout the Iron Hill region, and although ore bodies occur beneath it in a number of places and some of them are fairly thick and extensive, they have been disappointing compared with those on the other contacts.

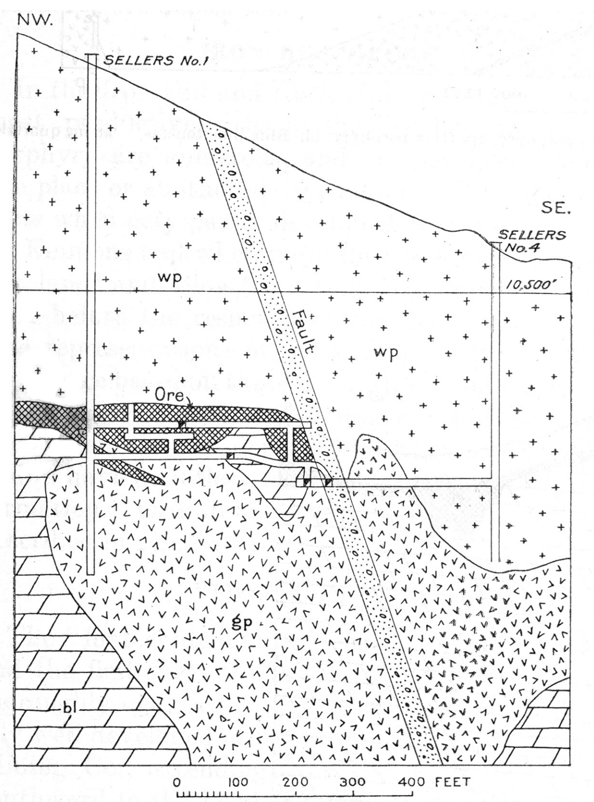


Figure 94. Section through Sellers shafts Nos. 1 and 4. (After Freeland) bl, Blue limestone; wp, White porphyry; gp, Gray porphyry

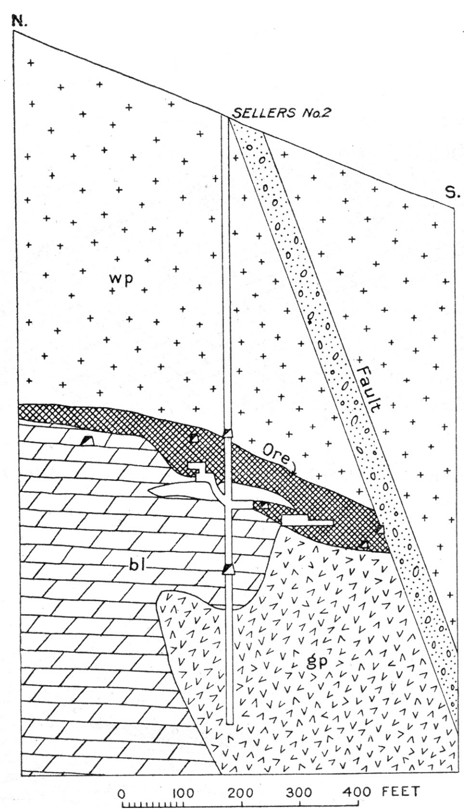


Figure 95. Section through Sellers shaft No. 2. (After Freeland) bl, Blue limestone; wp, White porphyry; gp, Gray porphyry

Throughout much of the area no ore has been found beneath it, a somewhat remarkable fact in view of the heavily mineralized character of this part of the area. At a few places where short sills branch from the dikes or from the main sill above, ore has been found beneath them, especially adjacent to the dikes.

Ore is found on the Parting quartzite in the Colorado No. 2, Louisville, and Horseshoe mines and in the White Cap and Cord winzes. This ore has not proved very extensive, and only a few bodies of it are known. Much of it merely forms the basal parts of ore shoots that lie mainly within the Blue limestone.

Ore is rarely found within the Parting quartzite in the Iron Hill area. The only productive shoot in this rock was found along the Cord vein where it crossed a member of the Tucson fault zone. Drill hole No. 71 from the Yak tunnel also disclosed a body of ore in the Parting quartzite.

Some ore bodies have been found at several “contacts” within the White limestone and underlying “transition shales” and quartzite in the Cord and Tucson mines and are described on the following pages. The “seventh contact,” which is well marked from the Moyer mine on the northeast to the White Cap winze on the southwest, is unusual in containing large ore bodies that lie on top of a sheet of Gray porphyry but are separated from the ore immediately beneath the Parting quartzite by an intervening zone of barren limestone.

Iron Hill

CORD MINE

The most instructive group of ore bodies in the western part of the district comprises the Cord vein and associated stockworks and replacement bodies, which have been worked below the Yak tunnel between the Cord and White Cap winzes. As shown on page 41 (Chapter 9) and in Figures 18, 19, and 21–24 (extra figures and plates), it has been followed from the Blue limestone down into the Cambrian quartzite and crosses the reverse faults within the Tucson-Maid fault zone. A parallel vein just east of the White Cap winze has been followed downward from the Yak tunnel level to a junction with a small replacement body, but nothing further is known about it.

The lowest ore shoots mined include a distinct vein on the eighth level midway between the two winzes. At No. 58 raise the ore shoot expanded to a pipe 14 feet in diameter, which was followed upward for 60 feet and found to be connected with a limestone replacement body. The ore mined in the raise was siliceous pyrite with a relatively high gold content. The vein was followed northward and downward, and on the ninth level, where it crossed two members of the Tucson fault zone, it opened into a stockwork or “brecciated ore body” in Cambrian quartzite, which had been stoped in 1919 for a length of 100 feet and a width of 20 to 35 feet. The two branches of the Tucson fault formed northeast and southwest walls and the hanging wall of the Cord vein a distinct southeast wall. On the northwest side the ore graded into pyritic quartzite of too low grade for mining. The ore in this stockwork consisted of vuggy veinlets of pyrite and quartz cementing the quartzite fragments and partly replacing them. It closely resembled the ore of the South Ibex stockwork in Breece Hill. The gold content was very irregularly distributed, and samples taken close together ranged from 0.1 ounce in gold and 7 ounces in silver to 2 ounces or more in gold and 100 ounces in silver to the ton. Some of the high-grade ore was thickly coated with chalcocite, but some of it appears quite unaltered and can not be distinguished from low-grade pyrite without an assay.

The shattered zone containing the stockwork, although not continuously productive, was followed up to the sixth level, where another stockwork was found in Gray porphyry. This stockwork in 1919 had been stoped in a roughly circular area with a northwest-southwest diameter of 100 feet. Its northwest end lay partly in White limestone, which underlay the porphyry, and its northeast end was connected horizontally with a replacement body in White limestone. The ore in this stockwork was similar in character and variations to that on the ninth level.

Elsewhere in the porphyry sills that cut the White limestone the ore occurred in vein-like form, but the deposits were too thin to be profitably worked. Where the veins passed into White limestone, however, they expanded into large bodies that partly or completely replaced the limestone. The ore in these replacement bodies was mixed sulfide but varied from practically pure pyrite to practically pure zinc blende. The zinc shoots formed flat to lens-shaped segregations in the pyrite, ranging from a few inches to several feet in length and thickness. Ore from the exceptionally large ones was shipped as zinc ore without concentration. Galena, on the whole, was very subordinate to the zinc blende but was conspicuous in a few places. In some places the two minerals were rather evenly mixed, but in others they were practically independent of each other. No chalcopyrite was seen, but assay records indicate its presence. The gangue was mainly dense quartz or jasperoid, which formed from 2 to 18 per cent of the ore bodies above the fifth level and about 40 per cent of those below it. It was less prominent within the ore bodies than around their margin, where it replaced limestone and porphyry. The top of the replacement body at No. 58 raise, already mentioned, is marked by a continuous layer of finely pyritized jasperoid that had been regarded as quartzite but proved under the microscope to be thoroughly silicified porphyry. The only other gangue mineral noted was barite in small crystals or aggregates thinly scattered through the ore.

Ore was mined between the second and third levels from a stockwork that extended into the hanging wall of the vein. This stockwork was inaccessible to the writer, but, according to John Pendery, who had previously mapped it, extended along one or more transverse fissures and was mainly in Parting quartzite but tapered downward in Gray porphyry and upward in Blue limestone. It is approximately in line with members of the Tucson fault zone exposed at lower levels. The ore was pyrite with more than 1 per cent of copper and a relatively high content of silver. Only 2 out of 28 samples contained zinc or lead.

Workings in the Blue limestone were inaccessible but a few small ore bodies have been found along the vein in its lower part and one large ore body near the Cord winze is represented in the profile of the workings (figure 24). Plate 25, section K—K' (extra figures and plates), shows a large "fist contact" ore body directly above the Cord vein and presumably connected with it.

A study of the differences in the ores at different levels and in contact with different rocks was made from representative assay records selected in 1918 by John Pendery, formerly engineer for the Yak tunnel properties. A condensed list of these assays appears on page 2. Only six assays represent the vein below the eighth level, which had been newly opened at that time, but the ores between the eighth and fifth levels were represented by 25 assays, those between successive higher levels by 24 to 27, and those between the Yak tunnel level and the White porphyry above by 27. Only a few of these assays are presented here to show the range in composition of the ores.

The ore in No. 58 raise below the eighth level was mainly quartz and pyrite, with low percentages of other s here and there and an average of 0.525 ounce to the ton of gold. The gold ranged from 0.08 to 2.05 ounces to the ton, the minimum quantity occurring in ore that contained the most zinc, lead, and copper and the maximum in practically pure pyrite. Silver also varied considerably. No assay records of the stockwork on the ninth level are at hand, but the ore is reported to have been high and variable in gold, like that in No. 58 raise. It showed some evidence of enrichment, but that in No. 58 raise showed little or none. The similarity of the siliceous pyritic ore in the Cord mine to that in the lodes of the eastern part of the district is very close.

Ore remaining in the stockworks on the ninth and sixth levels in 1921 was low in gold and for the most part in silver but in other respects was similar to that in No. 58 raise. The replacement bodies in White limestone between the eighth and fifth levels were also on the whole siliceous pyrite, though a few assays showed iron in excess over silica, and a few were comparatively high in zinc or lead or in both. Except in one assay, gold was very low and silver showed the same general range as ore in the stockworks and vein. The sample that was exceptionally rich in gold and silver happened to contain considerable galena, but another sample with more lead was low in silver and very low in gold. In short, the precious metals were independent of each other and of the other constituents, so far as detailed comparisons were concerned, but the higher gold contents were as a rule irregularly distributed in siliceous pyrite ore between siliceous wall rocks.

Between the fifth and fourth levels the ore was less siliceous but had not changed materially in other respects. The same was true of the ore between the fourth and third levels, except that one-third of the samples were rather high in gold (0.14 to 0.64 ounce to the ton), and the average was correspondingly raised. The average copper content was also higher. From the third level up to the Yak tunnel level the ore continued to be pyritic with more iron than silica and with relatively high copper, but the gold was low again. Zinc and lead were prominent in a few samples but averaged low. Above the Yak tunnel, however, zinc and lead were much more abundant, and all the samples were classed as zinc-iron or zinc-iron-lead sulfate. Silver was lower than in the pyritic ore below the Yak tunnel, and gold was characteristically low.

Unfortunately, the Cord vein could not be studied continuously up to the White porphyry, but the direct connection between the pyritic ores were sufficient to show that all these varieties of ore were found along one trunk channel and that the pyritic ore predominated at the lower levels in and close by the vein.

Representative assays of ore from different levels of the Cord mine

Between base of White porphyry and Yak tunnel level

[Average represents 27 assays]

	Gold (oz./ton)	Silver (oz./ton)	Copper (percent)	Lead (percent)	Zinc (percent)	Iron (percent)	Silica (percent)
	0.03	3.2	0.4	9.8	19.1	36.4	1.8
	.06	5.2	.0	1.8	13.6	34.2	3.2
	.03	2.8	Trace	5.2	7.6	34.1	2.2
	.02	4.2	Trace	3.8	22.4	25.8	3.4
	.04	4.6	Trace	7.8	31.2	20.8	4.8
	-	14.2	-	26.0	22.5	-	-
	-	5.9	-	7.0	39.0	-	-
Avg.	-	5.1	-	4.8	17.6	29.6	-

Between tunnel and first level below

[Average represents 27 assays]

	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Iron (Percent)	Silica (Percent)
	0.05	13.7	1.4	0.0	0.0	42.6	5.8
	-	10.8	Trace	12.2	20.0	-	4.0
	.01	3.7	.7	1.5	23.0	29.2	2.2
	.04	3.1	.0	4.4	4.8	34.8	8.4
	.03	2.0	.0	3.6	9.4	34.8	5.2
	.03	3.2	.0	2.8	9.4	38.4	2.7
	.06	30.8	3.0	.0	.0	40.1	3.5
	.06	28.0	4.1	.0	.0	40.2	4.6
	.05	13.7	1.4	.0	.0	42.6	5.8
Avg.	.04	9.6	1.1	1.2	3.7	39.4	4.9

Between first and second levels

[Average represents 27 assays]

	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Iron (Percent)	Silica (Percent)
	.03	2.8	-	8.7	14.9	-	-
	.05	5.1	0.2	4.9	35.1	17.8	6.5
	.04	5.1	.0	.2	2.6	33.5	15.8
	.06	29.4	.2	.0	.0	36.5	4.6
	.26	34.2	1.6	.0	.0	38.8	9.2
	.02	3.0	.3	.0	.0	39.9	4.8
	.05	7.4	.8	Trace	1.2	42.8	2.1
Avg.	.06	14.0	2.1	.6	2.7	38.6	7.2

Between second and third levels

[Average represents 28 assays]

	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Iron (Percent)	Silica (Percent)
	.04	201.0	2.5	20.8	19.0	20.8	6.7
	.06	4.1	.0	.0	2.1	33.7	17.2
	.10	71.3	.0	.0	.0	38.7	7.2
	.05	28.6	3.2	.0	.0	42.2	3.2
	.04	6.7	.9	.0	.0	43.1	2.3
	.01	1.6	.0	.0	.0	44.0	5.8
Avg.	.05	23.4	1.2	.7	.8	40.3	5.2

Between third and fourth levels

[Average represents 24 assays]

	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Iron (Percent)	Silica (Percent)
	.05	22.1	22.4	0.2	4.8	31.2	1.1
	.04	7.0	6.5	.0	14.8	33.1	-
	.03	4.4	.8	.4	9.4	36.2	6.9
	.30	43.0	.0	.0	.2	37.8	17.9
	.64	5.2	.2	.6	Trace	41.2	6.2
	.28	1.6	.0	.0	.0	42.1	7.8
Avg.	.13	10.4	1.6	.2	2.0	37.9	8.0

Between fourth and fifth levels

[Average represents 25 assays]

	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Iron (Percent)	Silica (Percent)
	.03	4.0	-	10.3	20.8	-	11.2
	.02	4.0	0.0	2.3	29.5	17.7	7.1
	.05	8.6	.0	2.3	3.1	31.9	17.8
	.01	1.2	.0	Trace	16.1	32.0	8.1
	.13	32.6	.0	.2	2.4	38.4	11.9
	.05	18.4	2.8	.0	.0	39.1	8.2
	.06	11.8	1.0	.0	.0	42.4	4.2
Avg.	.05	10.9	.7	1.1	4.8	36.7	8.8

Between fifth and eighth levels

[Average represents 25 assays]

	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Iron (Percent)	Silica (Percent)
	.02	3.0	0.0	0.0	0.0	5.7	74.4
	.02	1.5	.0	.0	.0	10.2	74.6
	.03	9.1	.5	15.7	19.5	12.8	26.8
	.01	1.2	.0	.0	.0	13.8	71.0
	.44	440.0	2.3	11.3	.0	21.2	36.6
	.05	22.5	1.4	2.1	.0	36.3	17.2
Avg.	.06	28.0	.5	2.1	2.4	22.5	43.7

Below eighth level (winze below No. 58 raise)

[Average represents 6 assays]

	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Iron (Percent)	Silica (Percent)
	0.12	4.5	0.2	Trace	0.0	12.8	71.0
	.08	18.0	2.1	2.9	3.9	28.2	28.0
	2.05	24.5	.0	.0	.0	45.2	1.6
Avg.	.53	15.0	.6	1.1	.9	27.6	37.8

TUCSON MINE

No vein-like deposits have been developed in the Tucson mine for any great distance, but the ores connected with auxiliary fissures on the footwall side of the Tucson fault and locally within the fault have certain similarities to those mined in distinct veins. Ore has been mined at all levels from the base of the White porphyry or “first contact” down into the Cambrian quartzite as far as the tenth level [**figures** 18, 20, (extra figures and plates) **96, and 97**]. Those at and below the fourth level lie in or near the Tucson fault and are described in ascending order.

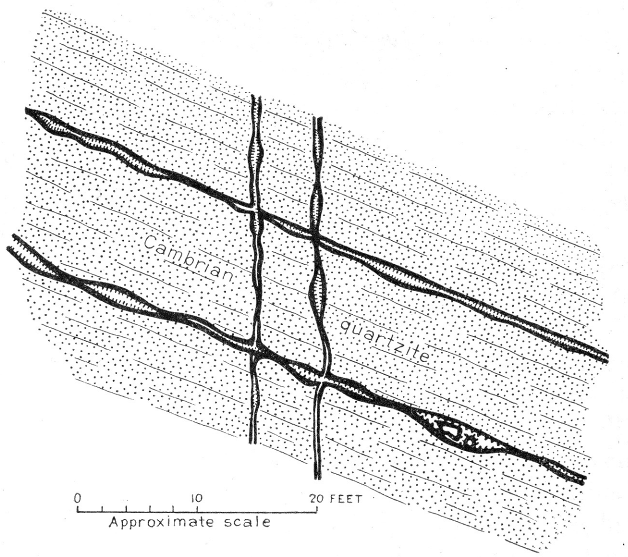


Figure 96. Fissures in Lower or Cambrian quartzite, Tucson mine, North Iron Hill, showing crustified linings of sulfides and manner in which they connect with irregular solution centers, which follow the eroding of the quartzite and are now lined with incrustations of sulfides. Scale about 4 feet=1 inch.

Deposits in Cambrian quartzite— Between the tenth and eighth levels an ore body very rich in silver and gold has been mined in Cambrian quartzite. The ore (figures 84, 85) has replaced and filled cavities in a certain bed of quartzite along a network of vertical fissures, the strongest of which trend east-northeast, about at right angles to the strike of the Tucson fault. There is no connection with the fault, however, the ore stopping 100 feet away from it. The workings were flooded when the mine was visited in 1913 and the following description[9] is quoted from a paper by George O. Argall, manager of the mine:

"The Cambrian quartzite in the vicinity of the Tucson shaft is shattered by a series of vertical fractures striking approximately northeast and southwest. Along these fractures occur open cavities of varying dimensions from oval-shaped conduits a few inches wide to channels 10 feet wide and 4 feet high along the strike of the quartzite beds. Incrustations of ore, from a few inches up to 2 feet in thickness, completely line these openings, but where the large cavities occur the roof ore is often found on the floor with fragments of the quartzite roof caved down upon it.

…it would appear from the thickness of the mud deposited on this caved ore and quartzite, often 10 inches in depth, that the collapse of the roof is not by any means a recent occurrence. Furthermore, this brown mud deposit might indicate the downward circulation of meteoric waters from the Silurian [White] limestone ore deposits immediately above. The longest distance so far opened in a vertical fissure in the quartzite is 80 feet; this fissure shows three chimneys, the largest 3 feet by 1½ feet, standing vertical and lined with the same minerals. The openings in the fissures vary from a width of 18 inches down to a mere film or incipient fissure, often difficult to follow. Cross fissures also occur carrying the same mineralization, while open joints in the rock are often coated with pyrite or blende.

The ore occurs in the fissures and cavities mainly as a crusted structure with a regular succession of mineralogically different layers, as follows: Argentiferous sphalerite, pyrite, galena, and chalcopyrite. The sphalerite and galena are found throughout the entire length of the fissures, while the pyrite and chalcopyrite occur at infrequent intervals. At points where these cavities take a sudden pitch downward and where "potholes" or other irregularities occur in the floor, pockets of a rich silver sulfide mineral are found.

The quartzite often shows a honeycomb structure where the channels split up into numerous small cavities, usually along a bedding plane. The cavities are always lined with ore. Invariably a small seam of ore connects one cavity with another, and on being followed…these seams eventually lead into a large single cavity where the ore has been deposited in much thicker layers.

[9] Argall, G. O., Recent developments on Iron Hill, Leadville: Eng. and Min. Jour., vol. 89, p. 263, 1910.

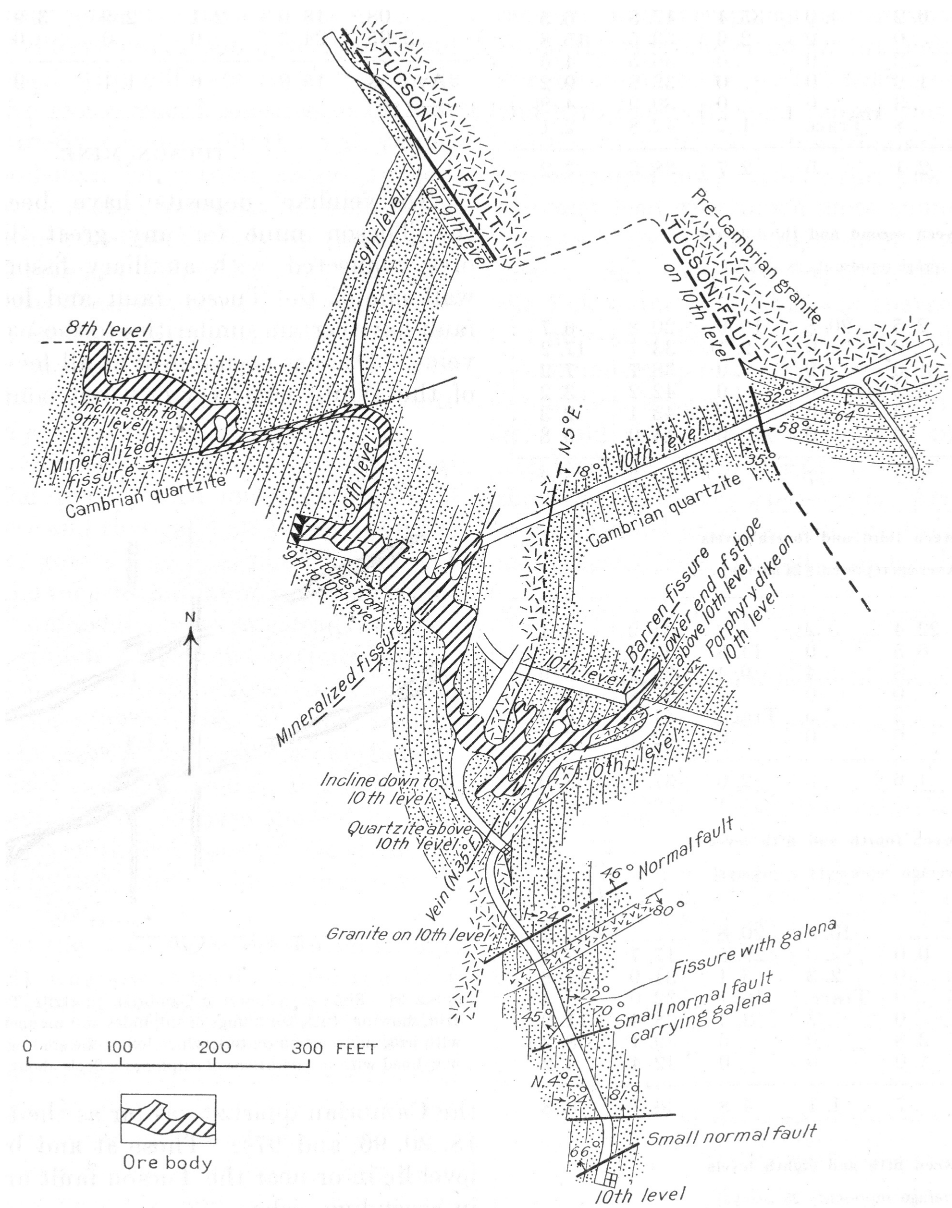


Figure 97. Plan of ore body in Cambrian quartzite between eighth and tenth levels of Tucson mine. (From map by F. A. Aicher, Iron Silver Mining Co.)

The ore minerals, besides forming crusts, impregnate and replace the quartzite to some extent. The replacing sulfides form a fine, even-grained mass, which passes abruptly into the coarse-grained crystals that line the cavities. Partly replaced quartzite fragments are enclosed in ore. In one thin section there is a perfect gradation from pure quartzite through a transition zone where the interstices are filled with s to a rim where quartz grains as well as the original interstitial matrix are almost wholly replaced by sulfides. Siderite impregnates and replaces the quartzite just within the rim and is also abundant among the coarse-grained s outside the rim. The fine-grained sulfides in the quartzite are chiefly pyrite and zinc blende with a little galena; the adjacent cavity filling consists essentially of galena and siderite with some zinc blende, coated by the argentite-bismuthinite intergrowth “lillianite.” of the minerals filling the cavities zinc blende was deposited first, followed by siderite and galena, in part intergrown but with galena also forming veinlets in the siderite.

No chalcopyrite was noted in this thin section, but specimens were collected showing chalcopyrite in relatively large grains scattered among mixed sulfides and also in relatively pure masses. Specimens were also found showing pyrite with a little chalcopyrite and a minor amount of unreplaced quartz but no zinc blende or galena.

Specimens broken from cavity linings were cellular; they showed crystals of all the sulfide minerals and of siderite, the last in minute yellowish-brown flat rhombs. Where an order of crystallization was distinct pyrite and blende were evidently formed before the galena and chalcopyrite, and siderite finished crystallizing last. A polished surface of quartzite and ore was described by Argall[10] as consisting of (1) an inner zone one-sixteenth inch thick of fine galena with a little blende and pyrite on quartzite, (2) a band one-fourth inch thick of blende and pyrite with a few spangles of galena, forming a distinct crust, (3) irregular grains of chalcopyrite lying mostly in cavities between the outermost crystals of (2), and (4) massive crystals of galena 1 inch thick, some of them coated with a film of the argentite-bismuthinite intergrowth. This film Argall considered to be a secondary deposit from descending waters.

The dissolving of cavities in the quartzite indicates that the solutions first passing upward through it were under-saturated in silica and did not deposit ore and gangue minerals until they had got farther along in their course. At a later stage solution of the quartzite was accompanied by deposition of pyrite and subordinate zinc blende and was followed by deposition of the s and siderite in open cavities. The minerals in the cavity filling represent a solution that had already been depleted in pyrite and silica and may be regarded as a product of the waning stages of ore deposition, which took place in cavities that had been opened in an early stage. The mud in the cavities, derived from shaly material above, shows that some material has been deposited by descending waters and lends support to Argall's inference that the coatings of argentite-bismuthinite intergrowth are of supergene origin; but the other minerals are identical in character with those of undoubted hypogene origin elsewhere in the district, and there is no proof that the intergrowth also is not hypogene.

Deposits in White limestone—Ore bodies in the White limestone occur at intervals from the eighth up to the fourth level. All but the highest thus far found are on the footwall side of the Tucson fault, some wholly separated from it, others connecting with it and one probably crossing it [(figures 18 and 20 (extra figures and plates)]. One stope, on the fourth level, is on the hanging-wall side of the fault.

The lowest stope in White limestone extends from the eighth up to the seventh level, 300 to 400 feet south of the Tucson shaft. Its east wall is from 180 to over 250 feet away from the Tucson fault and consists of Gray porphyry, which locally crosscuts the strata and extends eastward as far as the fault. The porphyry contact flattens westward above the seventh level and forms the roof of the stope. The outline of the stope is very irregular, and the narrower parts have generally northeast trends, parallel to the more conspicuous fissures in the quartzite stope, which lie 200 feet or more to the north. The ore is a mixture of pyrite and zinc blende, with little or no galena and low silver content. This stope terminates downward in a narrow sulfide vein[11] along the margin of the porphyry mass.

Another stope has its lowest point in the Tucson fault above the seventh level and about 100 feet southeast of the shaft. It rises with irregular outline in the fault up to the sixth level and is continuous with a blanket replacement deposit 13 to 19 feet thick, which extends in a generally north-south direction for over 300 feet and has a maximum width of nearly 200 feet. The outline of the stope suggests that the ore body formed along a series of intersecting north-south, east-west, and northeast-southwest fissures [(figure 20 (extra figures and plates)], which lie at angles of about 45º and 90º to the local trend of the Tucson fault (N. 40º W.). The stope lies almost directly above the ore body in the quartzite, and it is believed that the solutions rising through the

[10] Op. cit., p. 264, fig. 5.
[11] Argall, G. O., op. cit., p. 265, fig. 6.

quartzite during the early stage deposited the ore by replacement of White limestone along the impervious barriers formed by the porphyry sill and by the gouge and quartzite hanging wall of the Tucson fault. The ore body is bordered on the southwest by manganosiderite accompanied by patches and streaks of magnetite ore. It is a varying mixture of pyrite, blende, galena, and chalcopyrite and includes three commercial varieties, zinc, zinc-lead, and copper ore. A blende-pyrite mixture commonly predominates at the top of the stope whereas blende and galena, the latter in thin distinct layers parallel to the bedding, are found in its lower part. The silver content of these ores is low. Chalcopyrite is inconspicuous in the stope except close by the Tucson fault, but it forms prominent lenses in the lowest part of the stope, which occupies the fault between walls of siliceous rock, quartzite, and porphyry. It also extends with the other s a short distance into the quartzite hanging wall. This one ore body, in short, shows a gradation from the gold-copper ore characteristic of the lodes in the eastern part of the district to the mixed sulfide ores characteristic of the "blanket" ores in the western part of the district. According to Argall[12] chalcopyrite accompanied by chalcocite impregnates the zinc ore in the stope along fissures or watercourses. He states that enriched ore, composed of chalcopyrite, chalcocite, and silver , was concentrated in the fault and for a distance of 30 feet from it; but no specimens of such ore could be obtained when the mine was visited in 1913.

At one place in the fault, 50 feet northwest of the shaft and 30 feet below the sixth level a lens of arsenopyrite was found. The lens was 4 or 5 feet long, 3 feet wide, and 1 foot thick, lying parallel to the pitch of the ore shoot in the fault. At another place a pocket in the hanging wall of the fault at the sixth level contained distinct blende crystals one-fourth inch in diameter, with a few of chalcopyrite enclosed in the outer parts of blende crystals or perched upon them. Distinctly later than these was a deposit of fine galena crystals, some in drusy aggregates lining depressions among blend crystals but many in small stalactites grown upon blende crystals. The galena was largely coated with a fine dust, which may represent a secondary silver mineral, as the ore at this place contained 80 ounces of silver to the ton. The appearance of the galena is strongly suggestive of secondary origin, although it may be impossible to draw a sharp line between primary and secondary galena, as both have crystallized later than the blende. The facts, however, accord with observations and the results of experimental work which have been discussed by W. H. Emmons[13] and which show that secondary galena may be deposited on blende or pyrite, whereas secondary silver sulfide may be deposited on galena, blende, or pyrite.

The stope is continuous up the fault to the fifth level, where it extends along the west side of the Tucson fault for about 150 feet. It is roofed by another porphyry sill, which has a slight southeastward pitch. Two other stopes on the sixth level, about 300 and 600 feet northwest of the shaft, have the same general character and variations as the stope just described. They both extend up to the fifth level.

On the fifth level about 100 feet south of the shaft is a stope extending about 130 feet from east to west and 80 feet from north to south. It crosses the line of the Tucson fault, both walls of which at this place are White limestone. The footwall part of the stope lies between two porphyry sills, which converge westward. The hanging-wall part replaces the shattered basal beds of Cambrian "transition shales" and passes eastward into a low-grade material, which extends a considerable distance farther. The shaly character of the "transition shales" is not very marked in this vicinity, and as they are not readily distinguished from the lower part of the White limestone as lying directly upon typical Cambrian quartzite. [See figure 20 (extra figures and plates)].

The only stope opened on the fourth level in 1913 was about 700 feet northwest of the shaft in the White limestone hanging wall of the fault, against a footwall of Parting quartzite. When visited it had been opened only for a short distance, and no adequate idea of its outline could be

[12] Op. cit., p. 265.
[13] U. S. Geol. Survey bull, 625, pp. 137-140, 1917.

formed. It lay approximately at water level, and its ore, a zinc-lead sulfide mixture was partly oxidized, oxidation working inward from numerous fractures and bedding planes.

Ore in cross faults—Some of the cross faults in the quartzite hanging wall are metallized. One is said to contain zinc blende, pyrite, limonite, and a little copper stain on the seventh level about 200 feet east of the shaft, showing that locally oxidation has extended considerably below the fourth level. Another cross fault has been worked on the sixth level, about 260 feet northwest of the shaft. The ore at this place runs 2 ounces of gold to the ton. It consists chiefly of pyrite, blende, galena, and a little chalcopyrite scattered through a quartz or quartzite gangue. Sooty chalcocite has been deposited along fractures and has replaced all the sulfides to a small extent. Scattered grains having a blue color suggestive of covellite and green specks of malachite are also present. A little chalcedony or opal was deposited after the black material. This local downward enrichment in copper implies that the high gold content also may be due to downward enrichment.

Deposits in Blue limestone—The ore above the fourth level is all oxidized. Three stopes of moderate to small size have been mined in Blue limestone on the third level. The largest stope, about 400 feet due south of the shaft, lies approximately where the Tucson fault should cross the third level if it were continuous to that height. Its major axis lies at about right angles to the trend of the fault, but its branches follow the same directions as those of the lower stopes, suggesting that the ore replaces Blue limestone along a network of fissures related to the Tucson fault. Another ore body, shown in [figure 18 (extra figures and plates)], lies along the fault at the second level, and still another lies along the fault at the second level, and still another lies not far east of the fault beneath a Gray porphyry sill. This last-mentioned ore body as outlined by stoping, is 300 feet long and averages 100 feet in width. Its western half trends southwest, at right angles to the fault and its eastern half trends a little south of east. Short branches from it trend northwest, north, and northeast. Directly above it is the great North Iron ore shoot, which also trends northeast, parallel to the mineralized cross faults and other mineralized fissures at lower levels. Oxidation prevents close comparison between these upper ore bodies and those in White limestone along the Tucson fault, but the large quantities of siliceous iron and manganese oxides and zinc carbonate along the North Iron shoot [figure 18 (extra figures and plates)] show that it was originally similar to the zinc-iron-lead ores on the fourth, fifth, and sixth levels, although the ratio of lead to other metals may have been higher.

Representative assays of ore between the fourth and tenth levels are shown below. The ores that were highest in gold and silver were much less in quantity than the others, as may be realized from the plans and sections of the stopes. The most striking features bearing on genesis is that ores represented by analyses 3, 4, and 5, which strongly resemble ores of the Winnie-Luema lode, occurred along the same pre-mineral fault as ores represented by analyses 1 and 2, which are typical of ores in the blanket deposits of the western part of the district.

Assays of ores in Tucson mine, along the Tucson fault and in the Cambrian quartzite

	Gold (Oz./ton)	**Silver (Oz./ton)**	**Lead (Percent)**	**Copper (Percent)**	**Silica (Percent)**	**Iron (Percent)**	**Manganese (Percent)**	**Zinc (Percent)**
Fourth level stope:								
Oxidized ore	-	13.7	14.9	-	32.1	22.8	1.8	2.3
Sulfide ore	-	8.0	11.65	-	-	-	-	26.2
Sixth level, mixed sulfide ore from bottom of White Limestone trending into Tucson fault	0.45	148.0	13.2	2.8	16.8	5.9	-	34.3
Seventh level, sulfide ore in Tucson fault	.045 .52	17.15 125.00	- 12.3	2.7 9.95	24.0 15.4	27.3 18.3	- -	4.5 11.45

Ninth level:								
Rich (sorted) silver-gold ore in Cambrian quartzite	14.45 15.27	3,987.0 4,109.0	44.7 42.5	- -	- -	- -	- -	- -
Remaining ore in quartzite channels [a]	.3	140.0	15.0	-	17.0	-	-	35.0

[a] Sulfur, 25 percent.

ADELAIDE PARK GROUP

The Adelaide Park group includes the small, wedge shaped block between the Iron and Adelaide faults and the adjoining area between the Adelaide fault and the Eureka pipe of rhyolitic agglomerate. The wedge-shaped block has been developed through the Argentine and Camp Bird tunnels and the Adelaide Nos. 1 and 2, Terrible Nos. 1 and 2, Ward, Humboldt, Frenchman, and Flagstaff shafts. In the early eighties a considerable quantity of ore was mined in this area, but the workings have long been inaccessible, and records of them are insufficient to permit a satisfactory discussion of the ore horizons or to supplement the data presented in the Leadville monograph.[14]

Column J on plate 59 (Chapter 9) represents the horizons at which ore is known to have been found. The Argentine tunnel, which was driven southward from Stray Horse Gulch, cut strata of steep southward from Stray Horse Gulch, cut strata of steep southeastward dip beginning with White limestone and extending into the main sheet of White porphyry, which here has cut downward to the lower part of the Blue limestone. Other sills of porphyry, cut at different intervals, are represented in plate 13 (extra figures and plates).

Most of the ore first found in Adelaide ground was east of the tunnel. It consisted of small bodies of relatively high-grade carbonate ore and lay for the most part immediately under the Parting quartzite. Later developments in the Ward shaft of the Adelaide mines found ore at a still lower horizon, apparently in the transition beds beneath the White limestone. Ore was also found in the workings of the Frenchman, Humboldt, and Flagstaff mines, still farther east, but its exact geologic relations in these mines could not be ascertained. The Flagstaff workings are said to have cut the Adelaide fault. In one place drifts were run for several hundred feet along the fault, which contained considerable dragged-in galena ore.

East of the Adelaide fault a considerable quantity of ore is reported to have been mined in the Park Benton, Morning Glory, and Lady Alice mines, and in the Park No. 2 shaft a body of low-grade pyrite was found at a depth of 65 feet; but neither the outlines of these ore bodies nor their geologic horizons are known. The ores in these mines, particularly the Park Benton, contained varying quantities of magnetite and specularite and in this respect are closely related to the ores of the old Breece iron mine and other mines in the Penn group to the east. Gold-bearing ore was also found in the Park Benton mine.

PENN GROUP

The Penn group of ore bodies, which lies beneath the northwest slope of Breece Hill, includes one productive vein and several blanket deposits, some of which are of considerable size. The vein was first cut on the first level 95 feet west of shaft No. 3 and 80 feet below the surface. It consists of a zone of much broken and decomposed porphyry between fairly well defined walls, with a comparatively narrow seam of ore occupying the middle of the crushed zone. Its trend is nearly north, but its south end bends slightly to the east of south and its north

[14] U. S. Geol. Survey Mon. 12, pp. 401-408; atlas sheets 26 and 27, 1886.

end slightly to the west of north. It dips 85º W. and ranges from 3 to 6 feet in width. It was not followed upward to the surface, nor to its end in either direction. The workings on the vein at the time of visit consisted of four drifts at depths of 80, 155, 500 and 800 feet below the surface. Along the strike it had been opened up for a distance of 200 feet.

The ore in the upper levels was a soft, oxidized, iron-stained material with a high content of gold, in the middle of a clayey mass. At the lower levels it changed to sulfide, chiefly pyrite much enriched by sooty chalcocite, which contained as much as 8 percent of copper and from half an ounce to 5 ounces of gold to the ton. A connection between this vein and the blanket ore bodies above could not be observed in the mine workings although one may exist.

The most productive portion of the area and that portion of the area and that portion within which the blanket ore bodies are closely spaced and comparatively extensive comprises the flat ore shoots worked from the Penn No. 2, Penn No. 3, Nettie Morgan, Big Six, Little Prince, Ballard, and President shafts. These ores replace Blue limestone beneath an earlier replacement mass of magnetite, specularite, and silicates. The unproductive part of the limestone has been so greatly changed by metamorphism and by subsequent hydro-thermal alteration and oxidation that it is now difficult to judge of the original character of the rock or to determine at what horizon the ore bodies occur.

The available maps of the mines in this area are insufficient for the mines in this area are insufficient for the determination of any dominant trends to the ore bodies of the group. The altered sedimentary formations extend southward past the Penn No. 3 shaft, beneath a capping of Gray White porphyries, and are finally lost in the great stocklike mass of porphyry. The Chippewa shafts Nos. 1 and 6 were sunk to depths of 230 and 500 feet, respectively, without penetrating the porphyry.

On the east the Penn group is separated by the Weston fault from ground that has been productive, but of which no records remain. Ore has been worked in the Eliza and adjacent mines east of the fault, and the ground between the groups of ore bodies shown on plate 45 (extra figures and plates) may not actually be barren, although no production from it is on record.

On the west the ore-bearing rocks are cut out by the Eureka pipe of agglomerate. There are no records of the Kent and Ishpeming mines, southwest of the Penn No. 1 shaft, and here again the apparent gap between the ore bodies of the Penn and Adelaide Park groups may be due to the lack of records as well as to destruction of ore bodies by the agglomerate.

Northeast of the agglomerate the limits of the Penn group are still more indefinite. The only data obtained on mines in this vicinity since Emmons' first survey is furnished by recent developments in the Great Hope mine. There the ore has been found in Blue limestone, which is also known to be mineralized in the White Prince, Bosco, and Across the Ocean mines. This portion of the Leadville district seems to have remained comparatively idle for a long period and not to have had the attention paid to it, which its favorable conditions would seem to justify. The work done has been above ground water. The ore of the Great Hope mine is described on pages 225-226 (Chapter 10, not in this report). The workings indicated on plate 45 (extra figures and plates) were completed by 1882 but still represent the area fairly well, as probably less than 1,000 tons of ore has been shipped from it since then.

YANKEE HILL AREA

The Yankee Hill area, between the Fryer Hill and Penn group of ore bodies [(plate 13, (extra figures and plates], is not known to have contained any important ore bodies or to have produced any considerable amount of ore. It presumably is one of the several comparatively barren and unproductive areas that intervene between the more heavily mineralized portions of the district. Extensive exploration has been carried on in this area, however, and has apparently resulted in the discovery of some small, discontinuous deposits.

Northeast of Yankee Hill the Mammoth Placer shaft has been sunk on the north side of Evans Gulch just south of the thick glacial moraine. bodies of low grade and of considerable size have been disclosed in the lower workings of this mine but have not been worked at a profit. Some high-grade ore is also said to have been found. The possible extension of the Colorado Prince reverse fault in this direction has been suggested and if proved will be a favorable structural feature. Very little is known of the geologic structure here, however, and considerable exploration will be necessary before prospecting can be established on a sound geologic basis. If the Canterbury Hill tunnel eventually drains this ground, as planned, conditions for exploration will be considerably improved.

PRINTER BOY GROUP

Both veins and blanket deposits are present in the Printer Boy Hill area, but no evidence establishing their relations was found during Emmons' first survey or later. The only deposits of which anything is known are the Printer Boy vein and the blanket deposits of the Lilian or Florence mine.

The Printer Boy vein was very productive from 1866 to 1870, and was operated through the Upper Printer Boy and Lower Printer Boy shafts. Only the lower shaft was open during Emmons' first visit, and no information about the vein has been obtained since then. According to Emmons[15] the vein in Lower Printer ground was double, and the two branches were separated by 10 to 12 feet of decomposed Gray porphyry. The gangue of the ore was also thoroughly decomposed porphyry, and scarcely any metallic minerals were visible in the vein. The rich ore in the old workings contained visible gold, and that in the deeper workings considerable pyrite and chalcopyrite, as well as some galena and tenantite. The gold was present in both pyrite and galena, and one show specimen contained galena crystals connected by a filament of wire gold. Selected specimens were said to have contained 122 ounces of gold to the ton, and the average content was said to be 3 to 4 ounces.

The width of the vein ranged from 1 inch to 4 feet and averaged about 7 inches. From the surface to a depth of 200 feet branches, some as much as 3 feet thick and containing the same kind of ore as the main vein, extended into the west wall. South drifts from the Upper Printer Boy shaft were said to be cut off a few hundred feet from the shaft by a "cement deposit" which Emmons interpreted as "lake beds".

A number of small gold-bearing veins were found in the Gray porphyry near the Printer Boy vein. The most productive of them was the Five-Twenty vein. It was opened by a tunnel which also cut a body of lead carbonate ore, not worth considering at that time and so far as known not developed later.

The blanket deposits of the Lilian or Florence mine are considerably to the east of the veins [plate 45 (extra figures and plates)] but are similar in containing relatively large quantities of gold. They are in Blue limestone, and all but one are at the upper or White porphyry contact. The one exception is at the top of the Parting quartzite. These deposits are only 2 or 3 feet thick. The ore minerals, according to Emmons[16], contained, besides the usual lead carbonate and silver chloride, "several minerals not common in the district, among which may be mentioned native gold, visible to the naked eye, and a sulpho-carbonate of bismuth." The bismuth minerals, according to Guyard[17], were bismuthiferous lanarkite and schapbachite, the latter of which was proved later by Laney's microscopic study to be an intergrowth of bismuthinite and argentite with some galena.

[15] U. S. Geol. Survey Mon. 12, p. 514, 1886.
[16] Idem, p. 510.
[17] Idem, p. 616.

In a tunnel directly below the main workings Emmons noted a vein of galena several feet thick in limestone. It connected with a blanket body but pinched out a short distance below it and could not be regarded as representing the channel through which the solutions rose; nor although the elongate shape of all the blankets indicates that they have developed along fissures, have any such feeders been recognized. The blankets are surrounded by "contact material," which replaces the uppermost part of the limestone in the area between the eastern and western dikes of Gray porphyry shown in plate 13 (extra figures and plates).

East of the Lilian mine the Minor tunnel was driven several hundred feet along the contact without finding ore, but ore of good grade was reported in the First National mine, farther east. West of the Lilian mine some ore was shipped from the Wilson, Brian Barau, G. M. Favorite, and others, but nothing is known of its quantity or quality.[18]

IBEX GROUP

The Ibex group includes veins and blanket deposits within the Ibex mine itself and the adjacent Golden Eagle and Little Vinnie mines, on the west, and the Garbutt and Modoc veins, on the east. On the south and southwest it can not be sharply separated from the Antioch stockwork and the Forest Queen, Tribune, and other minor veins. On the north it is connected with the Big Four group by the vein designated No. 20-b in plate 57 (Chapter 9).

Ibex Mine

BLANKET ORE BODIES

SILICEOUS OXIDIZED AND ORES

The deposits in the Ibex group include blankets of magnetite ore, veins and blankets of siliceous pyritic ores and their oxidized equivalents, and blankets of mixed sulfide ores and their oxidized products, the silver-lead and zinc carbonate ores. The first ores were discovered in the outcrop of Blue limestone at the Little Johnny shaft. They were the usual oxidized ores typical of the large blanket deposits in the western part of the district. They contained much lead and considerable though varying quantities of silver, but very little gold and no zinc or copper, although zinc carbonate ore with more copper than usual was later found beneath some of them. These lead-silver ore bodies extended as far south as the No. 3 shaft and downward to the second and third levels, 300 to 350 feet below the surface, where they were most extensively developed.

Deeper exploration showed that the lead-silver ore was succeeded by blankets of highly siliceous gold ore. This ore contained 60 to 70 per cent of silica and consisted mostly of loosely compacted quartz crystals accompanied by a more solid cavernous iron-stained jasperoid. Its content of gold generally ranged from 1 to 4 ounces to the ton, and the gold could not be detected by panning; but all through the mine down to the seventh level pockets of ore rich in free gold were found, lots of a few to 100 pounds, containing 4 or 5 ounces to the pound, and one small lot containing 50 percent of gold. Some of these siliceous blankets graded into the oxidized lead-silver blankets, but other lead-silver blankets, so far as could be learned, were apparently isolated.

Near the third level the oxidized ore changed to pyritic ore, in which iron was usually in small excess over silica. In this respect it deferred from the oxidized siliceous ore, from which considerable iron had been leached. Its content of gold was generally less than half an ounce to the ton, but its silver content ranged as high as 40 ounces to the ton, and it uniformly contained copper, which in many shipments ranged between 8 and 15 percent. Some blankets of sulfide were found, but these were given little attention because of their low value, and their relations to the siliceous pyritic ore were not definitely determined. They were presumably similar to those in

[18] Idem, p. 511.

the Golden Eagle workings, described on page 40. The sulfide blankets in developed ground are most abundant between the third and fifth levels and have been worked as low as the seventh level; but some of the veins with which they are connected have been mined down to the bottom level, 1,300 feet below the surface. The blankets around shafts Nos. 1 and 2 are in Blue limestone, and those recently worked north and east of the Little Vinnie shaft are in White limestone. Around shaft No. 3, however, some of the sulfide blankets may be in the Weber (?) formation, which the southward pitch of the strata has brought below the fifth level. Farther south the Blue limestone has been downthrown along the east side of the Garbutt vein, and its position has not been determined, as the few crosscuts to the east have been in porphyry. The structure east of the Garbutt vein and south of the Modoc vein is obscure, but prospecting for ore bodies in the limestone there is justified. The upward-tapering wedge between the Garbutt vein and the Ibex No. 4 vein is also complicated by porphyry intrusions and little understood; it apparently deserves further exploration, but it may terminate upward below the base of the Blue limestone. [See sections on plate 28 (extra figures and plates)]

MAGNETITE DEPOSITS

On the west side of the Ibex No. 4 vein down faulting has brought the Blue limestone down to the sixth, seventh, and eighth levels, where it has been explored in the vicinity of the Ibex No. 4 and Hopemore shafts [See plates 57 (Chapter 9) **and 68**].

Near both shafts it is extensively replaced by bodies of sulfide ore and also by magnetite serpentine, which is not worth mining and therefore is but little developed. The magnetite-serpentine bodies are very irregular principally because of the irregular intrusions of Gray porphyry that form most of their boundaries.

The serpentine commonly forms casings around the purer masses of magnetite. The magnetite, described in detail on page 1 (Chapter 8), is accompanied by specularite, small amounts of pyrite, a little chalcopyrite, and usually manganosiderite. It contains 40 to 48 percent of excess iron, 1 to 4 ounces silver to the ton, very little gold, and usually less than 1 percent of copper. In some places it apparently grades into siliceous pyritic ore, but in others it is distinctly cut by the pyritic ore, and the apparent gradation may be due to subsequent replacement of the limestone at the margins of the magnetite. The magnetite bodies in some places are also confusingly mingled with bluish jasperoid or silicified limestone, which has often been mistaken for quartzite.

No magnetite bodies have been found below the eighth level near the Ibex No. 4 shaft, but the only workings below the Blue limestone are in porphyry, and nothing definite is known of the location or mineralization of the White limestone west of No. 4 vein.

The magnetite just east of the Hopemore shaft, in the Comstock workings, is of particular interest in showing the relations of magnetite to siliceous pyritic ore. It is above the seventh Ibex level, through which it was worked. When studied by Irving it had been opened for a length of 200 feet in a northwest-southeast direction and a width of 90 feet (**Figure 98**), but its limits had not been fully determined. It was bounded on the northeast by the Ibex No. 4 vein, and on the southwest it graded into limestone.

A raise was put up for 290 feet above the seventh level along the dip of the vein. The footwall of the vein was slickensided White porphyry, and the edge of the vein along it consisted of somewhat brecciated and partly oxidized ore. The hanging wall was magnetite replacing Blue limestone for 125 feet above the seventh level and Gray porphyry still higher, as shown in **Figure 99**. The vein continued upward between the two porphyries but was of too low grade for mining.

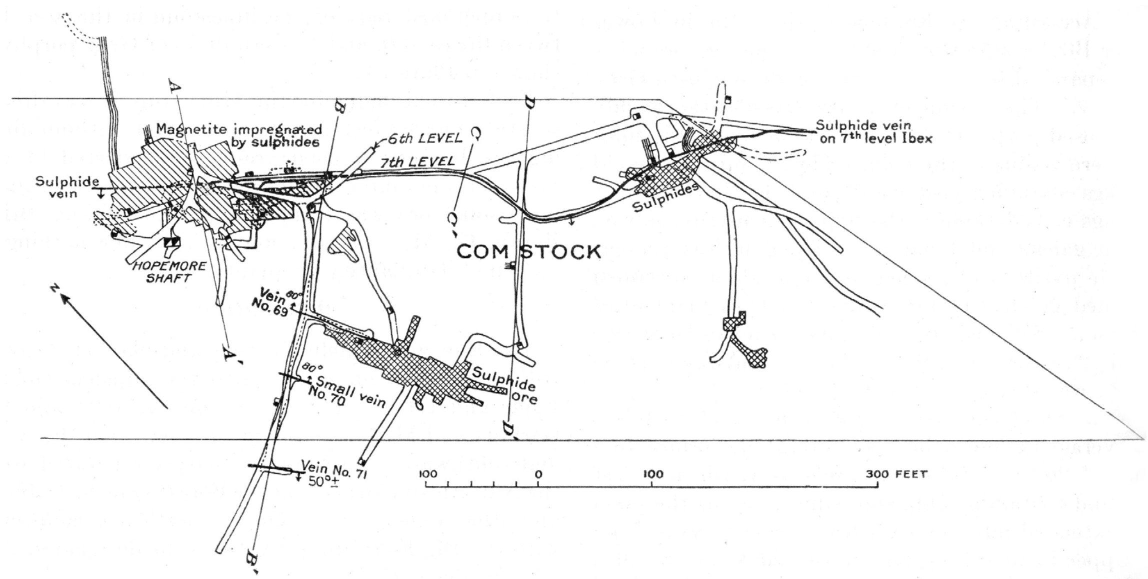


Figure 98. Plan of ore bodies in Comstock workings. A–A' etc., lines of sections in Figure 99.

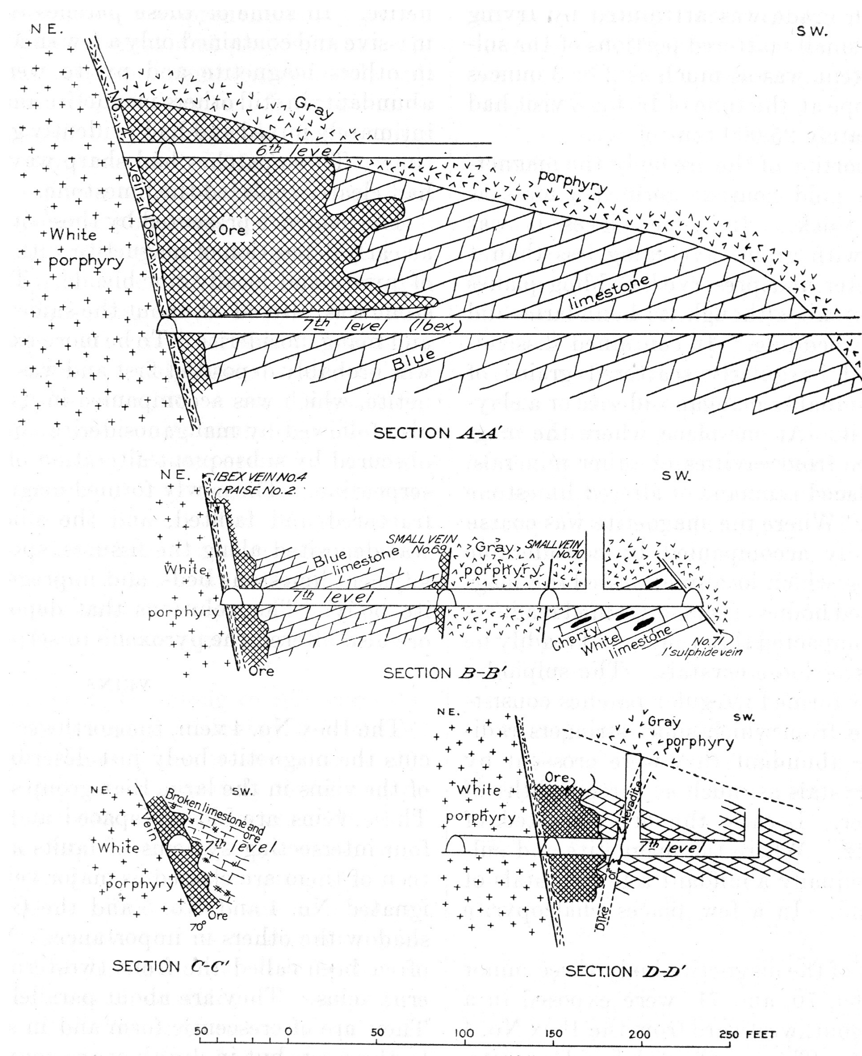


Figure 99. Cross sections of ore bodies in Comstock workings. For lines of sections see Figure 98.

The ore body adjacent to this raise extended 60 to 100 feet east from the vein fissure into the limestone, and it was stoped up for a vertical distance of 100 feet to the overlying Gray porphyry. The larger portion of the ore mined from it was composed of rather coarsely crystalline pyrite with some chalcopyrite and subordinate quantities of magnetite. This ore had a rather high content of gold and silver with some copper, and Irving attributed its high grade to enrichment. In small scattered portions of the sulfides the gold content was as much as 2 or 3 ounces to the ton. The stope at the time of Irving's visit had produced approximately 25,000 tons of ore.

In the unmined portion of the ore body the magnetite, with negligible gold content, formed a mass as much as 20 feet thick. In some places it was very fine grained, with grains averaging less than 1 millimeter in diameter and preserved bedding planes of the original limestone, although its boundaries did not conform to the bedding. It contained disseminated sulfides and irregularly scattered grains of white material, presumably manganosiderite or a clay-like replacement of it. At one place, where the magnetite was most free from cavities or other minerals it enclosed an unreplaced remnant of altered limestone or manganosiderite. Where the magnetite was coarse grained it was usually accompanied by considerable quartz and sulfides, which locally exceeded the magnetite. Some isolated bodies of coarse-grained magnetite were so loosely compacted that they could readily be crumpled to a mass of loose crystals. The sulfides where less abundant formed irregular patches consisting mainly of pyrite, from which short stringers radiated. Where more abundant they were crosscut by veinlets of pyrite crystals as much as three-eighths of an inch in diameter. Locally the ore consisted of sulfides and quartz. Where the magnetite and sulfides were about equally abundant a few crystals of vivianite were found. In a few places chalcopyrite exceeded pyrite.

To the southwest of the magnetite body three minor pyrite veins (Nos. 69, 70 and 71) were exposed in a crosscut extending southwestward from the Ibex No. 4 vein (figures 98 and 99). These contained, besides pyrite, considerable sooty chalcocite and some bornite and were coated with water-soluble sulfates of iron, zinc and copper.

At the beginning of this crosscut the ore along the southwestward-dipping Ibex No. 4 vein was 20 feet thick and graded into Blue limestone on its southwest side. It was free from magnetite. Barren limestone intervened between this vein and next vein, No. 69, 100 feet to the southwest, which dipped 80º NE, converging downward with the westward-dipping No. 4 vein, of which it may therefore have been a branch. Its footwall was slickensided Gray porphyry and its irregular hanging wall Blue limestone. It was 2 to 3 feet thick and was followed for some distance southeastward and upward to the blanket of sulfide shown in figure 98. Both vein and blanket were free from magnetite.

Veins Nos. 70 and 71, farther southwest, were also sulfide veins free from magnetite. The limestone between them was considerably serpentinized and contained irregular patches of sulfides mixed with magnetite. In some of these patches the magnetite was massive and contained only a few small grains of pyrite; in others magnetite and pyrite were about equally abundant; in still others magnetite and zinc blende were intimately mixed and had evidently grown at the same time. These patches had sharp wavy boundaries and had clearly replaced the limestone.

The evidence presented by these ore bodies indicates an early deposition of magnetite with a minor quantity of pyrite and locally zinc blende. The adjacent limestone was altered at about the same time to pyroxene and manganosiderite. To be more exact, the pyroxene was probably deposited first and was followed by magnetite, which was accompanied in its later stages and also followed by manganosiderite; but the evidence is obscured by subsequent alteration of the pyroxene to serpentine. The newly formed magnetite bodies were fractured and faulted, and the siliceous pyritic ore was deposited along the fissures, spread along certain adjacent limestone beds, and impregnated the magnetite body. The solutions that deposited the pyritic ore also altered the pyroxene to serpentine.

VEINS

The Ibex No. 4 vein, the northwestern part of which cuts the magnetite body just described, is the longest of the veins in the large Ibex group shown in plate 57 (Chapter 9). These veins are closely spaced and occupy at least four intersecting systems of faults and fissures. Fifteen of them are classed as major veins, but those designated No. 4 and No. 5 and the Garbutt vein overshadow the others in importance. Nos. 4 and 5 have often been called the front (western) and back (eastern) veins. They are about parallel in strike and dip. They are of crescentic form and in strike are concave to the west, but in dip they are convex to the west, as illustrated in figure 54 (Chapter 9). The No. 6 vein parallels the No. 4 on the west and is so closely connected with it by blanket replacement deposits that it may be regarded as an auxiliary vein. The No. 63 vein is without a doubt the upward continuation of the No. 4 vein.

The No. 4 vein extends from the thirteenth or Yak tunnel level upward to the third level, where it assumes a low angle of dip and connects with blanket bodies above. [See plate 28, sections K—K' and L—L' (extra figures and plates)] In its central part it bulges enormously to a lenticular form and in some places attains a width of 200 feet. This bulge is undoubtedly due to the ready replacement of shattered Blue limestone on the footwall side of the fault and where widest, on the seventh level, connects the No. 4 with the No. 6 vein. The length of the vein varies on different levels, but it is greatest on the seventh level, where the vein has been explored from a point 100 feet northwest of the Hopemore shaft for 2,800 feet to a point nearly 600 feet south of the Ibex No. 5 shaft.

The ore in the No. 4 vein was predominantly pyrite, part with a quartzose matrix and part without. It contained gold and silver and commonly considerable copper in the form of chalcopyrite. In the central bulge the ore consisted of pyrite crystals, single and in clusters, set in a solid grayish matrix of quartz or jasperoid. Where it was oxidized the pyrite crystals were removed, leaving a honeycombed rusty mass of quartz, in which the openings had the form of the dissolved pyrite crystals. Much of the partly oxidized ore consisted of a loose aggregate of pyrite crystals mingled with grains and crusts of quartz and loose particles of iron and copper sulfates. The vein was largely oxidized on the second level (vein No. 63) but consisted of sulfide ore south of the No. 3 shaft, where the country rock is “Weber grits”.

The No. 5 vein is relatively narrow, attaining a maximum thickness of about 15 feet. On nearly all levels it was followed on the strike for about 500 feet or somewhat less. Its ore was similar to that of No. 4 vein. It also passes into flat blanket bodies just above the second level. [See sections M—M' and N—N', plate 28 (extra figures and plates)]

The No. 1 vein appears to belong to this same system but was definitely known to Irving only on and above the first level, from which it extended almost up to the surface. It was extensively developed on the first level, where it had a known length of 860 feet. The No. 1 vein was usually from 6 to 12 inches wide in its productive portions but narrowed down to a mere streak in others. This vein was in porphyry throughout the larger portion of its length but passed into carbonaceous “Weber grits” to the south. In the porphyry the ore was all oxidized and had a high gold content, but in the “Weber grits” it was sulfide of comparatively low grade. The change was abrupt.

The No. 2 vein extends upward from the second level through the first to the C level, and its lowest exposed portion is well above the blanket bodies in the immediate neighborhood. Its greatest explored length is 350 feet. It belongs to a northeast-southwest group but appears to be of the same age as the crescentic veins Nos. 4 and 5. Little could be learned regarding it.

The No. 3 vein is a curved vein on the second level, which may be a continuation of No. 5. East of the No. 3 shaft is a complex group of small veins carrying pyrite and chalcopyrite. They are Nos. 14, 15, 16, 17, 32, 33, 34, 35, 36, 37 and 38. They form an interlocking series and are connected with the large blanket body on the third level. Their character may best be seen on plate 57 (Chapter 9) in plan and on sections O—O', P—P', Q—Q', [plate 28 (extra figures and plates)]. The No. 15 vein is probably a northward continuation of the Garbutt vein. Its northern part forks, and both forks (veins Nos. 14 and 15) curve sharply eastward and fall in line with the Modoc vein, to the east. The presence of these veins where the Garbutt and Modoc faults should join emphasizes the suggestion that prospecting is justified in the down-faulted limestone to the southeast of the junction.

The No. 7 is a north-south vein, which has been most extensively worked on the ninth and thirteenth levels. Its intersections with other veins have not been exposed. It dips eastward. The No. 8 is a minor vein known only on the ninth level. It dips 75º NE. The No. 8 a vein has likewise an easterly dip and has been worked on the eighth level.

The No. 10 vein, sometimes called the Hahnewald vein, is worked on the eleventh, twelfth, and thirteenth levels. It has a total known length of 806 feet on the eleventh level. It contains chiefly sulfides and resembles in most respects the other veins of the area but differs in producing from the Hahnewald stope a large amount of very rich gold ore. The gold was found as thin films in sheeted porphyry.

The No. 20a vein has been worked on the tenth level and thence almost up to seventh level, where it widens into a blanket body in limestone. Only its position on the tenth level is shown on plate 57 (Chapter 9). The vein is reached by a long crosscut eastward on the tenth level, and its north end lies about 150 feet southeast of the No. 2 Ibex shaft. It strikes slightly west of north, dips about 80º E., and has been followed for 380 feet, but its southward termination has not been reached, and on the north it terminates at a fault, beyond which its continuation has not been found. It is distinctly a filled fissure and not a replacement vein. It is from 3 to 9 inches or more thick and consists of pyrite, mostly coarse grained, mixed with chalcopyrite and considerable chalcocite and accompanied by no gangue. The filling, for the most part, adheres tightly to the well-defined walls. The walls, wherever observed, are porphyry. The ore in the vein was of good grade, containing 10 percent of copper, 30 to 40 ounces of silver, and half an ounce of gold to the ton, and little or no zinc. The blanket body connected on the seventh level contained 15 to 20 percent of zinc but was much poorer in copper, as downward enrichment was there unable to take place so readily as in the vein itself.

All these veins, both large and small, either connect with or terminate in blanket deposits of greater or less size, and unquestionably fill the conduits through which solutions arose to replace the strata with ore.

Golden Eagle Veins and Blankets

The Golden Eagle ground lies to the north and northwest of the Ibex No. 2 shaft. It comprises the Little Vinnie claim and parts of small claims immediately north and northeast. The only part of it studied was that leased to John Cortellini and others in 1922, at and below the Ibex seventh level. The country rock there exposed includes the White limestone, the Parting quartzite, the lower part of the Blue limestone, and several sills of bleached porphyry. Correlation of this porphyry as White porphyry is in accord with plate 13 (extra figures and plates), but owing to the similarity of the altered White and Gray porphyries in this vicinity some of the sills may be bleached Gray porphyry. The strata undulate to some extent, but the prevailing structure is synclinal [figure 55 (Chapter 9)], with a northeast limb dipping at least 45º SW and a southwest limb dipping 20-30º NE.

The principal vein in this ground is the Ibex No. 9, called the “Big vein”, which fills a fault fissure trending north-northeast and dipping 70º E. on the seventh level and below. It sends out branch veins at a few places and is also connected with blanket replacement deposits in White limestone. The No. 9 vein projected upward would connect with old blanket stopes on the fourth and third levels.

Near the Little Johnny shaft, 50 and 100 feet east of the No. 9 vein, there are two veins which parallel the No. 9 in strike but dip 70º W. They are developed along the strike for 80 feet or more and also connect with blanket replacement deposits. The easternmost vein, locally called the "east vein," is intersected by a small vein striking about S. 80º E., and ore was followed in a sinuous course along the general line of intersection for 140 feet in the "corkscrew" raise. The raise was not accessible at the time of visit, but the local structural conditions suggest that the raise stopped at or near the base of a porphyry sill.

West of the No. 9 vein two linear groups of blanket replacement deposits have been developed along the courses of small veins, as shown in plate 57 and figure 55 (Chapter 9). So far as records show, only one small replacement body (on the third level) has been found in the Blue limestone above them, and the ground appears undeveloped and promising; but here, as elsewhere, records of old workings may not have been kept. The ground west of these linear groups of ore shoots is also worthy of prospecting for ore of similar grade and extent.

Available data on the ore shipped from this ground are given below. The ore shipped in 1922 came from the replacement shoots on the Ibex seventh level, but the sources of earlier shipments are not definitely known.

Contents of ores shipped from the Little Vinnie and adjoining claims, 1902-1922[a]

Year	Operator	Class of Ore	Gold (oz./ton)	Silver (oz./ton)	Copper (percent)	Lead (percent)	Zinc (percent)	Silica (percent)	Iron (percent)
1902	Golden Eagle Co. (Little Vinnie Claim)	-	.040	20.0	0.9	-	-	-	-
1905	do	-	2.50	8.0	.003	0.3	-	-	-
1906	do	-	.18	7.0	-	5.5	-	-	-
1911	New Vinnie Co.	Dry siliceous sulfide	.30–2.50 .704	5.2–11.7 7.05	- .8	- -	4.9–8.1 6.5	40.0	0.18
1911	do	Dry iron sulfide	.38	9.5	.7	1.15	6.3	-	-
1915	do	Dry siliceous sulfide	.408	10.81	[b]1.8	[b].5	-	-	-
1917	do	Dry siliceous oxide	1.249	4.79	.8	.1	-	52.7	.17
1918	do	Dry siliceous sulfide	.573	5.40	.5	.7	-	-	-
1919	do	Dry siliceous oxide	.936	1.57	-	-	-	57.7	21.3
1919	Golden Eagle Lease	do	1.656	4.83	.4	.05	-	55.2	21.4
1920	New Vinnie Co.	Dry siliceous sulfide	.900	5.93	.6	-	-	-	-
1921	do	Siliceous copper oxide	.784	13.96	2.5	.4	3.0	44.0	24.0
1921	Golden Eagle Lease	Dry siliceous sulfide	.788	12.72	2.2	.9	-	-	-

[a] "Oxide" ore includes all containing less than 10 percent sulfur.
[b] Wet.

Garbutt Vein

The Garbutt vein [plate 57, Chapter 9) and figure 29 (extra figures and plates)] is one of the most continuous in the district. It has been developed for a horizontal distance of nearly 2,000 feet and to a maximum depth of 1,300 feet. So far as developments show, it forms the east boundary of the Ibex group from the Ibex No. 3 shaft southward. Its northern part trends a few degrees east of north and approaches a sub-group of short crescentic veins that curve sharply from northward to northeastward and fall in line with the Modoc vein (plate 57, Chapter 9). In the vicinity of the Garbutt shaft, about 300 feet from its northernmost openings, the Garbutt vein curves to a south-southwest direction, which it follows for 1,300 feet before it again curves to a few inches in width. About 800 feet south-southwest of the Garbutt shaft the Garbutt and Ibex No. 4 veins come very close together at a very low angle, and the Ibex No. 4 merges with the South Ibex stockwork. The No. 4 passes within 20 feet of the stockwork and is connected with it by mineralized fractures.

The dip also varies. From the surface down nearly to the tenth level (Ibex seventh level), a depth of 700 feet, it is about 70º W. From the tenth to the twelfth level (150 feet) it is vertical. Then the vein thins to a mere streak and extends for a short distance eastward in a horizontal position before it assumes a dip of 60º-65º E., which persists down to the bottom (Ibex thirteenth) level.

The succession of wall rocks [figure 29, (extra figures and plates)] has been determined only where the vein was accessible in 1919 and 1922. The vein had been reported to lie entirely in the porphyry except at its lowest levels, but the upper levels are in “Weber grits” cut by porphyry sills. The vein fissure, as shown on the fifth (Ibex fourth) level, is clearly a fault between a footwall of Gray porphyry and a hanging wall of “Weber grits,” but the amount and direction of faulting can not be determined. From the fifth to the thirteenth (Ibex tenth) level the west wall could not be studied. Neither could the east wall between the seventh and fourteenth levels. On the thirteenth level the west wall is Cambrian quartzite overlain by the dark “transition shales”, which dip steeply eastward near the vein owing to down-drag during faulting. The east wall on the thirteenth and lower levels is mainly Gray porphyry with a few enclosed large slabs of dark shale that have been dragged into a moderate to steep eastward dip. Although the Blue and White limestones have been found along the Ibex No. 4 vein 300 feet to the west, no limestone has been reported along the Garbutt vein. The position of these formations on the west side of the vein is approximately indicated in figure 29 (extra figures and plates), but the corresponding position on the east side can not be reliably indicated until it is known whether the dark shales on the lower levels are certainly “transition shales” at the top of the Cambrian quartzite and not deeply down-faulted “Weber shales” and until the structural details of the Gray porphyry intrusions are better understood.

Ore has been mined from the outcrop on the Negro Infant claim, 1,000 feet south-southwest of the Garbutt shaft, down to the lowest levels, but the better grades of ore have been found in cylindrical or cigar-shaped shoots that pitch southward at a very low angle, parallel to the pitch of the beds in the walls. So far as accessible workings afforded evidence, the vein pinches where one or both walls are shale and the shoots are found between these pinches. The shale beds in the “Weber grits” as well as the Cambrian “transition shales” are effective barriers to ore shoots. The ore is pyritic and is typically though irregularly enriched. The higher grades are commonly crumbly and stained black by chalcocite; the unenriched ore is hard granular pyrite, much of which is too lean to pay for milling.

On the fifth (Ibex fourth) level the vein merges with a blanket replacement deposit in coarse-grained “Weber grits”, which has been mined for 200 feet or more along the strike and for an average width of 50 feet. Its thickness ranged from 8 feet or more down to a few inches. About 20 feet west of the shaft it pinches and plunges to the next stratum of grit below, and 50 feet farther west it pinches to a thin layer which joins a minor vein parallel to the main Garbutt vein. This shoot, like those within the vein, is controlled by shaly beds above and below the replaced beds.

Although the vein has been prospected thoroughly through a great part of its extent, detailed mapping of the shaly and other beds and the porphyry intrusions is likely to indicate promising ground that has not been adequately explored, both at places along the main vein, and at places where minor veins intersect limestones or lime beds of the "Weber grits". As the bottom level is the lowest that can be drained by the Yak tunnel, exploration at greater depth will be more expensive; but the presence of enriched ore at the bottom level should encourage deeper development if detailed mapping of the strata indicates that the structure is favorable for ore shoots.

Drifting southward has ceased on the different levels after continuing for some distance along very narrow parts of the vein, and it thus appears that mineralization has been weaker to the south of the South Ibex stockwork than it has been to the north, especially in the structurally complex ground around the Ibex Nos. 3, 4, and 6 shafts. Crosscuts westward from the southernmost exposures of the Garbutt vein on the second and Negro Infant levels have exposed some small veins of approximate north-south trend, one of which has been followed for 150 feet on the Negro Infant level without marked success. The Agwalt tunnel, about 300 feet below the Garbutt second level, has also crosscut the ground in this vicinity, evidently without opening veins of workable size. In spite of these adverse indications, however, further prospecting may be more successful. The turning and pinching of the Garbutt vein and the presence of the small parallel veins west of it suggest that there has been a break in the continuity of fissuring and that at a moderate though indefinite distance farther south the fissures may resume a south-southwest trend toward the Printer Boy and Lillian deposits. The amount of bleached mineralized rock on the surface also suggests that at some place in this area there may be one or more veins of workable size and grade. The local structural details, however, are too little known to serve as definite guides for prospecting.

South Ibex Stockwork

The South Ibex stockwork is 800 feet southwest of the Garbutt shaft. It is of lenticular outline, and its long axis strikes N. 33º E. and dips 68º-70º W., nearly parallel to the dips of the Garbutt and Ibex No. 4 veins which are east of it [plate 57 (Chapter 9)]. Its strike length is 330 feet and its dip length 550 feet. A considerable part of it is as much as 60 feet thick, and it is locally as much as 120 feet thick where offshoots are present. This stockwork was discovered on the Garbutt second level 25 feet west of the Ibex No. 4 vein and was followed down to the seventh level. It was worked from 1915 to 1919. The production ranged from 200 to 250 tons a day and shipments averaged 0.21 ounce of gold and a few ounces of silver to the ton. Some shipments contained 1 ounce or more of gold to the ton. This deposit is of special mineralogic interest because of the presence in it of the tungsten minerals wolframite and scheelite.[19]

The ore body occupies a shattered zone in "Weber grits," which contain sills of Gray porphyry. The relative proportions of the two rocks are not definitely known, but the "Weber grits," which have been locally called "quartz porphyry," predominate. Both rocks are silicified, sericitized, and pyritized, and their identity in places is uncertain without microscopic study. In the most thoroughly altered rock the minerals are more coarsely crystallized than elsewhere, and the identity of the rock is completely destroyed.

The ore occurs as a network of veinlets and irregular bunches which bind together the fragments of altered rock. Ore of shipping grade occupies the outer and upper parts of the ore body and encloses a lenticular core of milling ore, which decreases in value inward. On the

[19] Fitch, R. S., and Loughline, G. F., Wolframite and scheelite at Leadville, Colo.: Econ. Geology, vol. 11, pp. 30-36, 1916.

second level a well-defined footwall with a thin gouge is exposed for 50 feet, and recent work has disclosed at one place a slickensided hanging wall. In general, however, there are no distinct walls, and the ore grades outward into material of similar appearance but of low value. This prevailing absence of walls prevents a correlation of the shattered zone with the intersections of fissures, but it is surmised that the major dimension has been controlled by one or more fissures parallel to those containing the Garbutt and Ibex No. 4.

Since the foregoing was written, Augustus Locke has examined the South Ibex deposit and noted similarities between it and certain other ore bodies, notably that of the Pilares mine at Nacozari, Mexico. According to his interpretation, rising solutions were at first able to enlarge their conduits by dissolving the wall rock. The removal of support by this process allowed the wall rock to be shattered by pressure of the overlying rock mass. The solution penetrated the shattered mass, and dissolving and shattering accompanied by slumping continued as long as the solution could dissolve rock matter without depositing an equal volume of material in its place. The limits of the slumped mass of corroded fragments are marked by vertical slickensided fissures, along some of which the amount of slumping can be measured. The inclination from vertical of the poorly exposed walls of the South Ibex mass may be attributed to tilting during post-mineral faulting. The stage of corrosion was followed by one of partial replacement, and finally by deposition of ore and gangue in crusts around the fragments.[20] This explanation has much to commend it, but evidence in the South Ibex deposit does not show to what extent shattering was due to complex pre-mineral fracturing as opposed to fracturing induced by the corrosive action of the solution. There is no doubt as to the corrosion of rock along the complex fractures, once they were formed.

The principal vein minerals are quartz, pyrite, wolframite, and scheelite. Sericite in parallel growth with quartz lies along the walls of the veinlets. The quartz occurs mostly as typical colorless crystals 2 inches in maximum length, which line cavities and are in part enveloped by or in parallel growth with pyrite. Locally, where the crystals are crowded together, the quartz has a massive milky appearance.

The pyrite is well distributed throughout the veinlets and occurs mostly in groups of rather large crystals. Single crystals of cubic form with edges 5 inches long have been found. The prevailing type of crystal is a combination of the cube and pyritohedron with several less common forms represented by small faces. Some of the striations on the cube faces are unusually large and are more aptly described as ridges. Besides the parallel growth with quartz, the pyrite shows in places a marked intergrowth with wolframite. Parallel growth with scheelite, though noted, is not common. The pyrite ranges from very hard to crumbly. The crumbly variety, especially where tarnished or coated with black films, has the higher gold content. The large crystals as a rule are poor in gold, but they have proved very efficient as detectors in the radio-telephone.

The two tungsten minerals are found along the walls of vugs and are too thinly and irregularly scattered to be regarded as a commercial source of tungsten. They are distributed throughout the middle part of the western pay shoot of the ore body and are closely associated; but the scheelite is more abundant on the upper and the wolframite on the lower levels.

[20] Locke, Augustus, Formation of certain ore bodies by mineralization stoping: Econ. Geology, vol. 21, pp. 431-453, 1926.

Contents of ores shipped from the Garbutt lode and South Ibex stockwork, 1913-1922

Claim and class of ore	**Year**	**Ore (tons)**	**Gold (oz./ton)**	**Silver (oz./ton)**	**Copper (percent)**	**Lead (percent)**	**Zinc (percent)**	**Silica (percent)**	**Iron (percent)**	**Sulfur (percent)**
St. Crispin:										
Average Contents-			0.15	25.0	2.0	0.2	-	-	-	-
Representative										
Lots—-			.09	35.45	-	2.35	-	-	-	-
Dry siliceous			.11	2.15	1.1	-	-	-	-	-
sulfide-			1.3	11.45	1.4	-	-	-	-	-
do—-	1913	2,253	.64	13.84	2.2	-	-	-	-	-
do—-			.46	20.10	3.8	-	-	-	-	-
do—-			.27	40.22	4.5	-	-	-	-	-
Copper sulfide-			.29	46.65	5.9	-	-	10	36	-
do—-										
do—-										
Dry Siliceous sulfide—	1914	185	.115 .175	10.65 5.55	- -	- -	5.1 1.0	23 21.6	31.6 35.7	- -
do—-	1916	22	.635	5.82	.2	1.3	-	-	-	-
do—-	1917	132	.299	8.20	.9	.2	-	-	-	-
do—-	1918	93	.232	10.71	2.3	-	-	-	-	-
Dry Iron sulfide—-	1918	22	.218	11.05	.28	-	-	-	-	-
Garbutt:										
Dry siliceous sulfide										
Range	1914	2,089	.085-.475	3.55–30.75	.2–1.8	?-2.35	.8–4.8	-	-	-
Average			.200	10.70	1.0	.9	2.8	-	-	-
Dry siliceous sulfide	1915	2,636	.786	.726	[a].4	[a]1.7	-	-	-	-
do—-	1916	155	.233	12.39	2.5	.5	-	-	-	-
Dry siliceous oxidized	1916	79	.612	1.03	-	-	-	-	-	-
Dry siliceous sulfide	1917	870	.541	10.41	1.5	1.2	-	-	-	-
do—-	1918	646	.289	11.21	1.8	.6	-	-	-	-
Dry iron sulfide	1918	85	.062	5.08	.5	-	-	-	-	-
do—-	1918	434	.312	11.57	1.2	.9	-	-	-	-
Dry siliceous sulfide	1919	429	.787	8.35	.8	-	-	-	-	-
do—-	1920	122	.114	14.96	1.6	.6	-	-	-	-
Dry iron (?)sulfide	1920	72	.699	12.10	-	.8	-	-	-	-
Dry siliceous oxidized	1921	50	.026	3.18	-	-	-	57	19	-
Dry siliceous sulfide	1922	139	1.243	12.59	1.7	2.15	-	-	-	-

Maud Hicks:										
Range Average Representative Lots—- Dry iron do—- Copper Iron	 1914	 3,836	.08- .56 .120 .08 .29 .11	3.2– 38.15 19.73 26.15 9.7 36.45	.08- 3.00 1.1 .7 .7 3.0	- 0.2 - - -	1.9–6.2 3.5 2.2 - -	9.5– 25.9 16.3 9.5 25.9 14.9	29.9– 38.7 35.0 38.7 29.9 35.5	- - - - -
Dry sulfide	1917	76	.118	2.88	.5	.1	-	-	-	-
Dry siliceous sulfide	1918	61	.875	8.51	.9	-	-	-	-	-
Dry iron sulfide	1918	213	1.138	8.40	.6	.5	-	-	-	-
Dry iron oxidized	1918	27	.230	7.37	.6	-	-	27.9	32.3	-
Dry siliceous	1919	540	.306	7.11	.4	-	-	-	-	-
Copper-iron sulfide	1920	41	.054	12.17	3.1	-	-	-	-	-
Springfield:										
Dry siliceous sulfide	1917	20	.461	6.15	.3	1.1	-	-	-	-
do—-	1919	49	.745	5.33	.6	-	-	-	-	-
Mary Alsberg:										
Dry iron sulfide —- Range——- Average—-	1914	1,962	.19– .73 .294	3.75– 19.00 8.16	.4–2.25 .6	0–1.3 .9	1–2.5 1.8	12.6– 28.0	29.9– 37.9 35.1	- -
Lead-copper sulfide	1915	1,222	.611	4.37	5.6	25.5	-	-	-	-
Dry sulfide	1916	189	1.374	4.55	.5	.5	-	-	-	-
do—-	1917	170	1.965	3.54	.1	-	-	-	-	-
Dry siliceous sulfide	1918	126	3.337	3.36	.6	-	-	-	-	-
do—-	1918	181	2.478	2.55	.1	-	-	-	-	-
do—-	1919	55	.611	4.89	.5	-	-	-	-	-

[a]Wet

—table continued on next page

Contents of ores shipped from the Garbutt lode and South Ibex stockwork, 1913-1922—continued.

Claim and class of ore	Year	Ore (tons)	Gold (oz./ton)	Silver (oz./ton)	Copper (percent)	Lead (percent)	Zinc (percent)	Silica (percent)	Iron (percent)	Sulfur (percent)
Nonie:										
Dry iron & siliceous ores Range——- Average—-	1914	7,691	.19– 1.97 .846	.35– 11.60 2.61	- .2	- .2	.0–1.20 -	15–69.6 -	14.8– 38.4 -	- -
Dry siliceous sulfide (representative lots)	1915	14,013	.876 1.495 .66 .81 .96 .98 .655 1.17 2.62	.58 1.00 .90 .55 .70 .95 .65 .70 .60	[b].05 - - - - - - - -	.006 - - - - - - - -	- - - - - - - - -	- 63.1 53.8 51.4 53.2 43.0 54.4 37.8 -	- 18.1 21.2 23.3 21.3 25.4 19.2 28.1 -	- 11.7 21.7 24.4 23.7 27.7 21.6 31.1 -
Dry siliceous oxidized Average—— Representative lot	1915	6,850	1.05 1.21	.49 .90	.1 -	- -	- -	- 68.8	- 15.2	- 9.3
Dry siliceous sulfide	1916	2,390	0.682	0.81	0.02	-	-	-	-	-
Dry	1916	6,399	.705	3.05	.2	0.7	-	-	-	-
Dry siliceous oxidized	1916	235	.568	.67	.1	.8	-	-	-	-
Dry sulfide	1917	3,844	.824	1.47	.2	.1	-	-	-	-
Dry siliceous sulfide	1918	1,387	1.519	1.76	1.7	-	-	-	-	-
do—-	1918	22	1.586	2.36	.8	-	-	-	-	-
Dry iron sulfide	1918	149	.626	.62	.3	.5	-	-	-	-
Dry siliceous sulfide	1919	735	.832	1.65	.7	-	-	-	-	-
Dennis:										
Dry sulfide	1917	49	2.811	3.33	.1	-	-	-	-	-
Dry siliceous sulfide	1918	54	19.24 8	7.02	.4	-	-	-	-	-
Dry sulfide	1918	51	4.504	4.29	-	-	-	-	-	-
Dry siliceous sulfide	1919	206	2.067	4.57	.02	-	-	-	-	-
Dry sulfide	1920	42	1.221	2.76	-	-	-	-	-	-
St. Paul:										
sulfide	1917	22	1.205	7.00	-	-	-	-	-	-
Dry siliceous oxidized	1917	140	1.629	7.32	-	.3	-	5.75	19.4	-
Dry siliceous sulfide	1919	276	.496	7.32	-	.07	-	-	-	-

[b]Recovered.

Modoc Vein

The Modoc vein, worked through the Elk, Donovan, and Modoc shafts, lies in the northeastern part of Breece Hill, east of the Ibex and northeast of the Garbutt (plate 27, not in this report). The country rocks north of the fault consist of a thick capping of Gray porphyry underlain by Blue limestone, Parting quartzite, and White limestone, which dip on the average 33º SW. The rocks south of the fault consist of another thick sheet of Gray porphyry within the Weber (?) formation. The vein strikes N. 72º E. and dips 73º SSE.

The Elk shaft passes through 60 feet of glacial "wash" and 450 feet of Gray porphyry and continues for 150 feet in "Weber shales" and "Weber grits". Levels have been run at depths of 400, 490, 550 and 645 feet. The first three levels extend to an ore shoot in the vein, between a footwall of Blue limestone and a hanging wall of the Weber (?) formation. The vein is 50 feet wide on the first level and 30 feet wide on the second and third levels. It consists mainly of extremely crushed "Weber grits," "Weber shales," and Gray porphyry bounded by well-defined walls. On the first and second levels this material is replaced and cemented by silica into a solid mass of siliceous ore containing disseminated cerusite in the oxidized zone and disseminated s below. It has been followed in the Elk mine for 350 feet along the strike. Any limestone fragments in the vein have been completely replaced. This ore shoot had a vein-like form and terminated abruptly against the wall of silicified limestone on the north and that of the Weber (?) formation and Gray porphyry on the south. It has been followed for 200 feet down the dip but was evidently not productive above the Blue limestone.

The silicified Blue limestone or jasperoid in the footwall contains enough metal to justify exploration. Toward the Ibex No. 1 shaft a few small irregular deposits of oxidized lead-silver ore have been found between the Blue limestone and the overlying Gray porphyry, but have not been profitably worked, as were the larger deposits close by the Ibex No. 1 and Little Johnny shafts.

The workings in the Ibex mine immediately west of Modoc vein were not accessible, and the continuation of the vein and its relation to the vein of the main Ibex group could not be established.

Forest Queen and Minor Veins Near By

The Forest Queen shaft, on the crest of the northwesterly slope of Breece Hill, was sunk to a depth of 627 feet, and a drill hole continued to a total depth of 1,353 feet. Three levels were run from the shaft at depths of 400, 450, and 600 feet (**Figure 100**).

The country rock found in the mine is entirely porphyry, although the drill hole and the Yak tunnel below cut the lower members of the "transition shales" between the White limestone and the Lower quartzite. At 70 feet east of the shaft, on the third level, a drift cuts the Weston fault, the fissure of which has at this point a width of 10 feet. This fault is also cut in the Yak tunnel about 150 feet farther west and shows a similar width [plate 15, Yak section (not in this report)].

A vein that strikes N. 6º E. and dips 73º W. was found on the first and second levels just west of the shaft. It was about 6 feet wide. In the two upper levels it consisted for the most part of a yellow clayey oxidized material which contained from 3 to 5 ounces of silver and from half an ounce to 1½ ounces of gold to the ton, showing here and there remnants of the original s, mainly pyrite. One wall was rather ill defined, but the other was sharp.

On the 600-foot (third) level the ore contained a large mass of enriched sulfide ore, carrying as much as 5 per cent of copper. Its gold and silver contents are not known.

The vein here is exactly parallel to the Weston fault both in strike and dip, but it pinches out above the level of the Yak tunnel. The parallelism of strike and dip in this vein strongly suggests that it fills a minor fissure of the Weston fault zone, but no mineralization within the main fault zone has been reported. This part of the Weston fault may have been formed subsequent to ore deposition. The Ella Beller and Clear Grit veins, in Iowa Gulch, occupy minor fissures formed at the same time as the Weston fault.

Several minor veins have been cut in the Agwalt, Tribune and Yak tunnels, in the western part of Breece Hill. Throughout these workings the porphyry contains large quantities of pyrite, and the joint planes in the rock are characteristically lined with crystalline pyrite, which in some places makes out into the body of the porphyry in irregular replacement bunches. In addition to the joint planes, definite veins have also been found, as indicated on plate 56 (Chapter 9). Four such minor veins were found in the Tribune tunnel at distances of 400, 900, 1,000, and 1,025 feet from its junction with the Agwalt tunnel. They had a north-northeast strike and a northwest dip and ranged from 1½ to 6 inches in thickness. They were filled with crystalline pyrite and showed here and there small quantities of galena. None of them had been followed along the strike at the time of Irving's visit, but the large quantity of water that entered the workings when they were cut seems to indicate that they were extensive. The material contained in them all assayed more than 1 ounce in gold to the ton and some assays ran as high as 2½ ounces. One vein carrying some galena assayed as high as 8 percent of lead and 36 ounces of silver to the ton. The galena enveloped pyrite crystals. The porphyry throughout the Agwalt tunnel is heavily impregnated with pyrite and assays from 0.04 to 0.05 ounce of gold to the ton. What is believed to be the Weston fault was cut in the northwestern end of the Agwalt tunnel and consisted of a broken zone about 2 feet wide, filled with clay selvage in which were included layers of fine crystalline auriferous pyrite. Another strong fissure which is believed by some to be the Weston fault, is cut by the Agwalt tunnel 280 feet southwest of its junction with the Tribune tunnel.

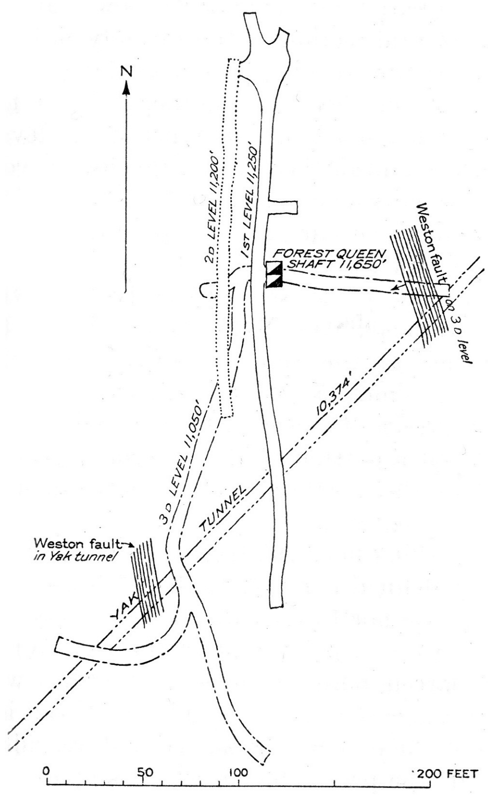


Figure 100. Plan of workings of Forest Queen shaft, showing Weston fault and fissure vein.

Antioch Stockwork

The Antioch mine (**Figure 101**) is on the west brow of Breece Hill 2,300 feet S. 18º W. from the Ibex No. 4 shaft. The bedrock surface, which is nearly bare, slopes westward at an angle of about 10º but steepens rapidly toward the west.

The workings of the mine are shown in figure 101. The main surface workings consist of a large open quarry of roughly elliptical form with its longer axis trending N. 17º E. The longer diameter measures 215 feet, and the shorter 150 feet. The walls are precipitous but converge downward, and at the deepest point the open cut is approximately 200 feet deep. The altitude of the north rim of the quarry ranges from 11,595 to 11,630 feet. The mine was worked at first by simple quarry methods, but the open cut soon became too deep, and an adit 200 feet long was driven from a point 60 feet vertically below the quarry rim. A second adit 600 feet long was later driven from a point 160 feet below the quarry rim. From the end of this adit, an incline leads downward to a stope floor 30 feet below the second tunnel level. A third tunnel, the Agwalt tunnel, only a portion of which is shown in figure 101, was then driven from White Gulch and a drift run from it to the ore body 559 feet below the quarry rim. Practically no mining was done from this tunnel because the presence of clay in the ore prevented profitable operation.

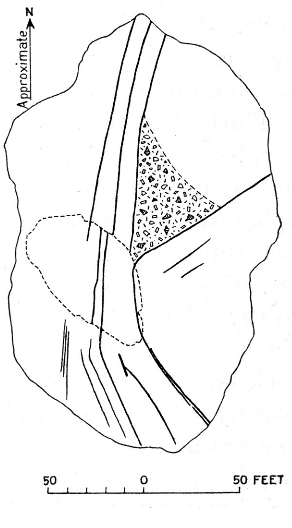


Figure 101. Plan of Antioch mine, looking down into the quarry from the surface, showing the north-south fracture system intersecting the northeast system and a mass of brecciated porphyry between the two systems.

The Antioch mine was one of the earliest important gold-producing properties, aside from placers, to be worked in the district. It was first worked by Frank Brooks, apparently in 1885, and appears, from such records as could be procured, to have been continuously productive in 1885 and 1886. From that time until 1889 it was worked intermittently. During the first two or three years it produced from 15 to 100 tons daily. The ore is reported to have assayed $10 in gold to the ton and to have yielded $7 to the ton on the plates in the stamp mill. It was hauled to a small mill in White Gulch but during a part of the time was handled in the Oro mill. The working was profitable as long as mining costs were low. According to Emmons, the open cut lies about 140 feet west of the Weston fault, the exact position of which north of the Garibaldi tunnel was known to him. Irving regarded the fissures in the Tribune tunnel as part of the Weston fault zone. According to a map of the Agwalt tunnel furnished by John Harvey, of Leadville, a strong sheer zone in Gray porphyry was cut 250 feet west of the Tribune tunnel and is believed by him and others to be the Weston fault. If so it reaches the bedrock surface close to the west edge of the Antioch open cut. The following description is based on Emmons' notes:

The country rock of the Antioch ore body is intrusive porphyry, the greater part of which is Gray porphyry; but at many points in the mine the fine-grained to aphanitic White porphyry is found. The two porphyries appear in places to be merely textural variations of the same mass. Abrupt changes from one porphyry to the other are also frequent, but these appear to be the results of faulting rather than the intrusion of one rock into the other. Some evidence exists of a Gray porphyry enclosing angular fragments of an earlier fine-grained rock, but this intrusion appears to be of small size and may not represent the main mass of Gray porphyry in the vicinity.

The ore body in the Antioch consisted of a mass of broken or brecciated porphyry cemented by a fine-grained reddish iron oxide, which filled fractures and interstices between fragments of porphyry and stained the fragments themselves. This iron oxide was evidently derived from pyrite, but oxidation was complete from the surface to and below the lowest workings. Emmons states that the gold content varied in direct proportion to the amount of this matrix of iron oxide. In some places the iron oxide was free from boulders of porphyry for considerable distances. The best ore was near the surface and continued to a depth of about 90 feet. Below that depth there appears to have been less limonitic matter and a greater volume of porphyry fragments.

The drift from the Agwalt tunnel found the ore well defined between the same walls as in the upper workings, though its thickness was somewhat less. The fragments of porphyry were in much larger proportion and the red matrix much less; but the matrix was even richer than that above and contained as much as 3 or 4 ounces of gold to the ton when separately assayed. It did not amalgamate, however, and contained too much clay to be economically separated by washing.

The ore body appears to have been an irregular chimney-shaped mass; wider at the top and with approximately the cross section indicated by the present rim of the quarry but narrowing downward. Successive horizontal sections of the ore body, as indicated by the stopes and workings, are irregular and do not lie vertically one beneath another. Thus the ore extended farther south on the upper tunnel level than at the surface and farther east in the lower workings from the second tunnel level.

The ore body occurs at the intersection of two systems of fractures, each with parallel sheeting (figure 101). One of these, apparently that which is dominant, trends about N. 15º E. but bends toward the southeast at the south end of the quarry. The other trends about N. 60º E. Little can be learned about the physical features of the ore body previously exploited, but a portion of the breccia mass remains unmined in the northeast angle between the two fracture systems.

In the working floor 190 feet below the quarry rim is a sharply defined northerly wall which has been followed from the northwest corner of the stope for 125 feet eastward to a point east of the surface rim (figure 101). A barren mass of breccia 2 to 3 feet wide extends into the east wall here. The west wall is fairly regular, but the east wall is jagged and irregular.

Although the permeable ore body is oxidized down to the lowest levels, the adjacent porphyry, even in the upper tunnel (60 feet below the quarry rim), contains unaltered pyrite is disseminated grains and veinlets.

BIG FOUR GROUP
Location and General Features

The Big Four group of veins lies beneath the hillside a short distance north of the Ibex mine. Immediately north of the Ibex group the hill is steep and precipitous, but the slope becomes nearly horizontal before reaching the bed of the gulch. On the steep hillside the Blue limestone and lower strata, cut by porphyry sills, are steeply upturned against the rather ill defined Colorado Prince fault, but the angle of dip decreases southwestward toward the Ibex workings. Northeast of the fault the only formations present are Cambrian quartzite and pre-Cambrian granite separated by a sill of White porphyry, and the large pipes of rhyolitic agglomerate shown in plate 27. The developed veins in this group are the Big Four, Big Four East, Gold Basin, Louise, No. 20-b Ibex, South Winnie, St. Louis, and Colorado Prince Nos. 1 and 2 to a west-northwest system.

The spaces of ground which intervene between these veins and in which veins have not so far been opened up are rarely less than 400 feet, being thus much wider than those in the Ibex group. Many extremely small mineral bearing veins, however, which have not been mapped, lie between the major veins. Some veins of the north-northeast system dip eastward and some westward, and they thus appear more nearly like a normal conjugate system than those of the Ibex group.

The two small west-northwest veins of the Colorado Prince occupy what are believed to be parallel slips of the Colorado Prince fault, but the mineralization extends along the strike for comparatively short distances. The reverse character of the Colorado Prince fault and its interpretation as the result of shearing in the limb of an anticline imply that this fault, like the Tucson fault, in Iron Hill, is for the most part too tight to permit circulation of ore-forming solutions.

The eastward and northward extensions of the veins of the Big Four group is limited by the large neck of rhyolitic agglomerate, which cuts some veins abruptly and either enters between the walls of others, breaking up the contained ore, or cuts across them as dikes. In a direction a little west of north lies a comparatively large area of pre-Cambrian granite in which little extensive exploration has been carried on. This group of veins may be eventually found to continue in that direction.

With the exception of the Big Four vein, the veins of this group are short and narrow and are not yet known to extend upward to the bedrock surface. The St. Louis vein is known to terminate upward before reaching this surface, but the exact nature of its connection with the blanket ores of the Miner Boy and Kentucky mines is not known.

The Big Four mine is opened by a shaft whose collar has an altitude of 11,348 feet (old datum). The shaft has been sunk to a depth of 600 feet, and from this point a drill hole was put down for an additional 600 feet. The records of the shaft are unsatisfactory, as no clear distinction has been drawn between the “transition shales” beneath the White limestone and the various porphyries which have been intruded into them. The geologic section must therefore be inferred largely from the information gained from the surrounding workings. The workings of the Big Four mine have not at any time been accessible to the writers, and the accompanying description is therefore compiled from the statements furnished by the management.

The collar of the shaft is 20 feet south of the outcrop of the Colorado Prince fault. The fault here dips northward at an angle of 51º. The geologic structure is shown by section B—B', plate 28 (extra figures and plates). On the south side of the Colorado Prince fault the upper portion of the shaft is in the White limestone or the underlying “transition shales”, which are turned upward at a steep angle against the Colorado Prince fault. It is probable that the rocks cut in the upper first 320 feet of the shaft belong mainly in the “transition shales” beneath the White limestone, although they are recorded by the company as porphyry. These shales have been frequently mistaken for porphyry. The workings of the third level of the Ibex mine, which have been visited, extend northward to the workings of the Big Four mine and clearly indicate the sedimentary nature of the geologic formations cut in the upper levels of this mine. The record of rocks cut by the drill hole below the shaft is also open to question. The material supposed by the company to be the lower sheet of White porphyry and the quartzite beneath it may prove to be granite, and if so the succession conforms to that on the south side of the Rawlings fault.

The country rocks north of the fault are not cut in any of the workings of the mine, all of which lie within the upturned strata on the footwall side of the fault. The Rawlings fault crosses the shaft at a depth of 190 feet. The dip slip along this fault has not been determined in the Big Four mine but is about 175 feet in the Fannie Rawlings mine (section A—A', plate 28- extra figures and plates). This fault meets the Colorado Prince fault at the bedrock surface immediately west of the Big Four shaft.

The workings of the Big Four are shown in **Figure 102** and also on plate 27 (extra figures and plates). Levels were run eastward and westward from the Big Four shaft at depths of 190, 246, 306, 385, 455, 524, and 599 feet.

Big Four Vein

Two veins were found in the Big Four mine. The comparatively small and unproductive “East vein” was cut on the second level 300 feet east of the shaft and followed for 150 feet. It was also worked on the fourth level for more than 300 feet. Its general trend, as shown by these workings, is N. 25º E. and its average dip 27º E. The wall rocks of this vein are exclusively Lower quartzite and White porphyry.

The second or main vein of the Big Four mine reaches the bedrock surface under 60 feet of glacial “wash,” close by the shaft (figure 102). It has been followed downward from the bedrock surface for 670 feet and has been worked on six levels. The average strike of the vein is N. 26º E., but, as shown on plate 56 (Chapter 9), it has a number of marked though gradual curves. This main vein extends from the southern boundaries of the Big Four property, where it is widest, to the point where it is cut off by the body of agglomerate that lies between the Gold Basin and Big Four shafts. It is also interrupted by three dikes of agglomerate, which are evidently branches of the main pipe. The vein in the upper levels from the bedrock surface down as far as the third level (250 feet) is practically vertical. From the third level downward it gradually assumes a westward dip of about 75º. On the strike the vein has been explored for a distance of 700 feet. At the south end it continues in undiminished strength but passes into the property of the Ibex Co., by which it had not been worked up to the time of Irving’s visit.

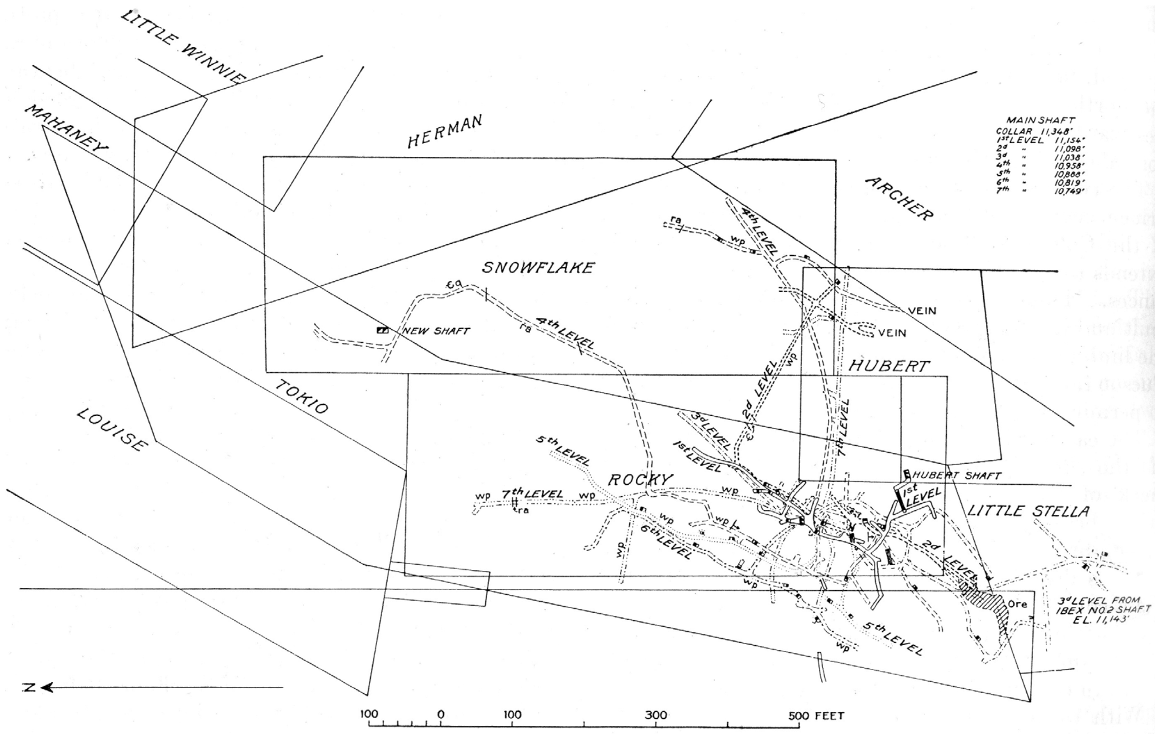


Figure 102. Map of workings of Big Four, Fannie Rawlings, and Gold Basin mines. ra, Rhyolitic agglomerate; pw, White porphyry; €q, Cambrian Quartzite.

The wall rocks of the vein include in descending order the "transition shales" beneath the White limestone, the underlying part of the Lower quartzite, and a great thickness of intrusive White porphyry. The vein, so far as worked, cuts the "transition shales" only in the upper levels in the southern portion of the mine southwest of the Colorado Prince fault. The thickness of the vein ranges generally from a few inches to 6 or 7 feet and in one place attains 10 feet. The vein is wide and productive in the upper portions and widest at the south boundary of the property. It gradually narrows to the north and downward. At the sixth level it becomes practically barren.

Between the second and third levels the vein splits into several portions, which were worked separately. These, however, pinch downward except one, which continues as a single vein on the fourth, fifth and sixth levels. Several horses of granite occur between the walls of the veins on the second and fourth levels.

The ore bodies consist of a mixture of s or oxides and crushed and broken rock. The ore at some places occupies the whole width of the fissure, at others only a part of it.

In several places the ore is reported to have branched out along certain beds in the sedimentary rocks, but these branches were subordinate in tenor and quantity to the main vein. The original ore consisted chiefly of pyrite with some chalcopyrite and a little blende, and galena. Above the third and fourth levels the ore was oxidized. From the lower limit of oxidation down as far as the vein had been explored the ore was irregularly enriched.

The range in contents of the ores based on smelter returns for different years is shown below:

Range in content of ores from Big Four mine

[Zinc not determined]

Year	Class of ores	Gold (oz./ton)	Silver (oz./ton)	Copper (percent)	Lead (percent)	Silica (percent)	Iron (percent)
[a]1903	(?)	0.59–8.5	4.4–130	1.0–13.9	([b])	([b])	([b])
1908	Sulfide Oxide	.1–10.945 .105-1.972	23.20–79.45 1.35–18.50	3.50–8.00 ([b])	[c]1.15–4.3 [d]0.5–1.2	([b])	([b])
1909	(?)	.120–1.950	.95–79.75	(?)–9.00	(?)–3.75	([b])	([b])
[e]1914	Oxide Copper	.090–2.430 .410	.85–10.00 23.5	(?)–.75 3.35	([b]) ([b])	34.8–92.8 76.6	0.5–26.5 2.2
1915	Oxide	.090–2.115	.83–3.35	([b])	([b])	89.3–92.4	2.9–3.9

a Does not include one lot of less than half a ton which contained 20.956 ounces of gold and 68.0 ounces of silver to the ton and 6.9 percent of copper.
b Not Determined.
c Wet.
d Dry.
e Contains less than 6 percent of sulfur.

According to these figures the vein originally contained ore of two classes—the pyrite-chalcopyrite ore and the highly siliceous ore. The richer ores were mined in 1909 and earlier years. In 1908 the sulfide ore was much more enriched than the oxidized ore. The records do not show from what parts of the vein the ores were mined. Most of the ores were presumably siliceous. The contents of the ore shipped in 1914 do not suggest enrichment unless to a minor extent in gold. The ore with high iron content must have been much oxidized, whereas that with minimum iron content and the one lot of copper ore may have been mostly un-oxidized, though classed commercially as oxide ore. The most siliceous ores shipped in 1914 and 1915 evidently consisted of quartz with 6 to 8 percent of pyrite, perhaps partly oxidized, and their gold varied independently of the other metals.

Study of individual shipments of ores represented in the above table shows the general independence of gold, although certain of the richer ores suggest a relation between gold and copper. The average content of silver, especially in oxidized ores, varies roughly with that of gold, but individual shipments both of oxidized and sulfide ores show no such relation. Shipments in 1903 showed a close though not constant relation between silver and copper, which suggests the presence of silver-bearing tetrahedrite or the precipitation of silver by chalcocite.

According to information obtained by Irving, the average gross value of the ore in 1909 and earlier years was $45 a ton and the average net value $3 a ton.

Gold Basin Vein

The Gold Basin shaft, or, as it is sometimes know, the Lower Big Four, is on the south side of Evans Gulch, about 600 feet north-northeast of the Big Four shaft. It has been sunk to a depth of 310 feet, passing through about 25 feet of “wash,” 200 feet of Cambrian quartzite, and 85 feet of White porphyry. Two levels have been driven from the shaft, one at 240 feet and the other at 310 feet below the collar (plate 27 –extra figures and plates).

A small vein was found in the White porphyry west of the shaft. On the lower level it crossed the drift 14 feet west of the shaft and on the upper level 50 feet west of the shaft, which gives a dip of approximately 53º E. It has been followed northward on the lower level and both northward and southward on the upper level and has been explored for a total length of 350 feet. It has not been followed upward into the quartzite. The White porphyry along the vein is usually very dense and hard and not appreciably altered except in the immediate vicinity of the vein.

The vein occupies a sheeted zone, which in the upper level has a maximum width of 3 feet. This zone contains small stringers of pyrite and chalcopyrite, which have become completely oxidized in portions of the upper level. At the lower level the vein consists of a few small stringers ranging from half an inch to 2 inches in width, and its width as a whole has decreased. Some of the sulfide stringers were very rich, containing as high as 27 ounces in gold to the ton and in places sooty chalcocite brought the tenor in copper up to 7 percent; but the small size and irregularity of the vein have prevented any extensive and profitable operations.

South Winnie Vein

The South Winnie shaft is on the south slope of South Evans Gulch, 170 feet north-northeast of the Miner Boy tunnel. The shaft is sunk for a depth of 307 feet in White porphyry close to the southern margin of a large body of agglomerate, which is cut by the shaft 2 feet from the bottom. The contact between the agglomerate and White porphyry is nearly vertical but inclines slightly toward the south. Its general trend near the shaft is east, but a short distance west of the shaft it curves northward.

Two drifts have been run at a depth of 202 feet, one eastward and one southeastward from the shaft. (**Figure 103**) The southeast drift branches 160 feet from the shaft. The northeastern branch cuts a vein 178 feet east of the shaft. This vein has an average strike of N. 26º W. At the level where it was first found it was included between walls of White porphyry and extended for a distance of 150 feet from its narrow southern extremity to the agglomerate body where it was abruptly cut off.

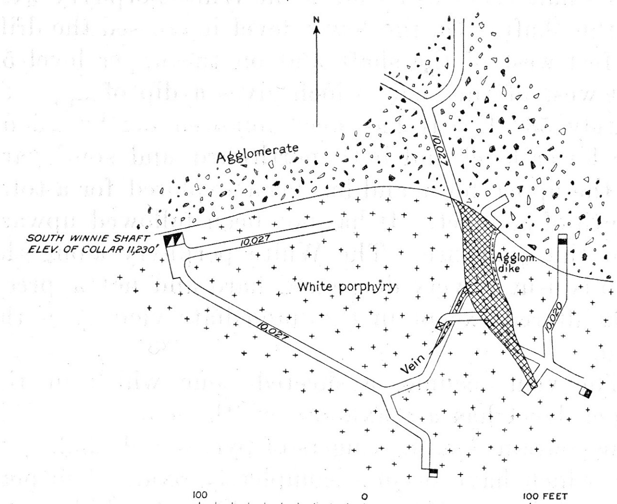


Figure 103. Plan of South Winnie mine, showing abrupt termination of ore at contact with agglomerate. Figures show altitude of drifts above sea level.

A dike of agglomerate extends southward from the main mass along the east wall of the ore body, and disconnected dike-like masses of agglomerate are also found along the western wall. These apophyses from the agglomerate do not extend to the narrow southern extremity of the ore body. The upper part of the ore body is reported to lie between walls of limestone, presumably a mass enclosed in the White porphyry; but as the geologic map (plate 27 – extra figures and plates) shows Cambrian quartzite to be the bedrock surface above the ore body, the presence of the limestone is not readily explained. It is possible that a casing of massive carbonate has been mistaken for limestone.

In form, the ore body is a lens-shaped mass, which is widest on the 202-foot level (figure 103), where it has a maximum width of 22 feet. Followed upward in a raise it was found to narrow to 6 feet, and a winze sunk on it for 50 feet proved that it narrows downward, also. Toward the south it pinches to a very narrow streak.

The ore in the upper portions of the ore body consisted of a mixture of manganese and iron oxides, lead carbonate, and a considerable amount of zinc carbonate or silicate. Throughout this oxidized material were scattered residual fragments of pyrite, galena, and sphalerite. In the lower and wider portions of the ore body the ore was chiefly. The richest portion of it lay along the western or footwall side, and a few assays of the ore from this portion showed as much as 40 ounces in gold to the ton. Streaks of galena along the footwall cut the main body of the ore and, when separated from the rest of the ore by sorting, carried 5 ounces of gold and 60 ounces of silver to the ton.

The center of the ore body consisted of low-grade pyrite. The richest portion of the ore body lay immediately adjacent to the agglomerate mass, presumably because at this point the loosely compacted nature of the agglomerate had permitted the maximum amount of enrichment.

St. Louis (Colorado Prince) Vein

The St. Louis, or Colorado Prince, mine has been idle most of the time since the early days of the Leadville district but was being worked by lessees in 1924. It is on the south side of South Evans Gulch, one-fifth of a mile northwest of the Big Four mine. The mine is opened by the St. Louis tunnel, whose portal is 60 feet above the bottom of the gulch, just below the very steep escarpment of Cambrian quartzite. The tunnel extends S. 9º W. for 500 feet, has a slightly more westerly trend for 200 feet, and finally continues S. 17º W. for 460 feet.

The rocks cut in this mine are shown on section J—J', plate 16 (extra figures and plates). The tunnel first passes through the White porphyry, which lies between the Lower quartzite and the granite, the contact dipping southward at low angle. It then penetrates the overlying Cambrian quartzite and the "transition shales" at its top. At 400 feet from the portal the Colorado Prince fault, containing 2 feet of breccia and dipping north, is exposed.

Thirty feet south of this fault is a small parallel fissure that also shows evidences of faulting. Both the Colorado Prince fault and the small parallel fissure contain ore and have been plotted on plate 56 (Chapter 9) as veins. About 100 feet beyond the Colorado Prince fault is a second fault with a similar dip and strike. The rocks between these two faults have a much steeper southward dip than those to the north. Beyond the more southerly fault the tunnel is entirely in sedimentary rocks. These form a local anticline whose crest is about 50 feet south of the southern fault and whose axis is nearly parallel to the strike of the fault. The tunnel, after passing through the crest of the anticline in White limestone, enters the Parting quartzite and Blue limestone.

The St. Louis vein was cut 175 feet from the portal of the tunnel in the White porphyry. Where found it trends nearly north, almost at right angles to the strike of the faulted and folded sedimentary rocks and their included porphyry sheets. Beyond this point it turns a little westward and was followed in the driving of the tunnel. Its dip is vertical, and its width is from 3 to 6 inches. It passes without interruption from White porphyry into Cambrian quartzite, through the Colorado Prince fault and through the small parallel vein to the south. It finally enters the "transition shales," where it becomes lost.

The pay streak within the vein is from 2 to 3 inches thick and is usually bounded by a zone of broken quartzite and porphyry which lies between it and the adjacent solid rock. It is significant that where the vein cuts the Colorado Prince fault no displacement is observable, although the fissure containing the vein was evidently formed later than the Colorado Prince fault. The ore shoots in this fault and its smaller parallel fault is here called the Colorado Prince No. 1 and No. 2 veins. They are branches of the St. Louis vein and extend for 20 feet along the strike on each side of it. Farther from the main vein the two faults are barren.

At the point where the vein enters the "transition shales" a winze was sunk for 15 feet, and the vein was found to continue this far down without interruption. It was reported by Emmons [21] that this vein widens to 20 feet in the "transition shales" at the top of the Cambrian quartzite but that part of the mine was not accessible during the resurvey.

The ore from the St. Louis vein consisted of broken material, mostly oxidized. The vein had no very distinct walls. Below the drift, where it joined a cross vein, it contained a solid filling of chalcopyrite with a corresponding high content of copper accompanied by 2 or 3 ounces of gold and 190 ounces of silver to the ton. A little lead was also present.

At the junctions with the two cross veins the ore in the main vein was richer than elsewhere. This difference may have been due to enrichment by waters whose downward circulation was concentrated along these junctions. Blanket deposits of oxidized lead-silver ore have been found at the contact of Blue limestone and White porphyry in the uppermost workings of the mine, and one was reopened by lessees in 1924; but their location and dimensions in general are not known, and they can not be accurately indicated on the map. Other deposits were mined beneath "wash" in the remnant of White limestone on the northeast side of the Colorado Prince fault in the Colorado Prince, Miner Boy, and Black Prince mines.

WINNIE-LUEMA GROUP

Winnie-Luema Vein

GENERAL FEATURES

The Winnie-Luema vein is the longest, most thoroughly explored, and most productive single vein in the Leadville district. It extends for nearly 4,000 feet in a northerly direction from the north edge of the Ollie Reed pipe of agglomerate in South Evans Gulch, which cuts it off on the south, into the southern part of Prospect Mountain, where it appears to die out in a number of diverging fissures. The upper part of the vein, above its productive part, is probably cut off by the Josie pipe of agglomerate near the Silver Spoon shaft. The vein was first developed in its southern part, through the Winnie shaft, and later and more extensively in its northern part, through the Luema (Valley) shaft and Silver Spoon tunnel. Its middle part has also been somewhat developed, but no data on this part of the vein have been obtained.

The vein occupies a sheeted fault zone, from which mineralized branch faults, some of which are connected with blanket replacement deposits in limestones, extend in an east-northeast direction, as shown in plates 27 (extra figures and plates) **and 69** and **Figures 104-107**. Owing to lack of exploration on the west side of the vein, it is not known whether similar branch faults are present there also, but the changes in altitude of formation boundaries in the Luema and Silver spoon ground suggest their presence, as shown in figure 107. Minor veins east of the main vein have been worked close by the Luema and Silver Spoon shafts.

The main vein strikes due north in the Winnie ground, but its northern part curves gradually westward, and its north end strikes N. 25º W. The undulations along its course are inconspicuous. The dip is vertical in its southern part, and the deviations from vertical to east and west in the Luema and Silver Spoon workings (figures 104, 105) are very slight.

The accompanying figures, together with plate 27 (extra figures and plates), show that all the rock formations of the district are found at one place or another along the walls of the vein. The "Weber grits," however, are present only where the northernmost part is opened by the Silver Spoon tunnel.

[21] Op. cit., pp. 504-505.

The strata throughout the length of the vein dip from 15º to 40º, averaging about 25º, north to northeast. The dip is north in the Silver Spoon but north-northeast to northeast elsewhere. The steeper dips along the vein, especially on the east side, are due to drag.

White porphyry forms a sill between Cambrian quartzite and underlying granite in the southern part [plate 14, sections B—B' and C—C' (extra figures and plates)], and another at the top of the Blue limestone in the northern part Two small sills are present within the Cambrian quartzite and White limestone in the Luema mine. An irregular sill of Gray porphyry lies between the Cambrian quartzite and White limestone in the southern part. A dike of porphyry, highly altered, impregnated with pyrite, and cut by stringers of ore, has been reported to lie in the main fault zone and to constitute the vein in the Winnie ground, and altered porphyry has also been reported in the vein in the Luema ground; but except for the sills shown in figure 104 no porphyry was found in the Luema. In its stead there was a large amount of white sericite and clay-like material filled with fine grains of quartzite, which resembled decomposed porphyry containing quartz phenocrysts but was in reality a gouge derived largely from granite, quartzite, “transition shales,” and limestone. Very little limestone unreplaced by ore remained, however. Close examination may prove that the reported porphyry in the Winnie ground is gouge also. If it is in reality a porphyry, it is exceptional and must be younger than both White and Gray porphyries; the fissure that it occupies must have been formed subsequent to the intrusion of Gray porphyry and reopened subsequent to the intrusion of the dike and prior to deposition of the ore.

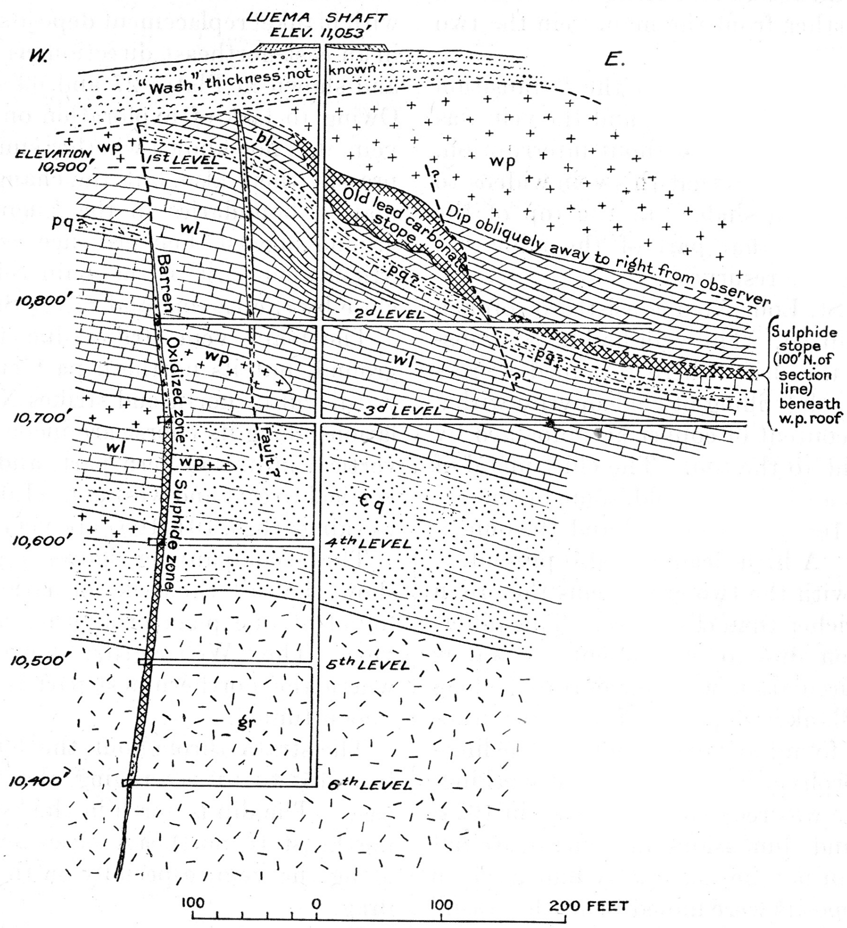


Figure 104. East-west section through Luema shaft. wp, White porphyry; bl, Blue limestone; pq, Parting quartzite; wl, White limestone; €q, Cambrian quartzite; gr, granite

There has been little opportunity for observation of formations on the west side of the vein. It is known that the formation cut by the Blue Ribbon and Chautauqua shafts are Cambrian quartzite and White limestone, dipping eastward, but there has been no opportunity to examine the two properties in detail. On the east side of the vein the rocks in the Winnie mine have a much steeper dip than on the west side, apparently having been dragged upward in the fault movement.

The main vein is itself slightly offset by a later fault exposed 1,100 feet north of the Winnie shaft at the extreme northern limit of the Cleveland workings. This fault is vertical and has trend of N. 60º E. Its northern wall has been offset 12 feet eastward and perhaps 200 feet downward, but lack of exploration leaves the amount of movement in doubt.

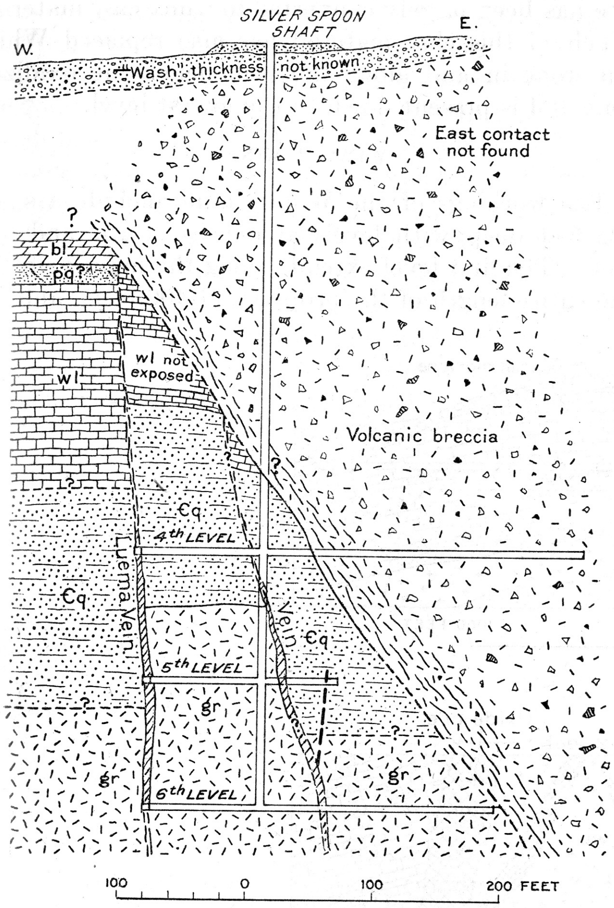


Figure 105. East-west section through Silver Spoon shaft. bl, Blue limestone; pq, Parting quartzite; wl, White limestone; €q, Cambrian quartzite; gr, granite

The vein ranges from 4 to 40 feet in thickness and consists of the gouge material, resembling decomposed porphyry crisscrossed by small veins and bordered by larger veins of high-grade ore. In some places, particularly in the north end of the Winnie and along the middle levels of the Luema mine, ore occupies the full width of the vein. There is little or no evidence of cavity filling, and the ore occurs as bands or lenses formed by replacement of the crushed rock along fractures in the fault zone. Typical vein quartz is inconspicuous on the whole, and the highly siliceous gangue is mainly the gougy material. The main ore shoots end along the shale beds at the top of the quartzite and in the White limestone, although certain favorable beds within this shaly zone have been replaced by ore both along the main vein and along the branch faults.

The ore above the third level of the Luema and the first level of the Winnie shafts is thoroughly oxidized, and some oxidation has occurred down to the lowest levels. The oxidized ore consists of brown loosely compacted ocherous material with isolated bunches and spots of sericite. The ore, so far as seen, is a mixture of black zinc blende, pyrite, galena, and chalcopyrite, named in the order of abundance. The general prevalence of zinc blende is also borne out by a large number of assays and smelter returns, but the rich gold-copper ore along the west wall of the main vein in the Winnie ground may have been low in zinc and considerably enriched by chalcocite. In both the Winnie and the Luema-Silver Spoon ore shoots pyrite and chalcopyrite are more abundant at the lower levels, where the wall rocks are quartzite and granite, than at higher levels, where limy "transition shales" and White limestone predominate. They are found in irregularly scattered bunches and grains with the blende and galena, and also as comparatively pure streaks; but as a whole they are rather evenly distributed at any one level. Galena is practically absent in some places and relatively abundant in others, especially in the wider and most thoroughly metallized parts of the main vein and in the adjoining blanket deposits a short distance from the connected branch faults.

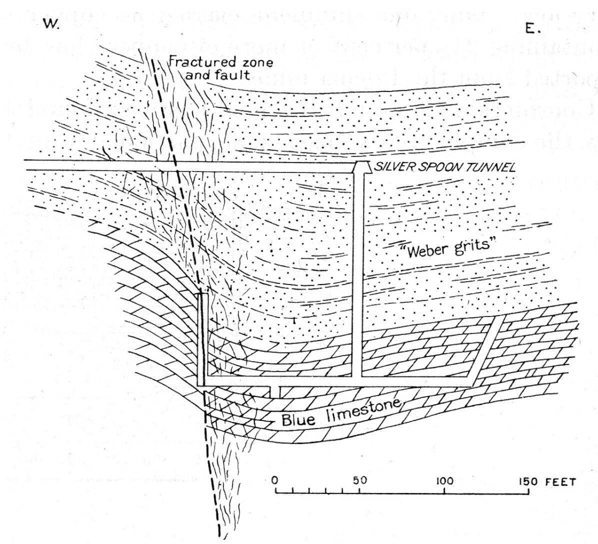


Figure 106. N. 78° E. section at north end of Silver Spoon tunnel, 1,475 feet north-northwest of Silver Spoon shaft.

Throughout the vein there is considerable black, sooty material, some of which may be the copper oxide tenorite [22] but most of which is chalcocite. It is very conspicuous in places, but available analyses and assays indicate that the copper content of the ore, except along the west wall of the vein in Winnie ground, is very low. Only one shipment classed as copper ore (containing 2½ percent or more of copper) has been reported from the Luema mine.

Considerable leaf and wire gold has been found below the completely oxidized zone, particularly in the Winnie workings, from which shipments of remarkably rich ore were made. The range in content of gold and other metals is shown in the detailed descriptions of the mines. Manganese is shown in only a few of the analyses and averages only 0.5 percent, except in iron-manganese oxide ore shipped from the Luema. This ore is very low in gold, and it is probable that in this as in other veins of the district manganese has been instrumental in the downward enrichment of gold.

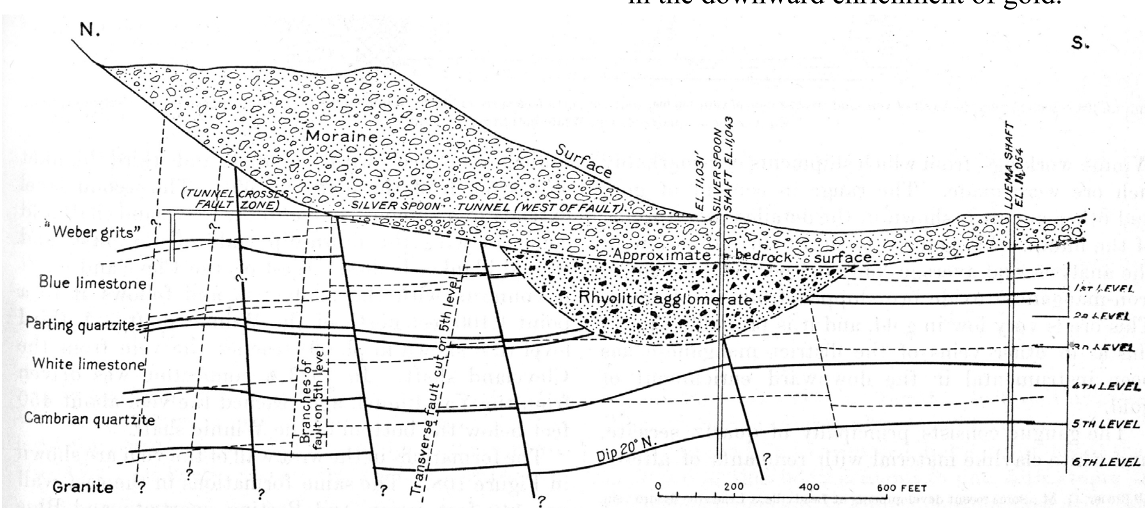


Figure 107. Longitudinal section showing variations in amount of displacement of Cambrian quartzite on both walls of Luema fault fissure.

[22] Butler, G. M., Some recent developments at Leadville; a Leadville fissure vein: Econ. Geology, vol. 7, p. 318, 1912.

The gangue consists principally of quartz, sericite, and white clay-like material with remnants of altered wall rock. Well-crystallized quartz is inconspicuous. Carbonate gangue is rare in the productive parts of the vein, but may be present in and around the associated replacement bodies in White limestone. Sericite has been largely converted to white clay material. Much of this clay material has also replaced White limestone in and along the vein below the oxidized zone and is present down to the lowest level.

WINNIE MINE

The workings of the Winnie mine include a shaft 322 feet deep, with levels at depths of 252 and 322 feet. The first level extends along the main vein for the entire length of the property (1,400 feet), and its branches connect with the first and third blanket stopes north of the shaft (plate 69). The second level extends in a sinuous course to the Cleveland shaft and connects with the down-dip ends of the first and second blanket bodies. West of the Cleveland shaft it connects with the main vein and follows it to a point 1,100 feet north of the Winnie shaft. A third level (not shown in plate 69) reaches the vein from the Cleveland shaft. In 1923 a connection was driven from the Yak tunnel, and reached the vein about 45 feet below the bottom of the Winnie shaft.

The formations in the west wall of the vein are shown in **Figure 108**. The same formations in the east wall are 140 feet lower, and Parting quartzite and Blue limestone cut by a White porphyry sill are present above the first level for 200 feet northward from the shaft; but White limestone and Cambrian quartzite and the intervening Gray porphyry are the only wall rocks exposed along the two levels. According to Philip Argall[23], who examined the mine in 1905, the first level follows the footwall of Cambrian quartzite for 700 feet and then passes along the Gray porphyry, which had caved. High-grade enriched sulfide ore was extensively stoped along the footwall. From 220 to 480 feet north of the shaft and 65 feet above the level the ore along the footwall joins a blanket replacement deposit of siliceous oxidized ore in White limestone, which has also been extensively stoped, although a little ore remains in pillars and in places around the edges. It is not known whether the west limit of the stope marks the limit of mineralization or only of high-grade ore.

The sulfide ore on the second level belonged to two classes—rich gold-copper ore and mixed sulfide ore. The gold-copper ore formed a seam 6 inches to 2 feet thick along and near the footwall. Only a few remnants of the footwall vein were left, and crisscrossing stringers of similar ore were present in the middle of the vein (figure 108).

Samples of ore of this class, collected by Mr. Argall, were assayed, and the results are shown on the first three lines in the following table. The smelter returns on carload lots, listed in the table, were furnished by the owners to Mr. Irving. The contents of gold, silver and copper in three of them indicate a high degree of enrichment and doubtless very selective mining. Failure to record the copper, lead and zinc contents in all assays prevents a thorough comparison of the ore in the main vein with the ore in the connected blanket replacement deposits.

[23] Written communication.

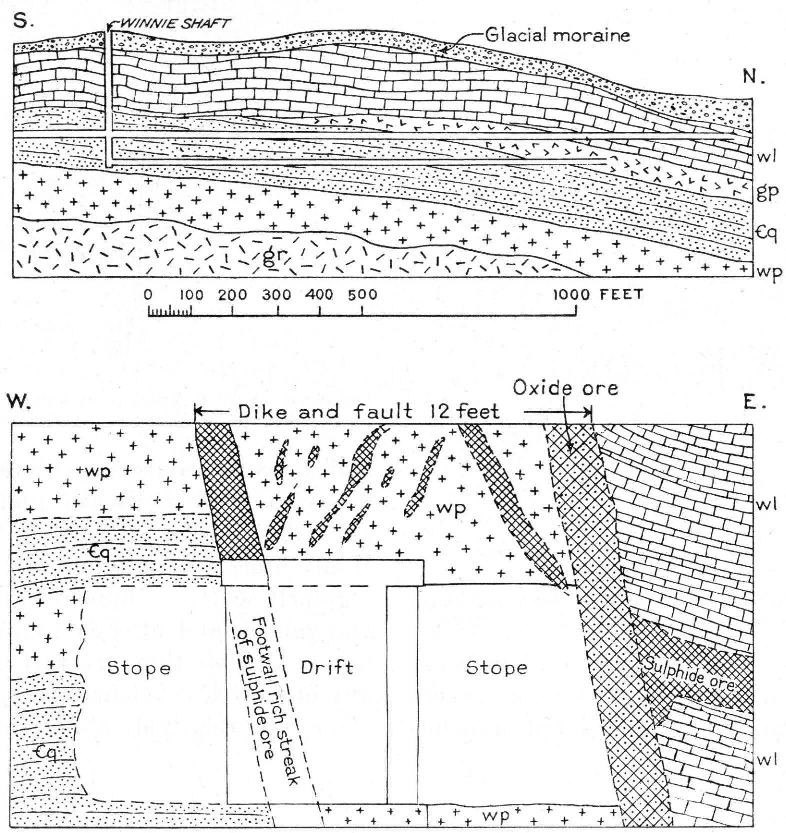


Figure 108. Section along footwall of vein and cross section of vein 140 feet south of north face of second level, Winnie mine. wl, White limestone; gp, Gray porphyry; €q, Cambrian quartzite; wp, White porphyry; gr, granite

Assays and smelter returns of ore from Winnie mine

	Gold (oz./ton)	**Silver (oz./ton)**	**Copper (percent)**	**Lead (percent)**	**Zinc (percent)**
Along Gray porphyry footwall (1 foot thick)	0.65	3.5	-	-	-
Along quartzite footwall (1.5 feet thick)	3.54	6.1	-	0.7	26.0
Stringer in quartzite hanging wall	2.18	32.0	-	4.6	20.7
Carload lots, main vein: First-grade ore	18	180	10.0	-	-
Second-grade ore	7	105	10	-	-
Third-grade ore	3	50	-	-	-
Fourth-grade ore	.9	40	-	-	-
Ore from minor parallel vein	8.40	76.7	11.5	4.5	9.5

The other class of ore was found near the hanging wall of the main vein and in the connected replacement deposits in the White limestone. It is represented by the following assays, in only one of which copper was determined:

Assays of mixed sulfide ore from hanging wall of lode and connected replacement deposits in the Winnie mine

	Gold (oz./ton)	Silver (oz./ton)	Copper (percent)	Lead (percent)	Zinc (percent)
First replacement body north of Winnie shaft: 1 carload lot	1.0	?	3.0	10.0	-
Samples along north wall- Range———	0.30–1.32	2.0–13.4	-	0.6–6.8	3.7–31.6
Average——	.59	5.0	-	1.7	10.0
Hanging wall of lode close by replacement body (average)	.50	5.0	-	6.0	15.0
Replacement body at Cleveland shaft: Range———	.10–.54	2.6–7.0	-	6.3–22.9	7.0–24.5
Average——	.289	4.4	-	12.0	18.7
Small shoot near vein west of Cleveland shaft Range———	.09–.34	2.1–7.0	-	2.3–12.9	8.3–21.8
Average——	.216	4.4	-	4.4	12.2
12 feet below No. 4 Range———	.25–1.18	2.7–9.4	-	0.7–4.6	5.0–21.9
Average——	.638	5.0	-	1.6	14.1
Replacement body at raise No. 18 Range———	.23–1.18	3.1–6.3	-	1.0–3.8	7.5–25.5
Average——	.506	4.7	-	2.2	17.7

The blanket replacement ore body just north of the Winnie shaft was stoped down the dip from the first level for a distance of 200 feet and an average width of 20 feet. Its height was not recorded, but ore remaining on the north side averaged 2 feet in thickness. When the stope reached the second level the ore body was found too thin to be mined, but it is significant that the trend of this body is about in line with stopes on replacement deposits in Blue limestone near the New Monarch shaft; the intervening ground is therefore worthy of consideration. The one carload of ore represented in the above table was richer in gold than the ore left along the north wall, and mining was evidently confined to the most enriched ore.

The next replacement deposit to the north was 3.7 feet thick near the Cleveland shaft, and the samples represented in the table were all taken in this vicinity before the bulk of the ore was mined. As they are relatively far from the main vein their lower gold content and high lead content suggest a gradation from the siliceous gold ore of the veins to the mixed sulfide ores of the blanket deposits, but this suggestion can not be emphasized without a study of the ore in place.

The small shoot along the east side of the vein, due west of the Cleveland shaft, is merely a bulging of the vein into the White limestone wall. The ore 12 feet below it, in crushed quartzite or gougy material, averages distinctly higher in gold and lower in lead. The replacement body at raise No. 18, 590 feet north of the shaft, was sampled only close to the vein, before the bulk of it was mined and here the gold was rather high and lead low. The northernmost 100 feet of the vein, along the second level, between walls of Gray porphyry, contained ore averaging 0.36 ounce but running up to 1.25 ounces of gold to the ton. Silver averages only 2 ounces to the ton, lead less than 1 percent, and zinc about 5 percent. It would not be surprising if a raise to the White limestone should disclose a replacement body at this place. In fact, raises and drifts along all the mineralized branch faults may disclose other replacement bodies in limestone above those already found, and ore may be expected along quartzite walls below the second level. Whether the vein will continue to be productive down into the granite is doubtful. Nothing encouraging has been reported from the Yak tunnel level.

Partial analysis of composite samples from the first and second levels shows, in addition to the metals already tabulated, 16 to 21 percent of iron, 22 to 29 percent of silica, and 21 to 25 percent of sulfur. Rough calculation indicates that about half the iron is present as carbonate or oxide, but no detailed descriptions of the gangue or the amount of oxidation in the commercial ores are available.

LUEMA MINE

The Luema mine consists of two shafts, the Luema and Silver Spoon, each about 600 feet deep, and six levels about 100 feet apart, as shown in plate 69. The first level driven from the Luema shaft was inaccessible when the mine was visited in 1913. North of these workings the upper part of the mine is opened by the Silver Spoon tunnel. The vein in the Luema mine has been worked in on continuous ore shoot, which extended for 1,500 feet northward from the Luema shaft (plate 69 and **Figure 109**). Farther north low-grade oxidized siliceous ore replacing Blue limestone was found along the vein below the breast of the Silver Spoon tunnel. A parallel vein east of the main lode, near the Silver Spoon shaft, and a vein of northeast trend and a large replacement body in Blue limestone, near the Luema shaft, have also been mined. The ore in the veins was similar to that in the main vein; that in the replacement body was more liked the oxidized blanket ores in the western part of the district, but no analyses of it are available.

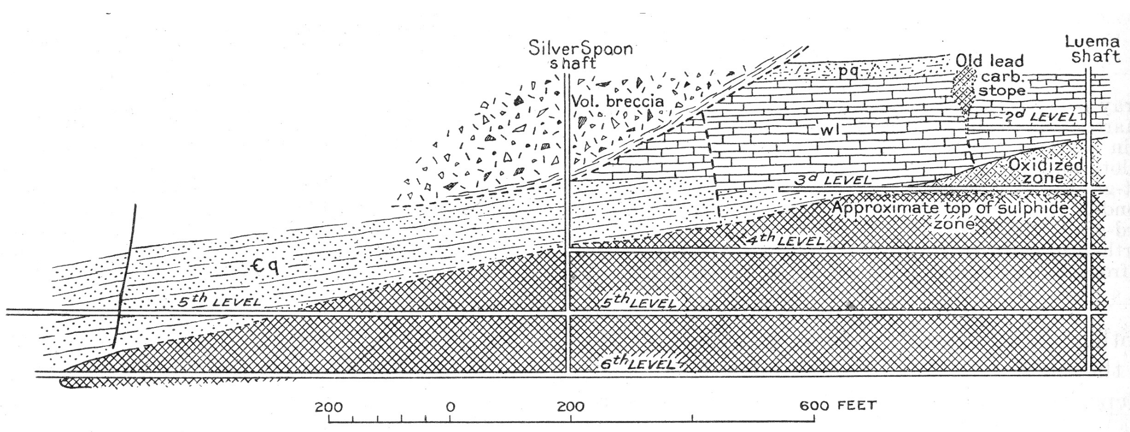


Figure 109. Longitudinal section showing approximate dimensions of Luema ore body and its relations to limestone of east wall. pq, Parting quartzite; wl, White limestone; gr, granite; €q, Cambrian quartzite;

The ore shoot in the main vein opposite the Luema shaft extends from a point 25 feet below the second level down about to the sixth level. Above the second level the vein fissure and its walls are thinly impregnated with pyrite. The top of the ore shoot pitches northward at an average angle of 12º, and its bottom extends almost horizontal to the point where the shoot pinches out on the sixth level. Below the fourth level, opposite the Luema shaft, the shoot splits into two branches, one along each wall of the vein, separated by fault material that contains short streaks of ore. The west branch or vein ranged from a few inches to 3 feet in thickness and was mined continuously to the sixth level. The east branch was narrower and less continuous and mostly of too low grade for mining. A series of short lenses lay a short distance east of and parallel to the east branch. Below the shoot on the sixth level the vein contains mainly veinlets 1 or 2 inches thick of typical ore of good grade but too small and too widely scattered to be mined. About 200 feet southwest of the Silver Spoon shaft, on the fifth level, the ore shoot maintained a width of 12 feet for a distance of about 100 feet and contained ore of very high grade.

The ore was thoroughly oxidized down to the third level. It presumably contained little or no zinc, and its tenor in gold was less than that of the underlying sulfide ore, from which, however, as shown on pages 64–65, it did not greatly differ in value per ton.

The north-south vein that parallels the vein on the east near the Silver Spoon (figure 105) and the northeast vein between the main vein and the Luema shaft (figure 104) are generally similar to the main vein in character and require little comment. That near the Silver Spoon shaft is cut off at the top by the agglomerate pipe. It was productive where one wall or both walls were of quartzite, but where both walls were of granite there were only small stringers of ore, similar to those below the shoot in the main vein. The vein of northeast trend near the Luema shaft was productive from a point below the second level up to the bedrock surface. This vein had been abandoned when the mine was visited, but so far as known no branch along the beds of White limestone had been found.

The only branch faults connecting with the main vein and corresponding to those in the Winnie mine are intersected by the fifth level 759 feet and more north of the Silver Spoon shaft (plate 69). They are in Cambrian quartzite, which is impregnated with pyrite. No effort has been made to follow them upward into White limestone with the hope of finding blanket replacement deposits.

The large replacement body in Blue limestone near the Luema shaft is capped by White porphyry. Its northern part trends N. 70º E., parallel to the mineralized branch faults of the main vein, but its larger portion trends N. 20º W., about parallel to the main vein, and terminates both northward and southward along steeply dipping fractures. It has not been proved to connect with the main vein or with the northeast vein that passes near the shaft. The stope in this body was inaccessible when the mine was visited. The ore was oxidized above the second level, where it graded into sulfide ore that continued as a narrow shoot trending N. 70º E. beneath the White porphyry. Nearly 200 feet southeast of this narrow shoot a fissure of northeast trend containing oxidized lead ore 1 to 3 feet thick was followed for about 80 feet. Where the second level passed close to the floor of the oxidized shoot small bunches of oxidized zinc ore of good grade were found scattered through low-grade zinc ore, which was stained brown and black by iron and manganese oxides. No oxidized zinc ore in commercial quantity was found.

The northward continuation of the main vein has been explored by the Silver Spoon tunnel (plate 69), which passes through glacial moraine and "Weber grits," and by drifts from a winze sunk 125 feet below the face of the tunnel into Blue limestone at ground water level. The vein fissure is there poorly defined and is represented by a broad shattered zone along an eastward-dipping monocline (figure 106). The Blue limestone has been replaced by jasperoid stained by iron and manganese oxides and containing in places enough lead (5 percent) to be classed as low-grade siliceous lead ore. This lead ore is said to contain about 0.3 ounce of gold and 10 ounces of silver to the ton, whereas the siliceous iron-manganese oxide ore contains only 0.05 ounce of gold and 10 to 15 ounces of silver to the ton. Shipments classed as iron-manganese oxide ore, evidently from this place, are represented in the following table.

The low grade of the ore, the "feathering out" of the fault, and the northeast dip, which carries the limestone below water level within a short distance, afford little encouragement for prospecting farther northward along the vein. It may be that the small amount of displacement along this part of the fault is due to another change in direction of throw such as occurs somewhere to the south of the Luema shaft, and that the displacement increases again to the northward. The structure in that case may be favorable for another ore shoot, but the cost of determining this question may be at present prohibitive. If the Canterbury Hill tunnel eventually reaches the vicinity and lowers the water level conditions for prospecting the ground beneath the Silver Spoon tunnel will be improved, and the outcome of prospecting there can determine the advisability of extending developments northward.

The Luema, then known as the Valley mine, was operated by lessees in 1891-1893, but no record of production prior to 1908 is at hand. The Luema Mining Co. was incorporated November 25, 1907, after the mine had been idle for at least two years, and its first shipment of ore was made in June, 1908. The average metal contents of annual shipments since then are shown in the accompanying table (below). The ores are all siliceous and are divided into two main classes—“oxide” (in which the sulfur content is less than 10 percent) and sulfide. These are sub-divided according to metal contents. The figures recorded are too incomplete to indicate the mineral composition closely. Sulfur, so far as determined in the oxide ore (in 1908 only), reached a maximum of 2.5 percent, suggesting that much of the lead was present as galena. Chalcocite may also be present in partly oxidized ore, but the percentage of copper is too little to account for an appreciable amount of sulfur.

Lead in single shipments of oxidized ore amounted to as much as 25 percent, but on the whole it is no more abundant in the oxidized ore than in the sulfide ore, despite the fact that the leaching of zinc and other soluble materials may have relatively increased the original percentage of lead by as much as one-fifth or one-fourth. The percentage of copper also shows little change from the sulfide to oxidized lead ore, although some leaching of the oxidized zone is proved by the films of sooty chalcocite in the sulfide ore below. The one lot of copper sulfide ore shipped in 1916 may be attributed to local enrichment.

Average contents of ores shipped from the Luema and Silver Spoon mines, 1908-1921

Oxide ores [a]

Siliceous lead ore

Year	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Silica (Percent)	Iron (Percent)	Manganese (Percent)
1908	0.328	4.87	(b)	c 9.99	(b)	-	-	0.5
1909	.519	7.42	(b)	c 11.42	(b)	-	-	-
1910	.623	8.15	d 0.648	c 7.25	(b)	-	-	-
1911	.174	2.89	d .099	c 5.95	1.0	60.0	14.0	.05–.50
1912	.597	7.81	D .62	c 6.95	(b)	-	-	-
1913	.205	3.99	e .131	e 7.82	(b)	-	-	-
1914	.210	5.08	e .265	e 9.38	(b)	-	-	-
1915	.351	5.34	d .181	d 15.16	(b)	-	-	-
1916	.438	7.36	d .284	d 15.66	(b)	-	-	-
1917	.377	6.68	d .413	d 13.64	(b)	-	-	-
1918	.382	6.33	d .239	d 14.65	(b)	-	-	-
1919	.414	5.46	d .248	d 11.63	(b)	-	-	-
1920	.204	4.70	(b)	9.67	(b)	-	-	-
1921	.403	8.71	(b)	16.15	(b)	48.0	15.0	-

Dry Siliceous Ores

Year	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Silica (Percent)	Iron (Percent)	Manganese (Percent)
1913	0.224	4.77	0.189	-	(b)	-	-	-
1914	9.31	5.88	-	e 2.73	-	-	-	-
1916	.124	8.8	-	d 3.65	-	-	-	-
	.660	22.11	d 2.23	d 2.38	-	-	-	-
1917	.088	7.46	-	d 3.56	-	60.0	9.00	-

Iron-manganese ores

Year	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Silica (Percent)	Iron (Percent)	Manganese (Percent)
1916	0.29	12.68	-	1.10	-	-	-	-
	0.38	13.22	-	.86	-	53.8	20.8	18.0
	0.35	12.63	-	.47	-	58.0	13.7	10.0

Ores
Siliceous Lead Ore

Year	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Silica (Percent)	Iron (Percent)	Manganese (Percent)
1910	0.836	8.42	D 0.695	c 7.84	-	-	-	-
1912	.836	8.43	d .698	c 6.27	-	-	-	-
1913	.484	6.88	e .426	e 8.42	-	-	-	-
1914	.420	7.15	-	e 15.06	-	-	-	-
1915	.374	5.10	d .288	d 6.11	-	-	-	-
1916	.398	6.53	d .340	d 13.85	-	-	-	-
1917	.051	2.02	-	d 5.90	-	-	-	-
	.412	6.55	.298	d 11.47	-	-	-	-
1918	.258	6.37	d .487	d 8.08	-	-	-	-

Dry siliceous ore

Year	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Silica (Percent)	Iron (Percent)	Manganese (Percent)
1911	0.916	11.17	d 1.66	c 2.59	10–15	6.0	14	-
1913	.864	7.01	e .78	e .76	-	-	-	-
1914	.744	6.36	e .54	e .54	-	-	-	-

Copper ore

Year	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Silica (Percent)	Iron (Percent)	Manganese (Percent)
1916	0.222	27.48	e 3.38	d 1.92	-	-	-	-

Zinc ore

Year	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Silica (Percent)	Iron (Percent)	Manganese (Percent)
1913	0.142	4.27	-	d 3.46	14.03	-	-	-
	.424	6.83	d 0.207	d 1.93	24.19	-	-	-
1914	.435	5.82	-	d 2.35	20.03	-	-	-
1915	.313	5.19	-	d 4.91	17.46	-	-	-
1916	.438	10.14	-	d 2.85	23.08	-	-	-
1917	.351	9.11	-	d 2.92	22.39	-	-	-

[a] The term “oxide ores” in this table implies a content of less than 10 percent sulfur, whether the ores are appreciably oxidized or not. It is impossible to estimate the degree of oxidation without determination of the iron, zinc, and sulfur present.

[b] Not determined. [c] Fire assay [d] Wet assay [e] Recovered.

Assays of unusually rich ore from the Luema mine

	Gold (Oz./ton)	Silver (Oz./ton)	Copper (Percent)	Lead (Percent)	Zinc (Percent)	Manganese (Percent)
Picked specimen, fourth level [a]	8.0	27	-	29.5	11.1	0.4
Rich ore, fifth level	3.0	18	2	2.0-3.0	-	-
East vein at Silver Spoon shaft, fifth level	2.0	40	3.0–5.0	25.0	-	-

[a] Butler, G. M., Some recent developments at Leadville; a Leadville fissure vein: Econ. Geology, vol. 7, p. 318, 1912

Zinc is much more prevalent than the partial analyses indicate, and it is likely that some shipments of lead sulfide ore have been penalized for zinc in excess of 12 percent. The zinc sulfide ore shipped evidently represents lots in which the percentage of lead fell below 5 and is not to be sharply distinguished from the lead and dry ores.

Gold, as usual, varies independently of the other constituents. The highest content recorded, 2.85 ounces to the ton, happened to be in one lot of lead "oxide" ore whose composition cannot be even approximately estimated; but on the whole the gold content is distinctly less in the "oxide" than in the sulfide ores, a fact that suggests partial leaching. As several lots of "oxide" ore, which were in fact considerably oxidized, averaged about 0.5 percent of manganese, it may be inferred that manganese aided in the downward concentration of gold. This inference is strengthened by the extremely low gold content in the iron-manganese oxide ores, which probably came from the northernmost and highest part of the vein, reached by the Silver Spoon tunnel.

Silver averages a little less in the "oxide" than in the sulfide ores, which implies a relatively small amount of downward enrichment on the whole, although highly enriched sulfide ores have been found locally. Single shipments both of lead "oxide" and lead sulfide ore contained as much as 25 ounces of silver to the ton and the one shipment of copper sulfide ore contained 27.48 ounces to the ton. The presence of maximum silver and copper contents in the same lot of ore suggests that enrichment in both metals has occurred and that chalcocite served as a precipitant of silver, but the ratio of silver to copper in most of these shipments is either not shown or is too variable to indicate that such a relation is general.

The predominance of lead ore in the Luema vein may be attributed in part to the influence of White limestone in the walls and within the fault zone, especially along the upper part of the ore shoot; but it appears equally probable that solutions which had already deposited much of their pyrite were unable to escape from gouge-line fault and were obliged to deposit the bulk of their minerals within the fault, regardless of the influence of different wall rocks. This interpretation also implies that the low-grade jasperoid ores found at a higher level below the Silver Spoon tunnel are more remote from the source of supply and consist of such material as was able to make its way though the gougy part of the vein above the main shoot. Such material is likely to be of low grade, except where conditions for enrichment have been unusually favorable.

Ore Bodies East of Winnie-Luema Vein

The outlines of the blanket ore bodies in Blue limestone between the Winnie and New Monarch shafts were furnished by the persons controlling the property subsequent to Irving's field work, but the former management refused admission to the mine. The workings have been closed during subsequent brief visits to the district, and nothing definite is known of them. Directly north of them ore bodies were worked through the Midnight, Katy and Valley shafts, but were cut off by the Josie rhyolite pipe, as shown in figures 13 and 14 (extra figures and plates).

Other blanket bodies were worked in the early days notably through the Virginius tunnel, where five tons of silver-lead ore is reported to have been produced daily during December, 1879, and in the Cleveland mine. Many large dumps in the vicinity contain mineralized limestone, but no other records of ore bodies have been obtained.

OLLIE REED-SILENT FRIEND GROUP

Another group of blanket deposits in step-like arrangement extends east-northeastward from the pipe of agglomerate (**Figure 110**). The others are in the Tenderfoot, Favorite, and Silent Friend mines and consist of long, narrow, irregular shoots with an average trend of N. 75º E. They are all in the Blue limestone and are mapped as "first contact" ore bodies, although they lie within the limestone well below the former position of the eroded White porphyry. The ore shoot in the Tenderfoot mine is illustrated in figures 110 and 111. It extends from the bedrock surface downward with a pitch of 45º to a floor of "flint" or jasperoid about 60 feet above the Parting quartzite. No records showing the contents of its ores have been obtained for comparison with those of the Resurrection group, to the east, and with the blanket deposits underlain by flint in the Iron Hill and Fryer Hill areas. **Figure 111** shows a small vein, evidently cut on the south drift, but nothing is known about it or the blanket deposit west of it. There is no record of any work below the Blue limestone.

The blanket ore shoot of the Silent Friend vein was examined by Irving on the Yak tunnel level, where it was found to trend N. 10º W. and dip 70º W. between granite walls and to consist chiefly of pyrite, with some zinc blende and galena. It had been followed upward for some distance and was said to connect with blanket ores, but no connection is indicated in figure 110.

RESURRECTION GROUP

Nine veins are known in the Resurrection group, and for convenience they have been distinguished by numbers. Four of them—Nos. 1, 2, 7 and 8—have a roughly crescentic form with large radii of curvature. Most of the veins terminate upward in blanket replacement deposits against the layer of the "Weber shales" that commonly lies between the Blue limestone and the overlying White porphyry; some, where the shales were absent, directly underlie the White porphyry. The replacement deposits have been the principal source of ore, and only one of the veins, No. 7, has produced any considerable amount. The relations of blanket replacement deposits and veins are shown in plates 27 (extra figures and plates) **and 70**.

The veins were all accidentally discovered by underground workings driven for the purpose of developing the blanket ores, and but little attention has been given to them. Some of them are reported to be connected with blanket ores belonging to a second or third contact. The spacing of these veins is relatively close as in the Ibex group. Some of them are cut in the Yak tunnel, nearly 200 feet below their termination against the overlying "Weber shales," but have not been followed on the tunnel level. All the veins belong to the north-northeast system, and they deviate somewhat less from that direction than the veins in the other groups, but the southern part of vein No. 3, which has so far been observed only in the Yak tunnel, assumes a south-southeasterly trend for a distance of 200 feet.

These veins range in width from a few inches to 4 feet. The No. 7 vein, which lies east of the Yak tunnel, is well defined and has been followed downward from the contact for a considerable distance, and it has also been cut on the Yak tunnel level. It has produced a large tonnage of siliceous gold ore, much of which contained galena and zinc blend with subordinate silver. This fissure is vertical as a whole, although locally it hades a little from one side to the other. It is slightly crescentic in form, with its concave surface toward the west. The vein fills a fault fissure, along which a displacement of approximately 40 feet is observable on the lower levels of the Resurrection mine.

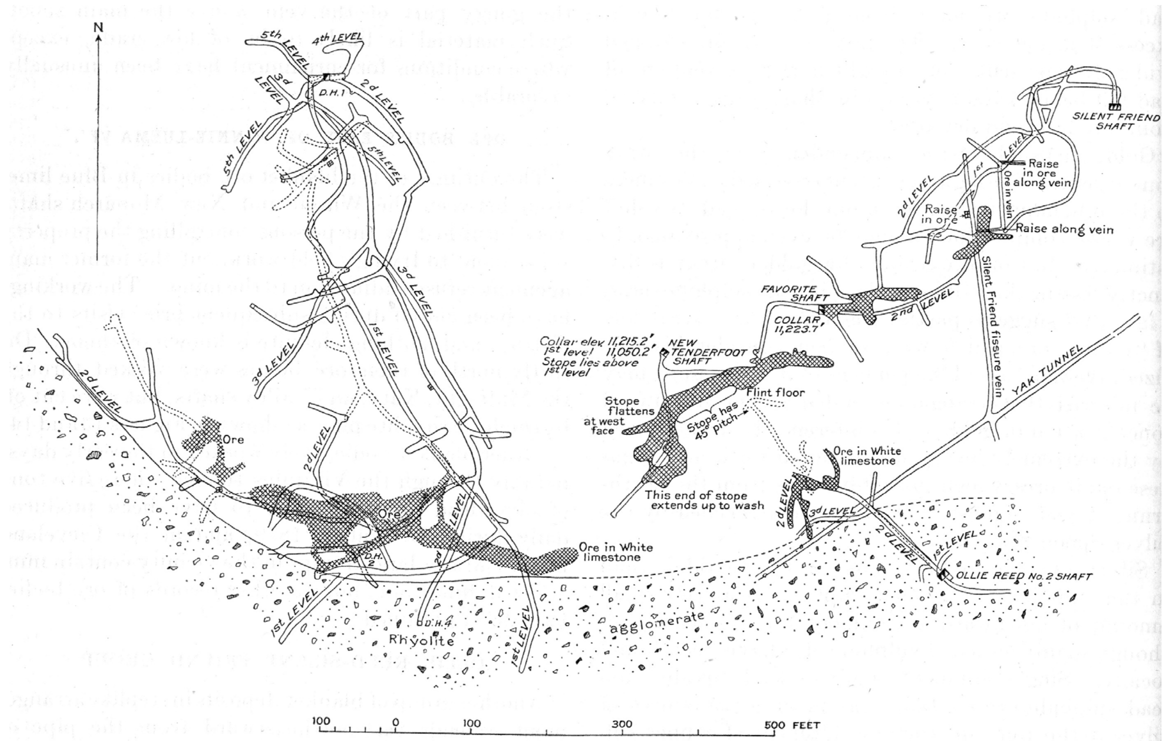


Figure 110. Plan of workings of Ollie Reed, Tenderfoot, Favorite, and Silent Friend mines, showing outlines of ore bodies and edge of great pipe of agglomerate to the south.

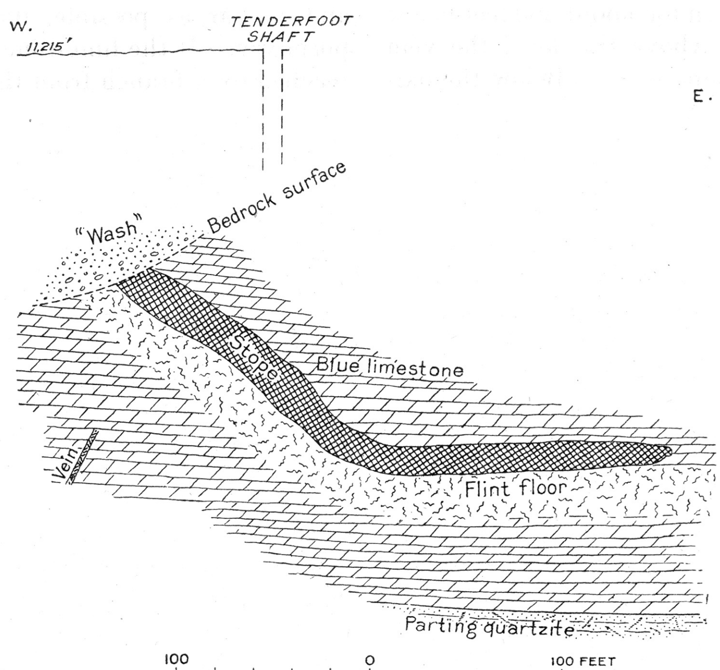


Figure 111. Profile of ore shoot near Tenderfoot shaft, looking north-northwest.

Another vein of the same character and attitude fills a fault fissure of slight displacement 100 feet east of the No. 7 vein. It has not been cut on the Yak tunnel level. The vertical vein just west of the Fortune shaft is undoubtedly the same as that cut 500 feet below on the Yak tunnel level. Besides the veins indicated on plates 27 (extra figures and plates) and 70 others have been reported in workings that could not be examined.

The tops of the blanket deposits pitch generally at an angle of 15º N. 20º E., but some of them have spread in other directions, apparently guided by cross fractures. No further data on these deposits are at hand, and it is not known whether the composition of their ores was generally uniform or changed as distance from the associated veins increased, or whether mining ceased when the ore became low in gold, leaving mixed sulfide ore in the walls. Two classes of ore, siliceous and lead, have been mined in recent years from both the oxidized and the sulfide zones, as shown below; but it is not known from what ore shoots they came. The ores classed as "oxide" include all containing less than 10 percent of sulfur. The zinc content of the lead sulfide ores is not known.

Content of ores shipped from Resurrection mine, 1915-1918

Class of ore	**Year**	**Gold (Oz./ton)**	**Silver (Oz./ton)**	**Copper (percent) (a)**	**Lead (percent) (a)**	**Zinc (%)**	**Silica (percent)**	**Iron (percent)**	**Manganese (percent)**
Lead Oxide	1915	0.552	3.17	0.9	5.4	-	(b)	(b)	-
		.551	1.27	2.0	11.8	-	(b)	(b)	-
Siliceous lead sulfide	1917	.228	5.23	.2	7.4	-	-	-	-
Siliceous dry oxide	1917	.374	3.91	-	9.6	-	32.0	25.0	-
Siliceous dry sulfide	1917	.327	3.02	-	2.2	-	44	21	8.0
Siliceous lead sulfide	1918	.305	17.00	.1	34.9	-	-	-	-
Lead-iron sulfide	1918	.277	2.33	-	7.7	-	-	-	-

a Wet assay. b Silica and iron equal, but record not kept

These replacement bodies are part of a group that extends from the outcrop of Blue limestone on the south side of Little Ellen Hill to the Diamond mine and perhaps farther. Oxidized lead-silver ore was discovered at the outcrop, and as early as 1880 the production amounted to 10 tons a day. The ore lay for the most part just beneath the White porphyry, but at some places it was wholly within the limestone and proved to be a thin blanket of great lateral extent. It was followed in a north-northeast direction by the Little Ellen incline, and its northward continuation, or another shoot in line with it, was reached by the New Years incline, driven from a lower position. Increasing depth northward led to the sinking of the Resurrection No. 1 shaft, on the northwest slope of Little Ellen Hill, which resulted in the discovery of the blankets and connected veins of siliceous pyritic gold ore already described. These ore bodies extended into the Fortune and Sedalia mines. Siliceous pyritic ore was reached through the Resurrection No. 2 shaft, but its metal content was disappointingly low. The northernmost ore bodies found in this group were reached through the Diamond winze, at the end of the Yak tunnel. They are large bodies of low-grade pyritic ore connected with feeding veins, but at the time of Irving's visit, in 1901, no ore of shipping grade had been found, and the mine has been idle for several years.

Blanket bodies similar to those in the Resurrection mine were also found at the "first contact" in the Dolly B. mine and perhaps in the Famous mine. In 1922 an inclined drill hole sunk normal to the bedding from the north drift of the Dolly B. mine cut mineralized rock within the Blue limestone 27 to 50 feet above the Parting quartzite, 0 to 6 feet below the Parting quartzite, in the lower White limestone or the Cambrian "transition shales" 38 to 78 feet above the typical Cambrian quartzite, and in the "transition shales" 19 to 28 and 0 to 5 feet above the quartzite.

SUNDAY VEIN

The Sunday vein is on the west slope of Ball Mountain and is opened by two shafts whose collars have altitudes of 11,921 and 11,929 feet. The vein has also been opened by the Garibaldi tunnel, which extends from the portal, at the head of California Gulch, 2,400 feet northeastward and reaches the vein at a depth of 700 feet.

The vein cuts “Weber grits” with intercalated sills of Gray porphyry. It trends N. 18º E. and dips 88º W. It ranges from 1½ to 8 feet in width and probably averages between 3 and 4 feet. The ore consists of pyrite, galena, small quantities of zinc blende, and chalcopyrite.

The ore was oxidized down for about 300 feet below the collars of the shafts. Above this level the vein was chiefly filled with carbonate ore. Below the oxidized zone a zone of enrichment extended down for at least 400 feet, to the present tunnel level, which is the lower limit of exploration. The value of the enriched ore was still continuing downward at the time of the visit in 1909. Its copper content averaged 6 per cent.

Recent shipments from the Sunday vein are represented below. There were no shipments in 1921 and 1922. Zinc was not recorded.

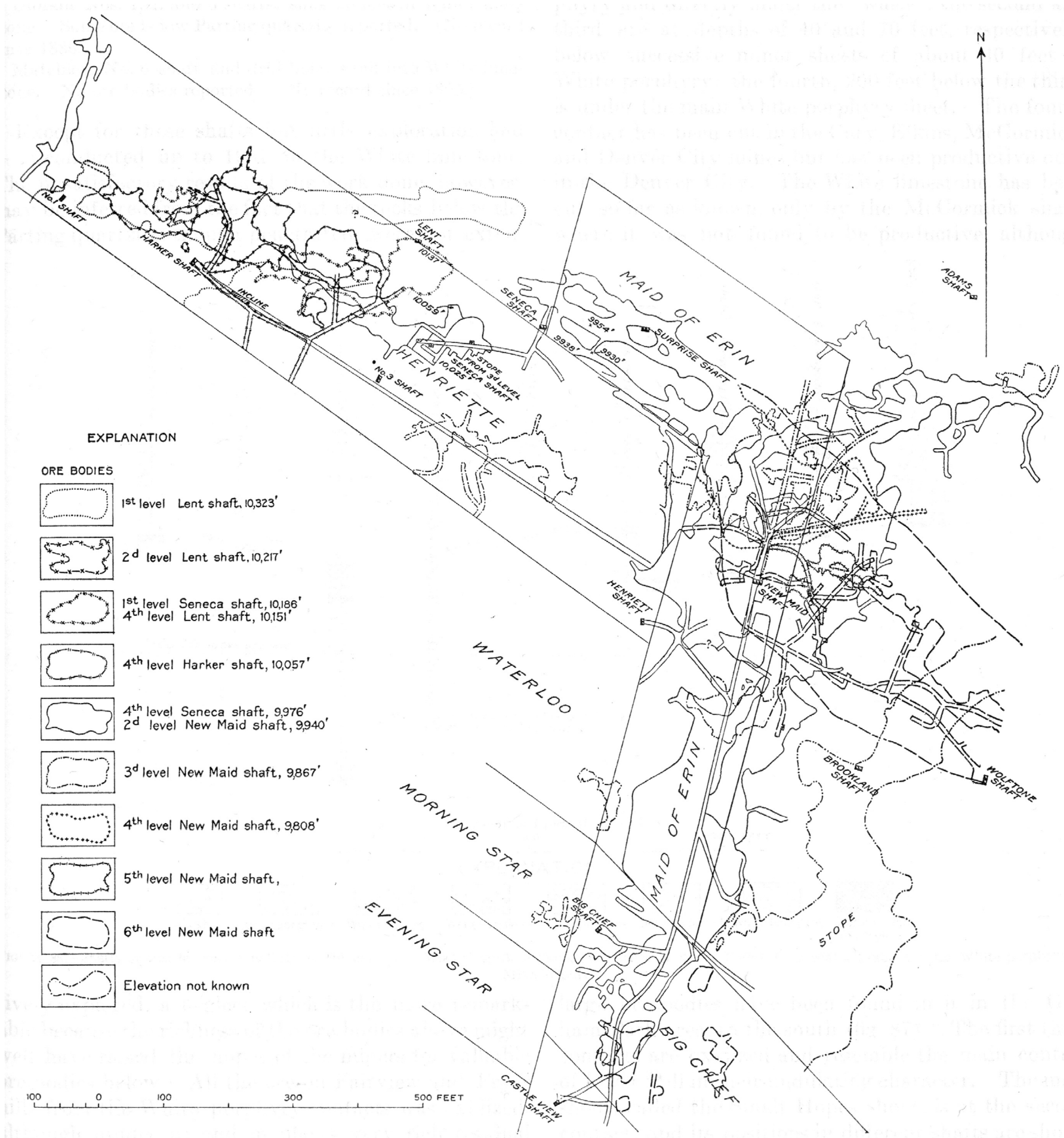
Contents of ore shipped from Sunday vein, 1917-1920

Class of ore	**Year**	**Gold (Oz./ton)**	**Silver (Oz./ton)**	**Copper (percent)**	**Lead (percent)**
Siliceous lead sulfide	1917	0.154	7.85	0.6	23.3
Siliceous lead oxide[a]	1917	.384	5.23	-	5.9
Siliceous lead-copper sulfide	1918	.161	7.30	4.6	18.7
Siliceous lead sulfide	1918	.151	3.53	.1	5.5
Siliceous dry oxide[b]	1918	.160	1.76	.01	2.1
Siliceous lead sulfide	1919	.083	8.98	.8	25.5
do—-	1920	.080	6.96	1.0	19.3
Iron-lead sulfide	1920	.098	6.80	1.1	17.6

a Silica, 42 percent; iron, 17 percent.
b Silica, 67.8 percent; iron, 10.3 percent.

The depth of the Blue limestone below the bottom level of the Sunday mine or elsewhere in the vicinity has never been determined and cannot be closely inferred because of the uncertain thickness of the porphyry sills. The depths indicated in sections E—E' and F—F' of plate 15 (extra figures and plates) are only rough approximations. The presence of the Sunday vein and of pronounced mineralization in its vicinity implies that the limestone below may be mineralized. Drilling is therefore justified to determine its depth, degree of mineralization, and, so far as possible, its relations with intrusive porphyry. If the limestone is not too deep, it may be reached by a branch from the Yak tunnel.

Plates



MAP OF HENRIETT AND MAID OF ERIN OLD WORKINGS

Plate 66

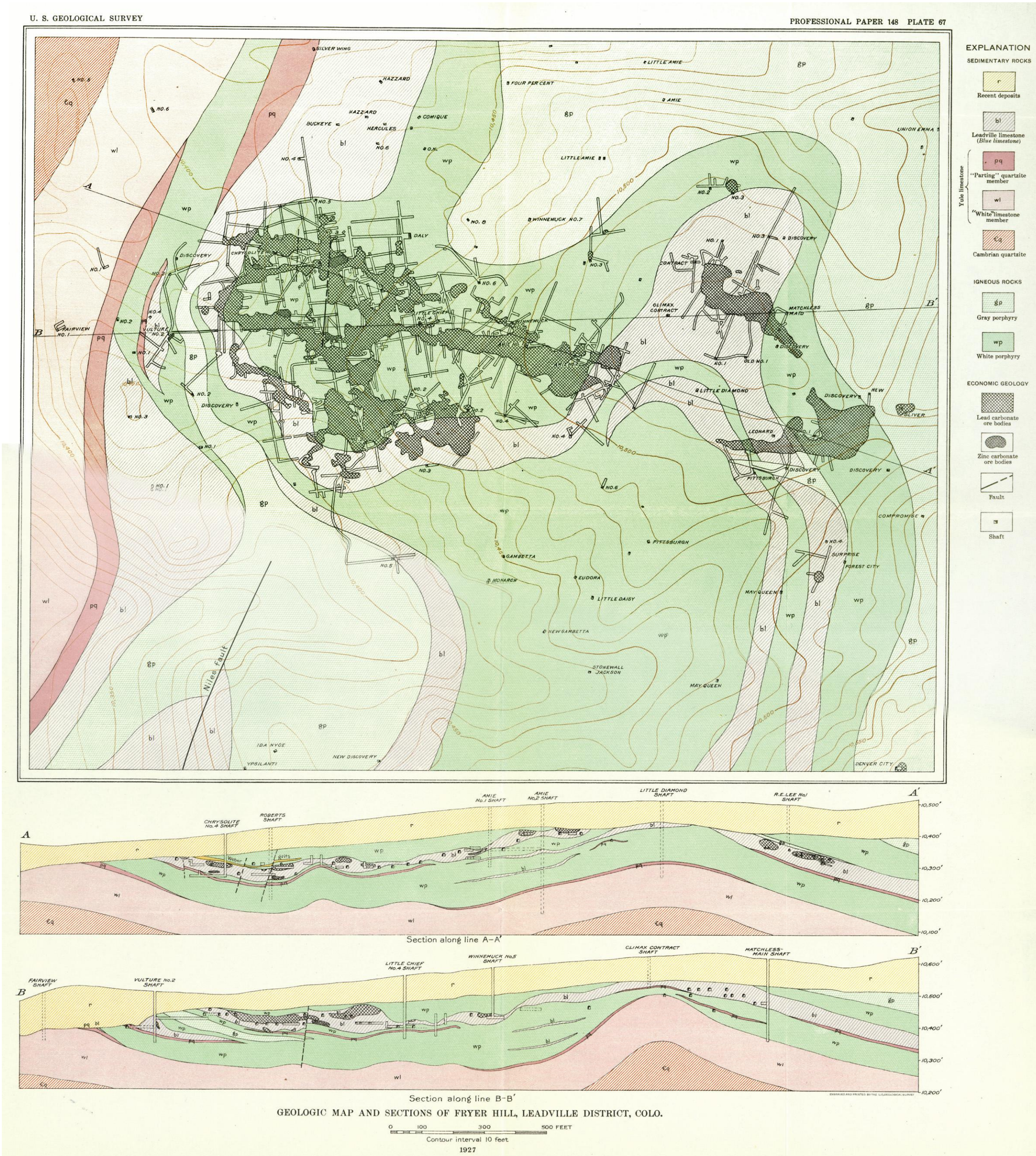
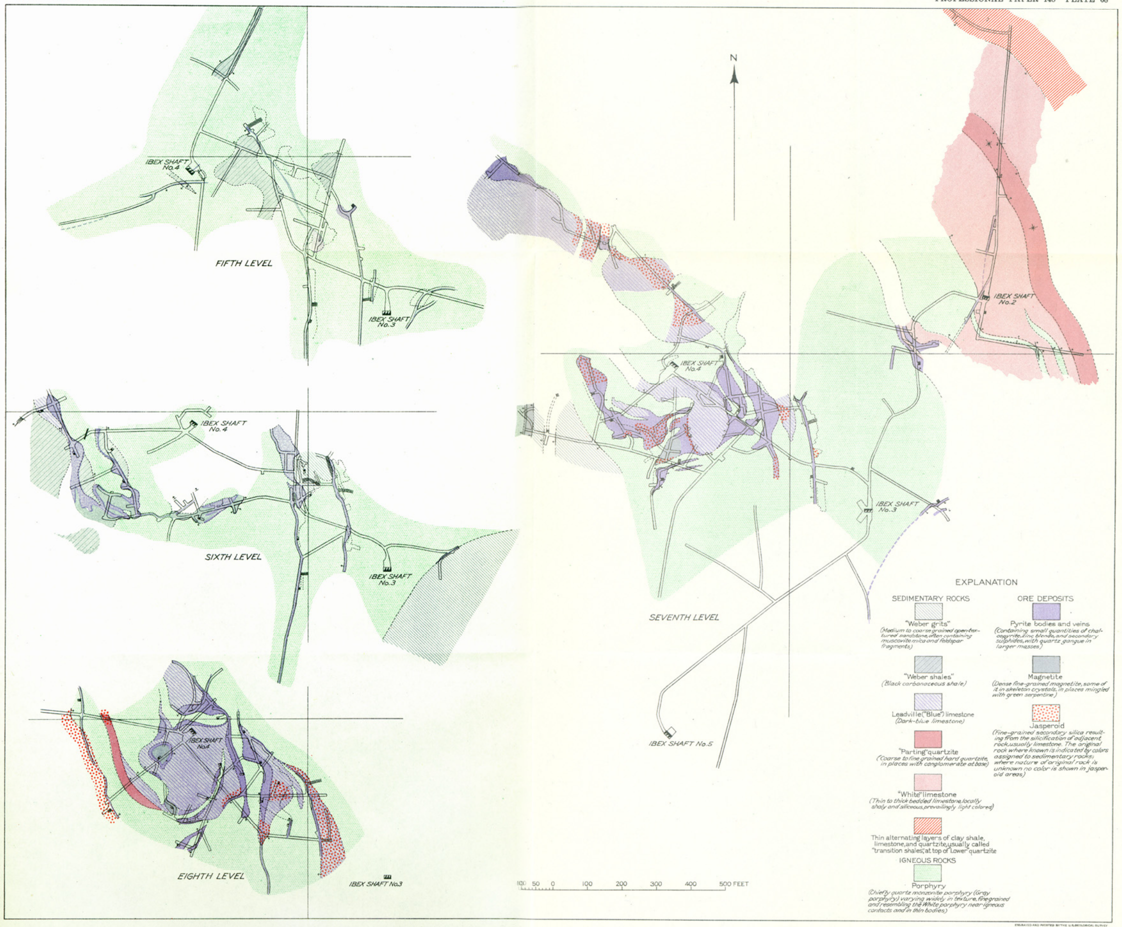
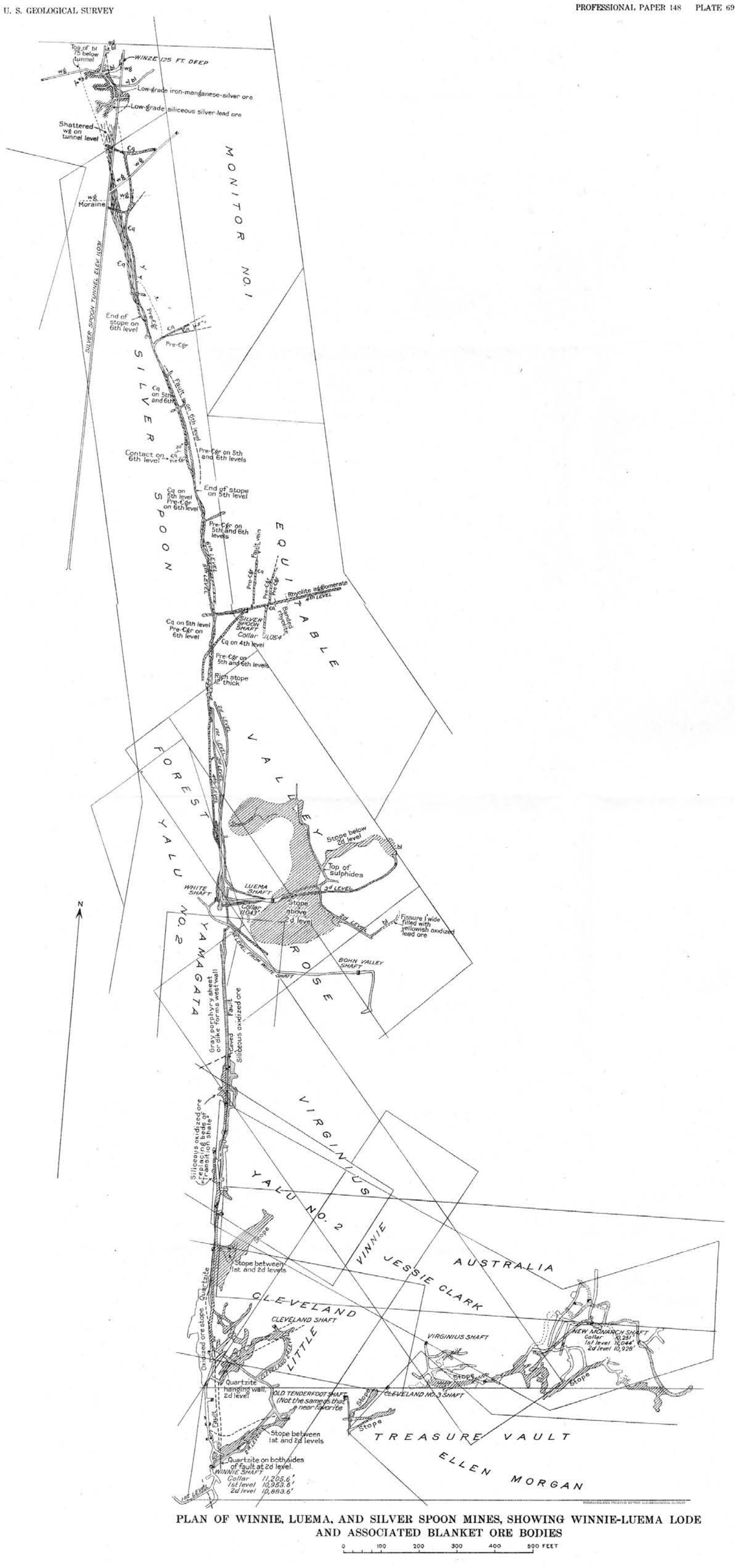

U. S. GEOLOGICAL SURVEY
PROFESSIONAL PAPER 148 PLATE 67
EXPLANATION
SEDIMENTARY ROCKS
Recent deposits
Leadville limestone (Blue limestone)
"Parting" quartzite member
"White limestone member
Yule limestone
Cambrian quartzite
IGNEOUS ROCKS
Gray porphyry
White porphyry
ECONOMIC GEOLOGY
Lead carbonate ore bodies
Zinc carbonate ore bodies
Fault
Shaft
Section along line A-A'
Section along line B-B'
GEOLOGIC MAP AND SECTIONS OF FRYER HILL, LEADVILLE DISTRICT, COLO.
Contour interval 10 feet
1927

Plate 67



GEOLOGIC MAP OF FIFTH, SIXTH, SEVENTH, AND EIGHTH LEVELS OF IBEX MINE

Plate 68



PLAN OF WINNIE, LUEMA, AND SILVER SPOON MINES, SHOWING WINNIE-LUEMA LODE AND ASSOCIATED BLANKET ORE BODIES

0 100 200 300 400 500 FEET

Plate 69.

MAP OF RESURRECTION MINE

Plate 70.

CHAPTERS 9 & 13

EXTRA FIGURES AND PLATES

Figures

These are figures and plates called out in the texts of Chapters 9 and 13 that are called out in the text but are from other chapters of Professional Paper 148 not present in this report.

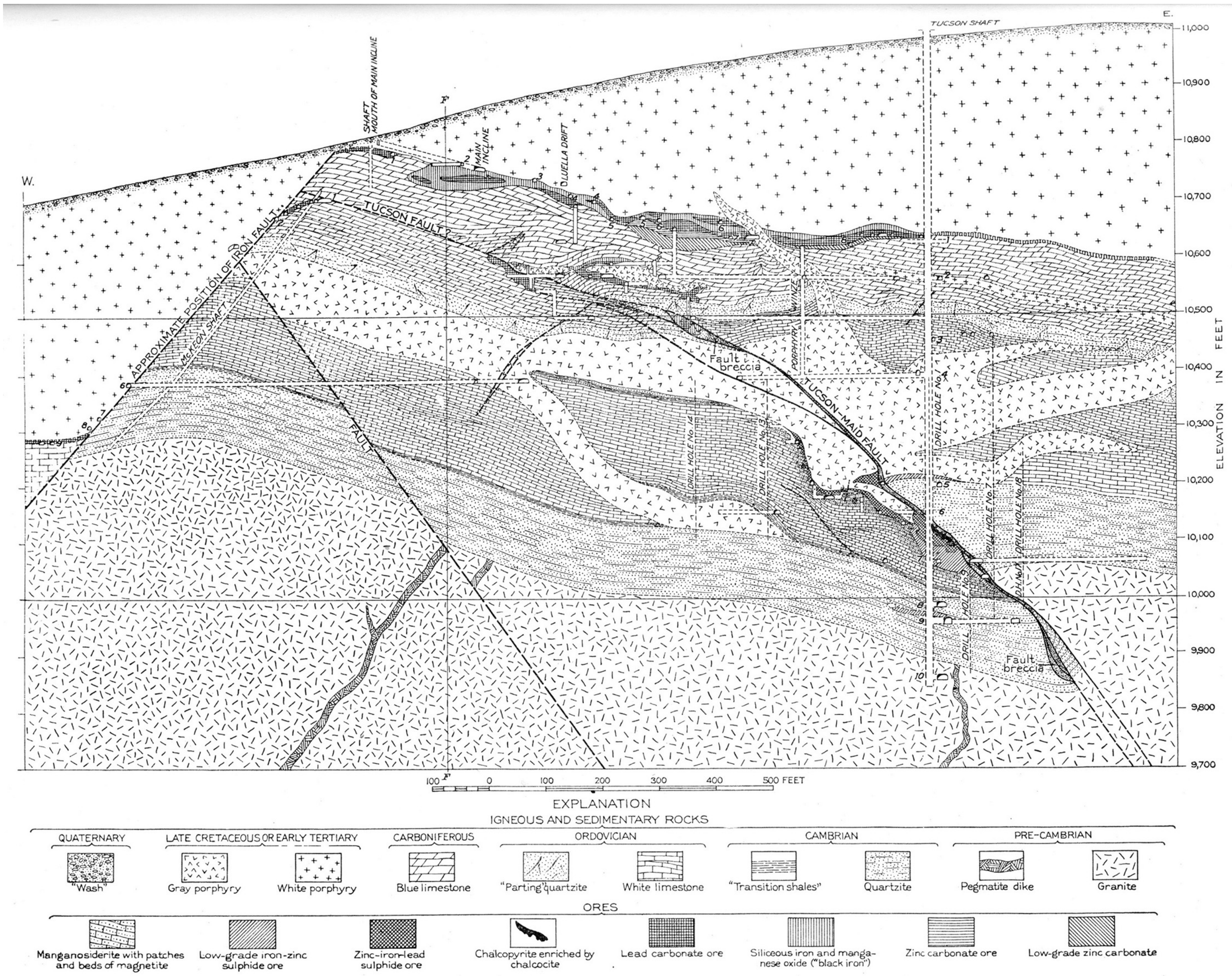


Figure 18. Section N. 63° E. through Tucson fault, looking northwest. By F. A. Aicher

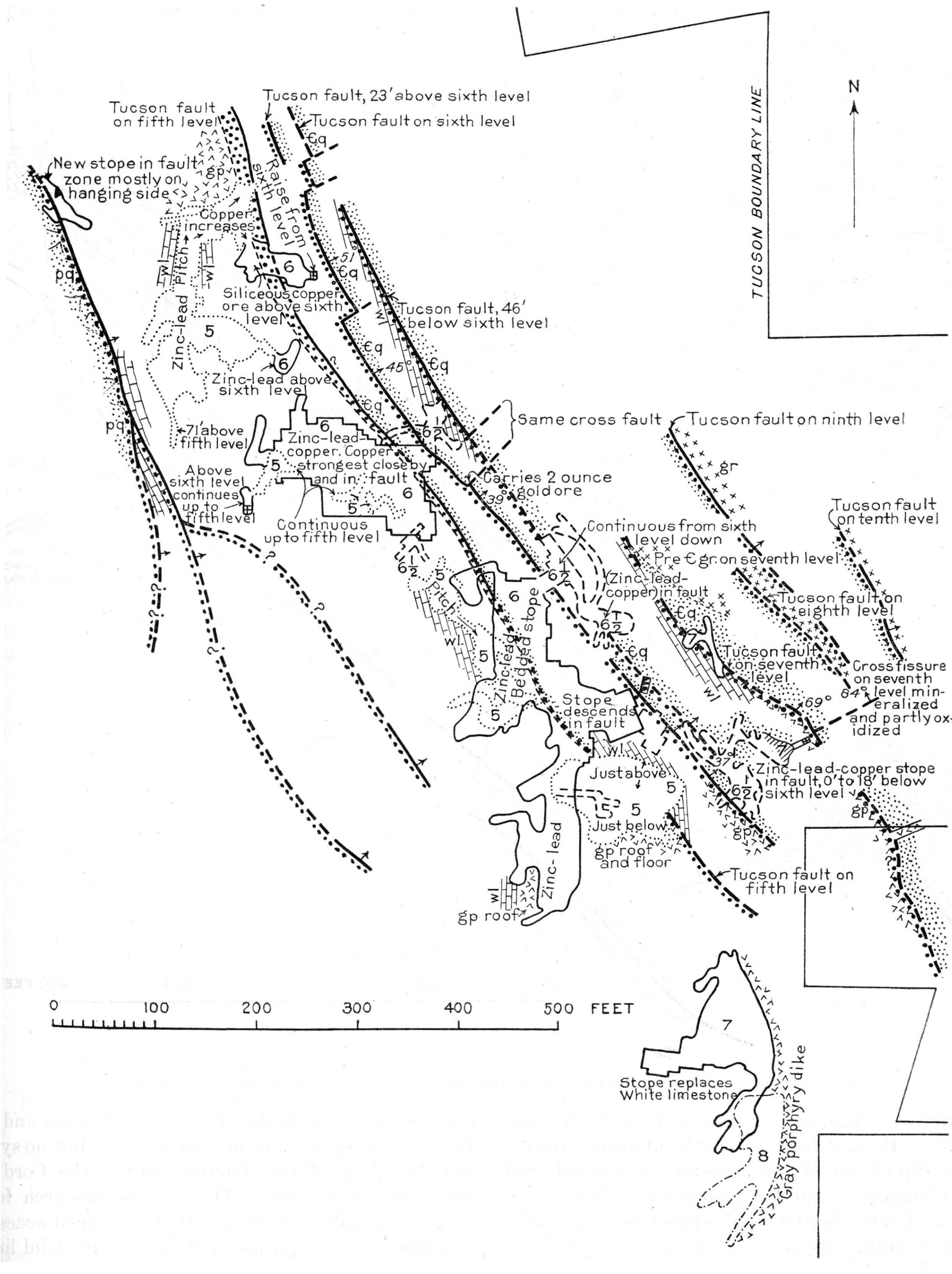


Figure 20. Plan of fourth, sixth, and seventh levels of Tucson mine, showing relation of Tucson fault to ore bodies. By F. A. Alcher, Iron-Silver Mining Co. Numbers in stopes refer to levels. Pq, Parting quartzite; wl, White limestone; -Cq, Cambrian quartzite; gp, Gray porphyry; Pre-C gr, pre-cambrian granite.

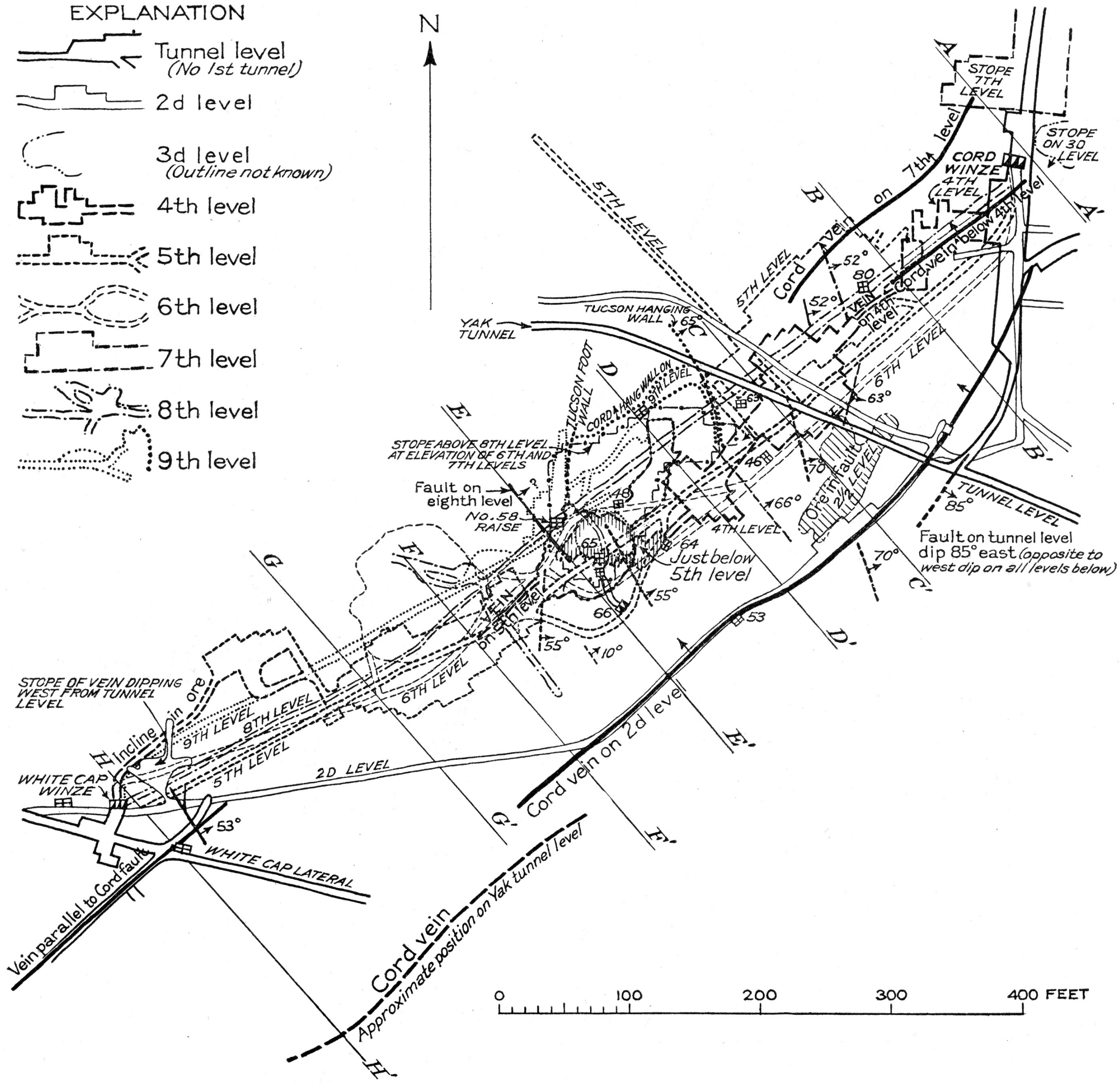


Figure 21. Plan of workings below level of Yak tunnel between Cord and White Cap winzes, showing relation of ore to vein.

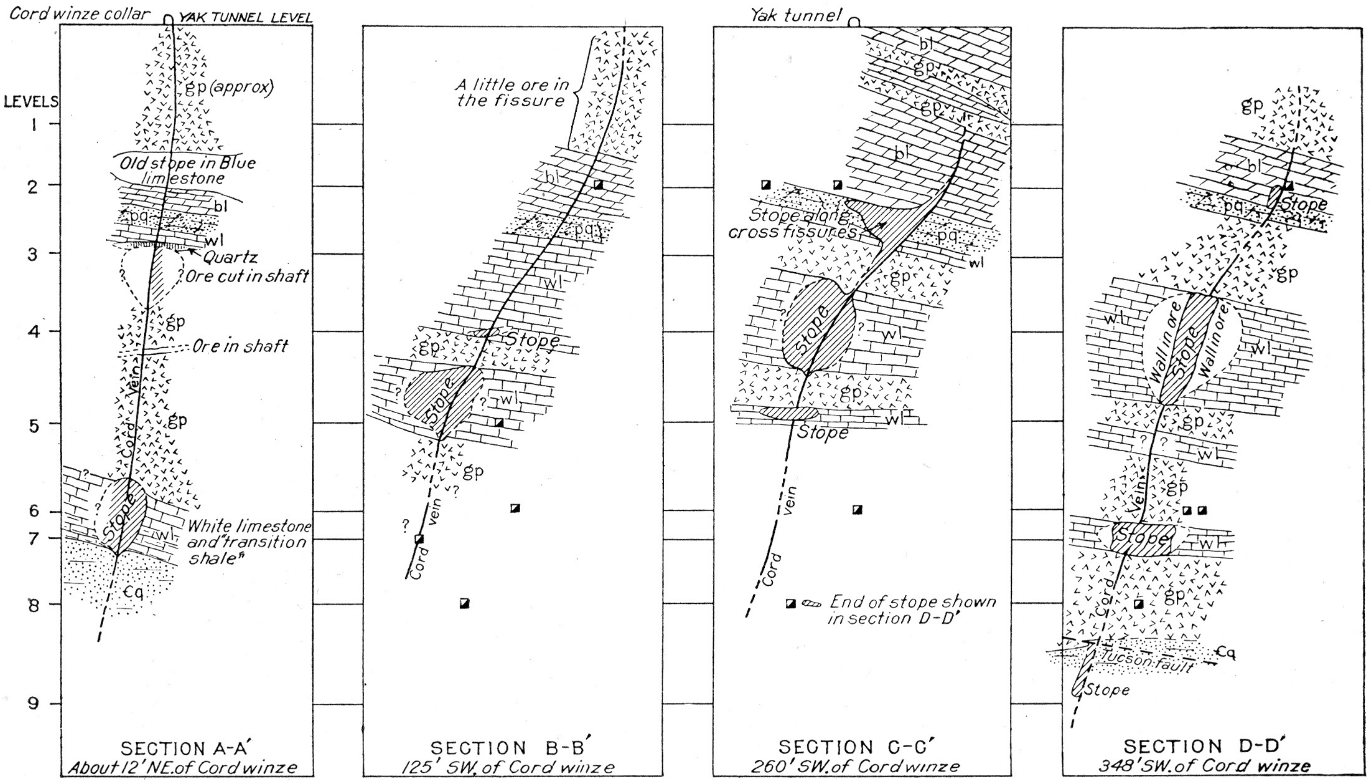


Figure 22. Northwest-southeast sections through Cord winze workings. Gp, Gray porphyry; bl, Blue Limestone; pq, Parting quartzite; wl, White limestone; Ꞓq, Cambrian quartzite; gr, granite

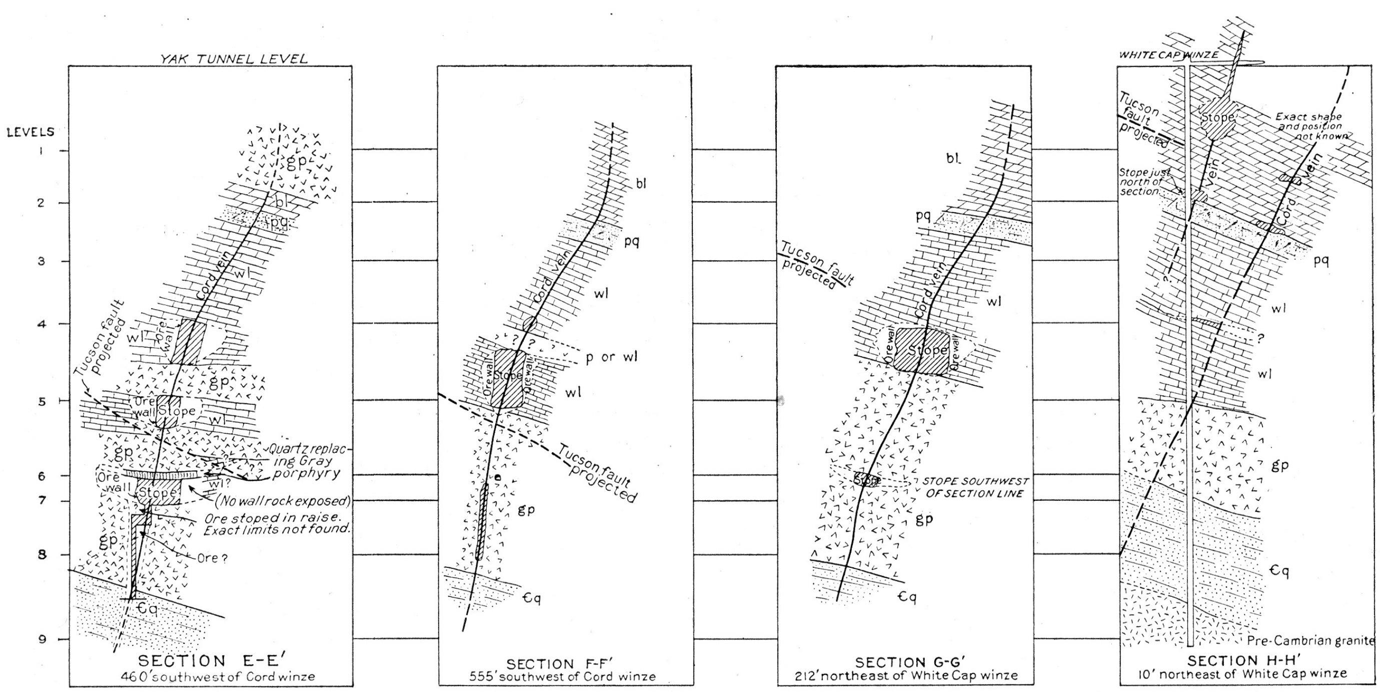


Figure 23. Northwest-southeast sections through Cord winze workings. Gp, Gray porphyry; bl, Blue Limestone; pq, Parting quartzite; wl, White limestone; Ꞓq, Cambrian quartzite; gr, granite

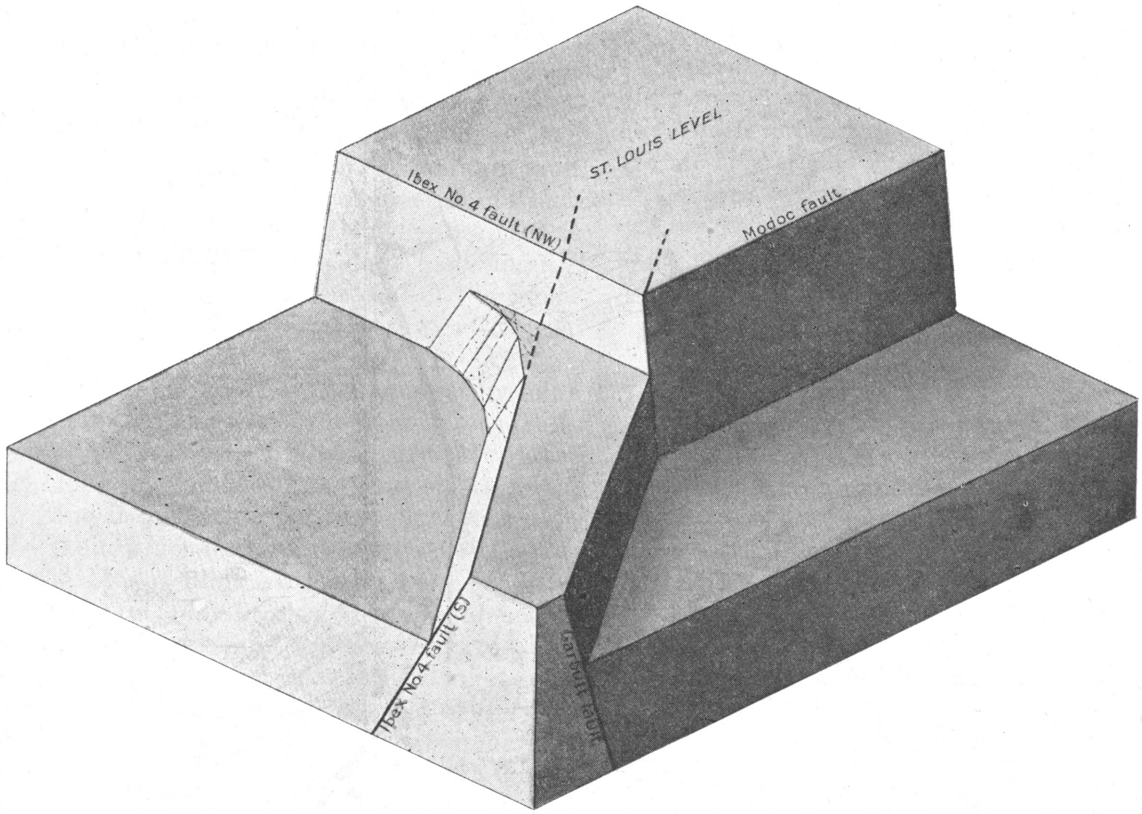


Figure 28. Diagram representing depression of blocks bounded by the Modoc, Garbutt, and Ibex No. 4 faults.

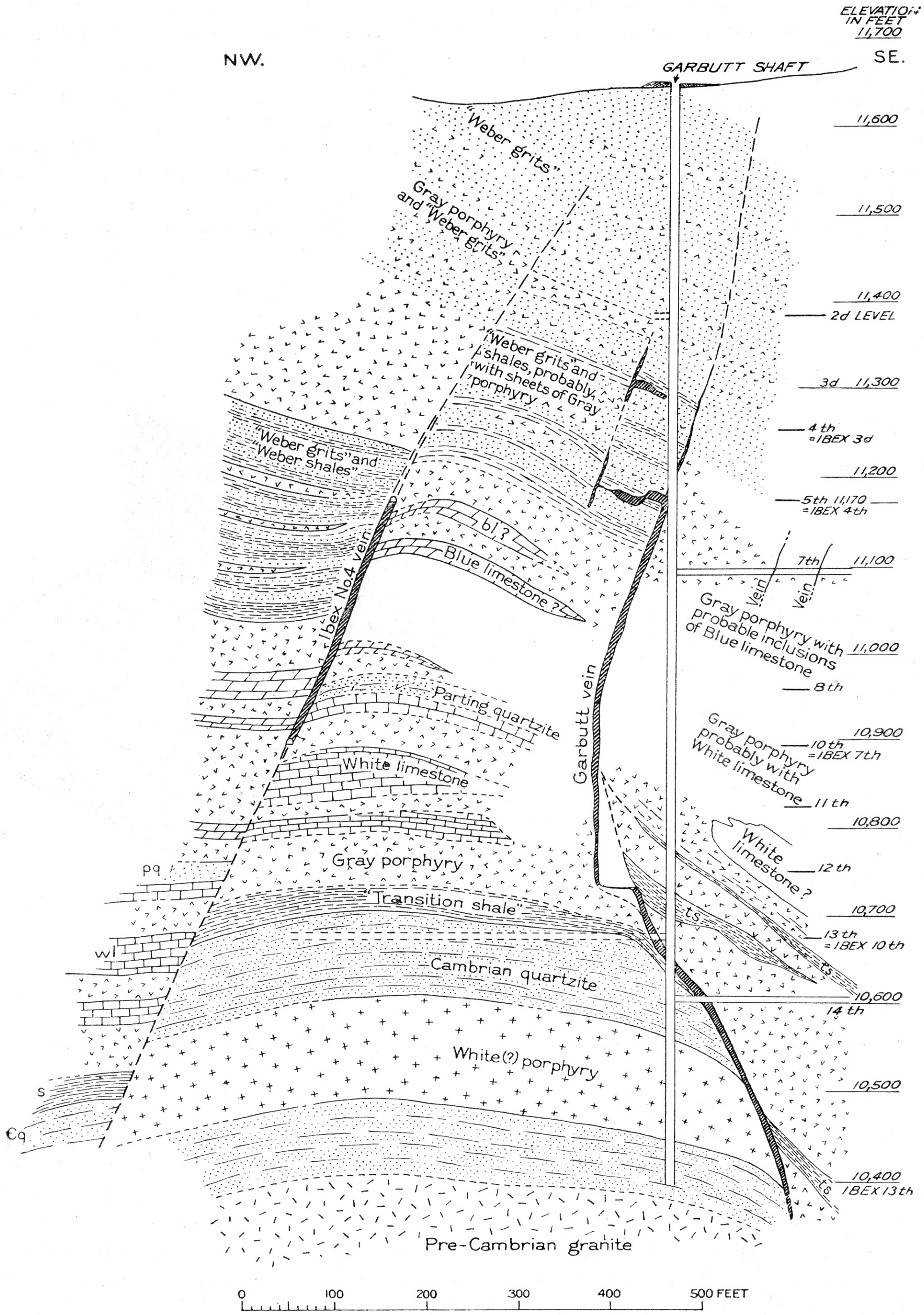


Figure 29. Section N. 70° W. through Garbutt shaft, showing faulting along Garbutt and Ibex No. 4 veins. Bl, Blue limestone; pq, Parting quartzite; wl, White limestone; s, "Transition shale"; €q, Cambrian quartzite.

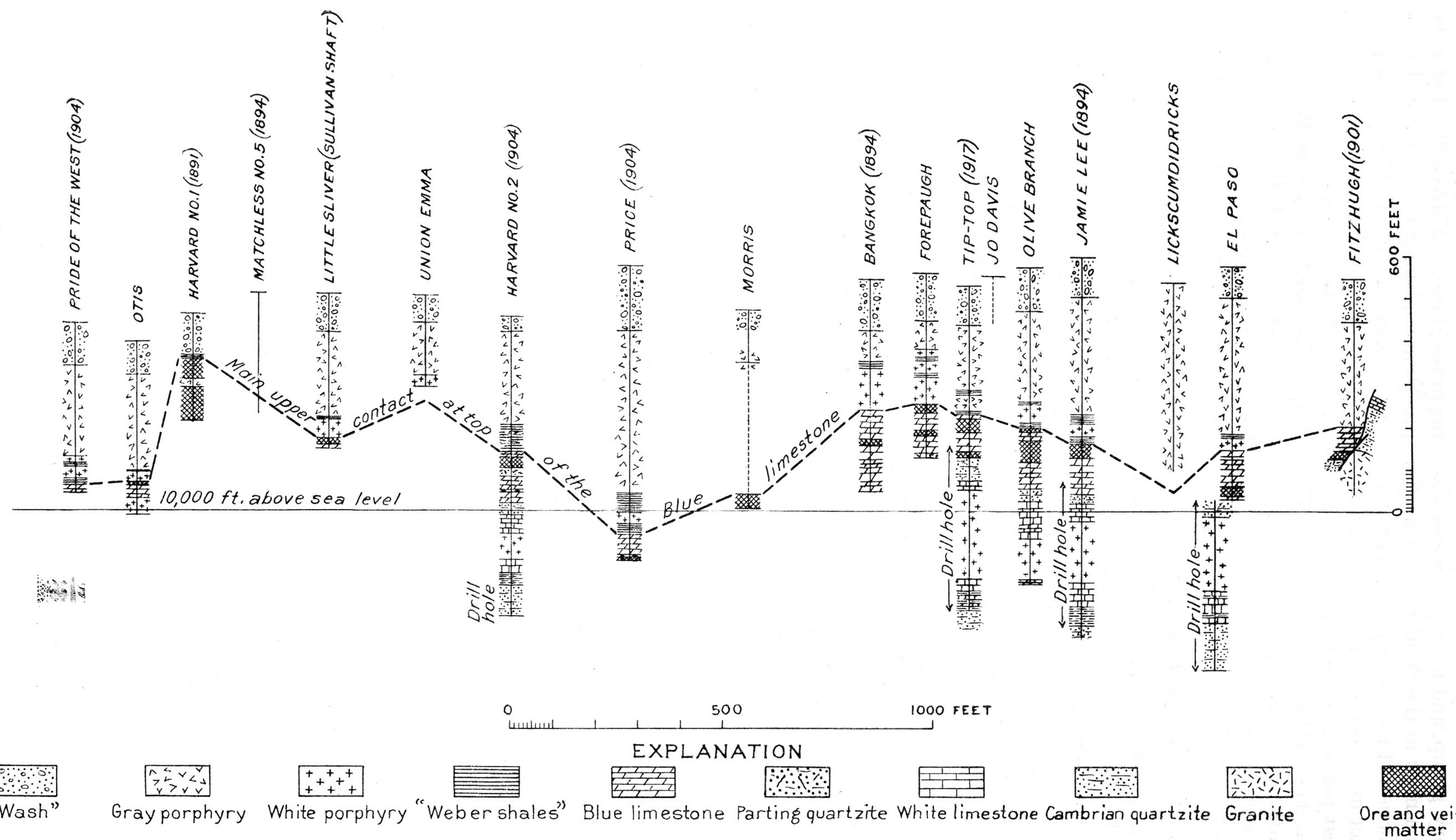


FIGURE 35.—Sections of shafts between Small Hopes mine, Fryer Hill, and Mikado fault, projected on a vertical plane trending N. 25° W. through Harvard No. 2 and Olive Branch shafts. Show developed ore bodies and relative amount of exploration of lower "contacts" in the years indicated

Figure 35. Sections of shafts between Small Hopes mine, fryer Hill, and Mikado fault, projected on a vertical plane trending N. 25° W. through Harvard No. 2 and Olive Branch shafts. Show developed bodies and relative amount of exploration of lower "contacts" in the years indicated.

INDEX TO SHAFTS AND TUNNELS

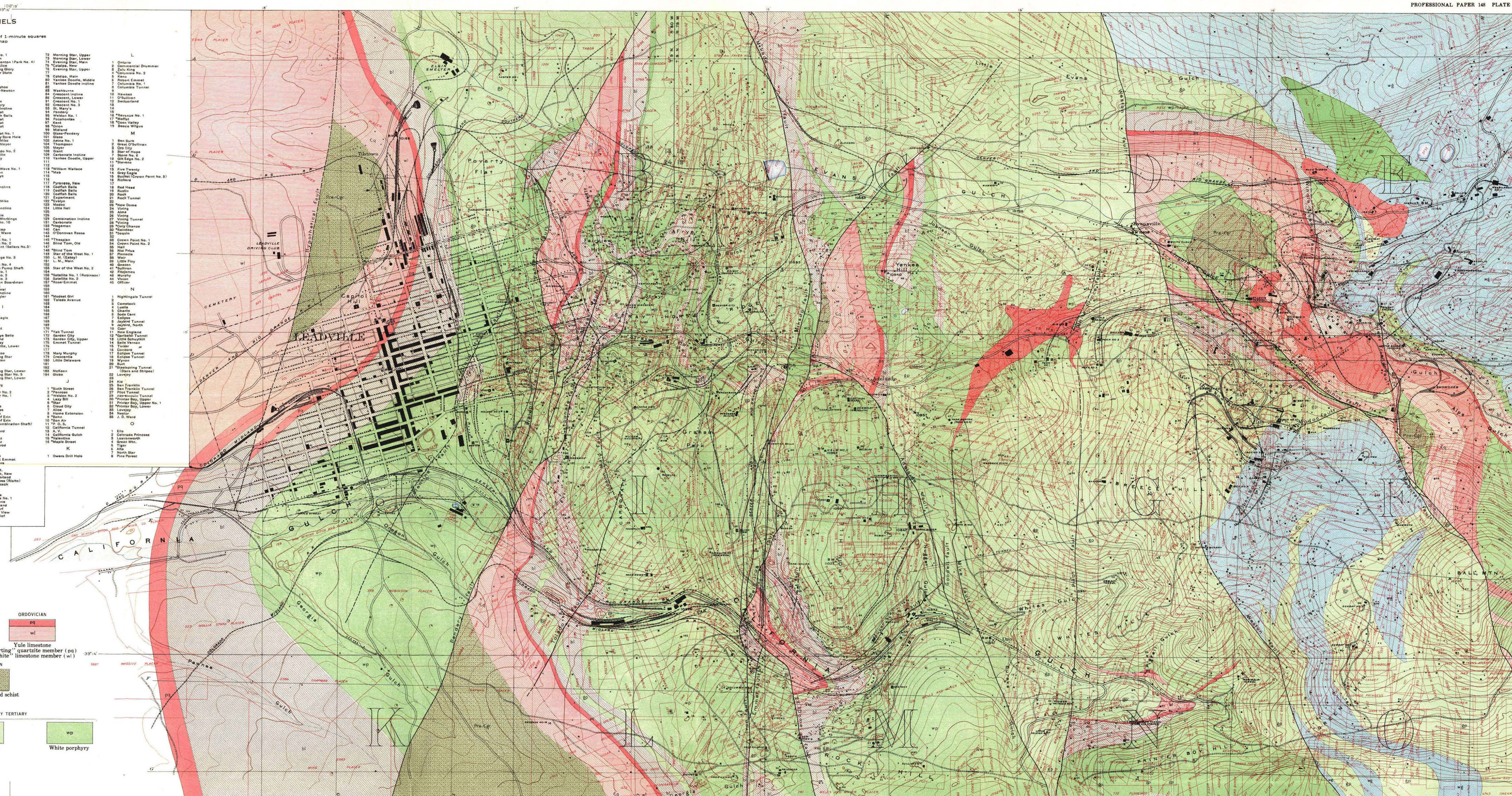
ALPHABETICALLY ARRANGED

Reference letters are large black skeleton letters near center of 1-minute squares
Asterisk (*) signifies that name is printed on map

INDEX TO SHAFTS AND TUNNELS

ARRANGED BY NUMBERS

Reference letters are large black skeleton letters near center of 1-minute squares
Asterisk (*) signifies that name is printed on map



EXPLANATION

SEDIMENTARY ROCKS

CARBONIFEROUS — DEV. (?)

Pennsylvanian — wg — Weber (?) formation

Mississippian *Upper* — bl — Leadville ("Blue") limestone

ORDOVICIAN — pq / wl — Yule limestone "Parting" quartzite member (pq) "White" limestone member (wl)

CAMBRIAN — Cq — Sawatch quartzite

PRE-CAMBRIAN — Pre-Cgr — Granite, gneiss, and schist

INTRUSIVE IGNEOUS ROCKS

Late Pliocene or early Pleistocene — ra — Rhyolite agglomerate

LATE CRETACEOUS OR EARLY TERTIARY — egp — Evans Gulch porphyry; gp — Gray porphyry; wp — White porphyry

R. B. Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by E. P. Davis and S. E. Taylor.
Control by R. B. Robertson, C. H. Semper, and S. E. Taylor.
Surveyed in 1911.

APPROXIMATE MEAN DECLINATION 1911

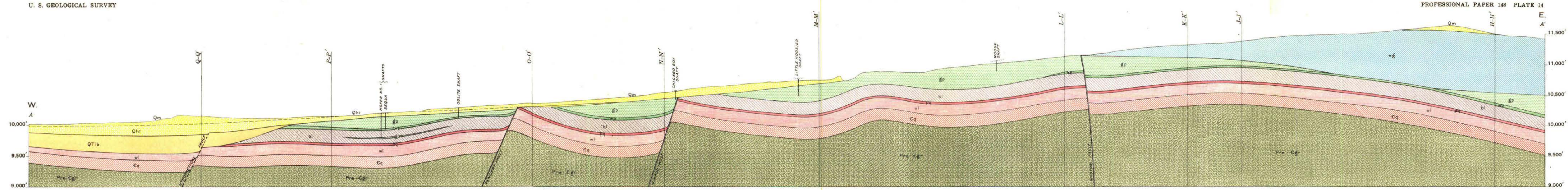
GEOLOGIC MAP OF LEADVILLE MINING DISTRICT, COLORADO

Scale 1/9600

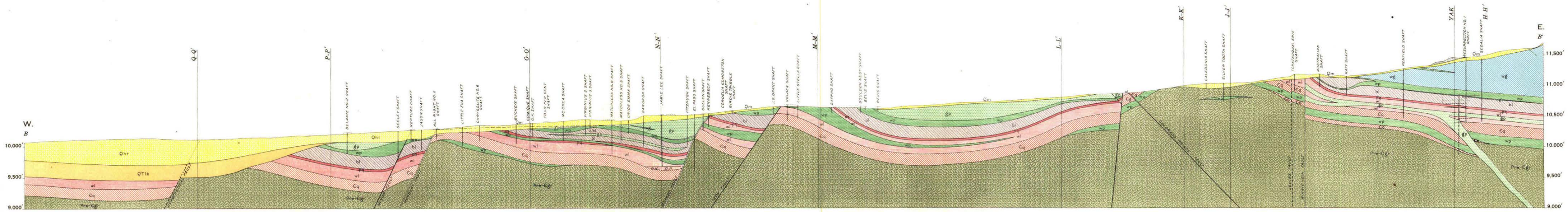
Contour interval 25 feet
Datum is mean sea level.
1927

Geology by J. D. Irving and G. F. Loughlin

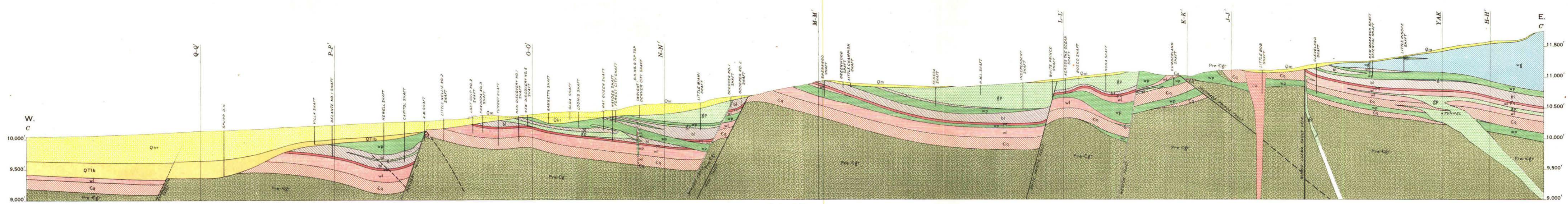
PLATE 13



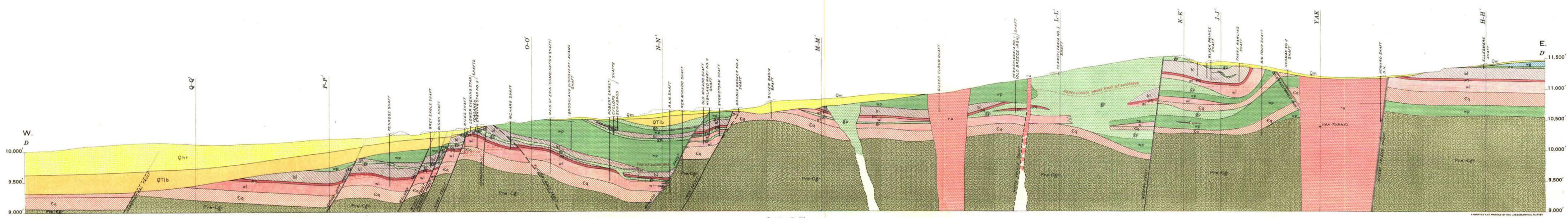
Section A–A'



Section B–B'



Section C–C'



Section D–D'

GEOLOGIC SECTIONS ALONG LINES A–A' TO D–D', PLATE 13, LEADVILLE MINING DISTRICT, COLORADO

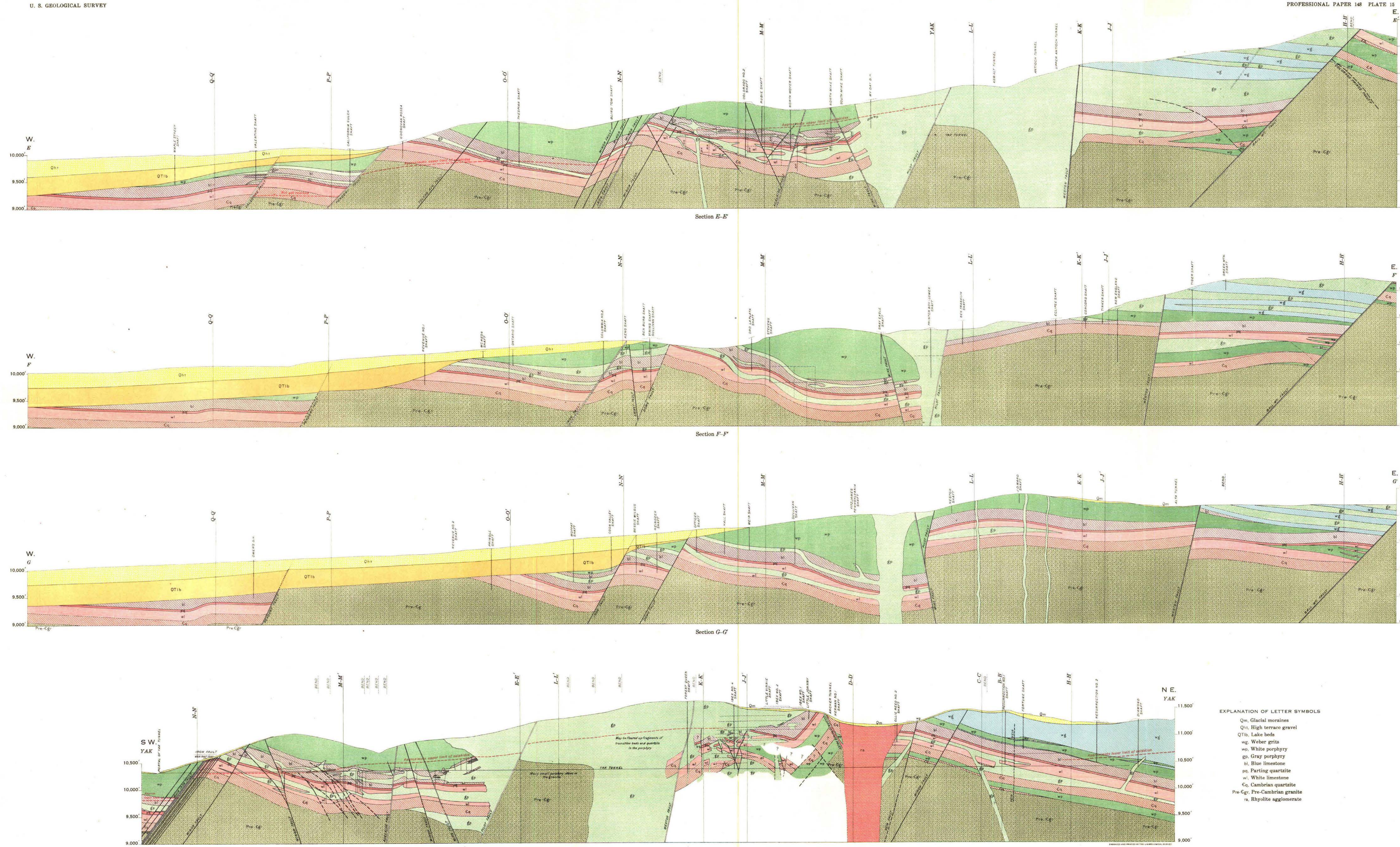
0 ⅛ ¼ ½ ¾ 1 Mile

EXPLANATION OF LETTER SYMBOLS

Qm, Moraines Qht, High terrace gravel QTlb, Lake beds wg, Weber grits wp, White porphyry gp, Gray porphyry bl, Blue limestone pq, Parting quartzite wl, White limestone €q, Cambrian quartzite Pre-€gr, Pre-Cambrian granite ra, Rhyolite agglomerate

1927

PLATE 14

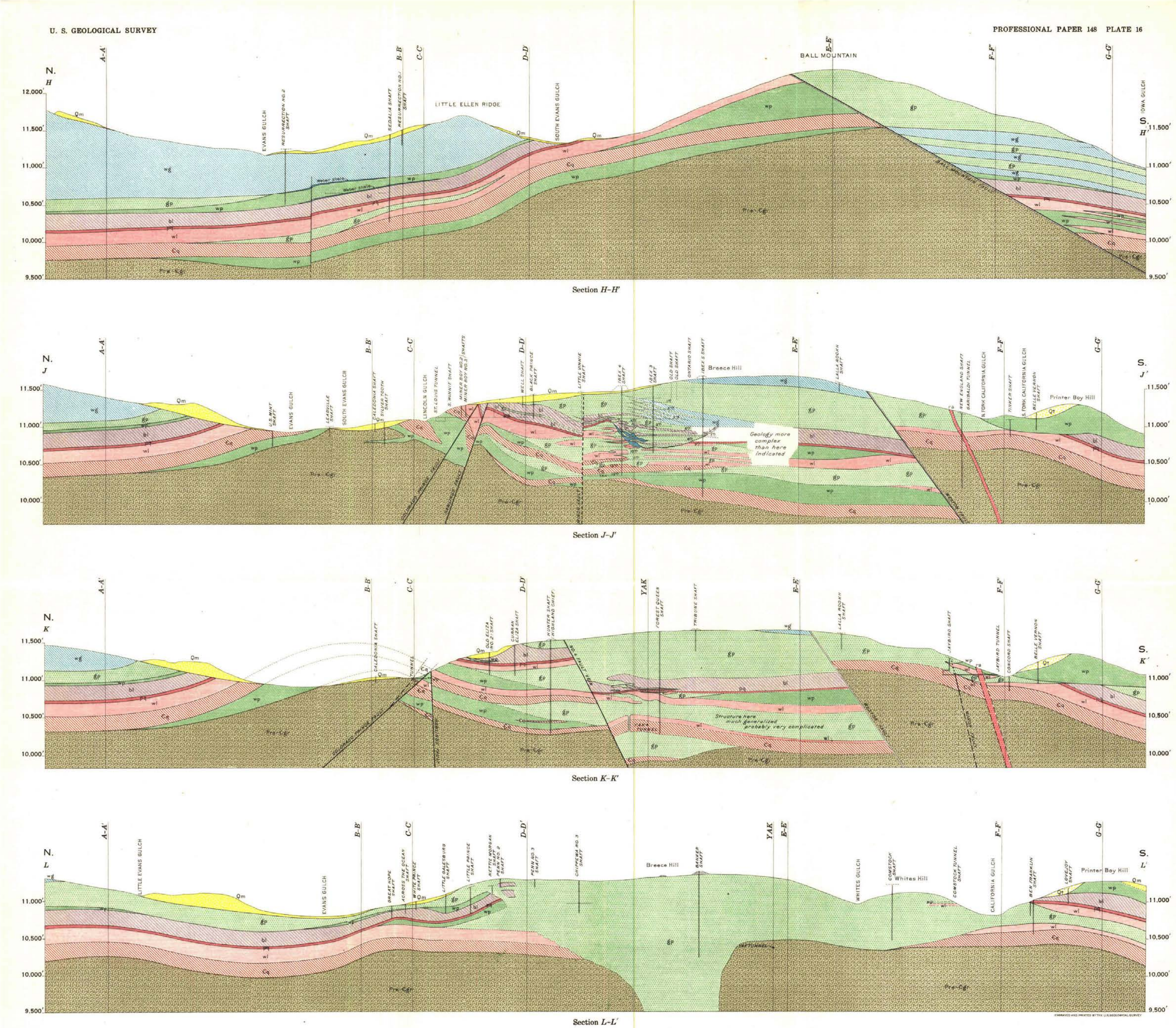


GEOLOGIC SECTIONS ALONG LINES E-E' TO YAK, PLATE 13, LEADVILLE MINING DISTRICT, COLORADO

1927

PLATE 15

PLATE 16.

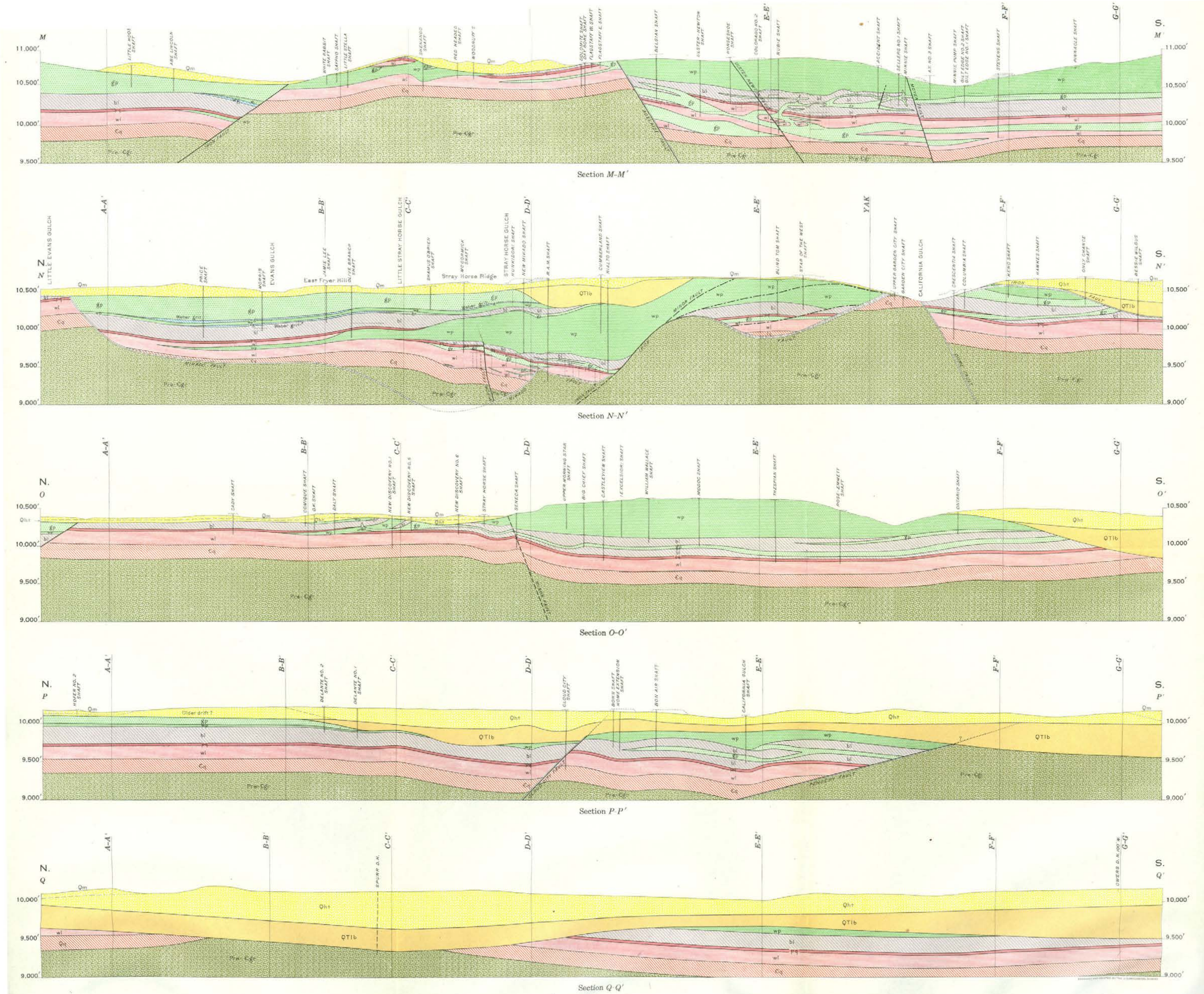


GEOLOGIC SECTIONS ALONG LINES H-H′ TO L-L′, PLATE 13, LEADVILLE MINING DISTRICT, COLORADO

EXPLANATION OF LETTER SYMBOLS

Qt, Talus   Qm, Moraines   wg, Weber grits   wp, White porphyry   gp, Gray porphyry   bl, Blue limestone   pq, Parting quartzite   wl, White limestone   €q Cambrian quartzite
Pre-€gr, Pre-Cambrian granite   ra, Rhyolite agglomerate

PLATE 17.



GEOLOGIC SECTIONS ALONG LINES M-M' TO Q-Q', PLATE 13, LEADVILLE MINING DISTRICT, COLORADO

EXPLANATION OF LETTER SYMBOLS

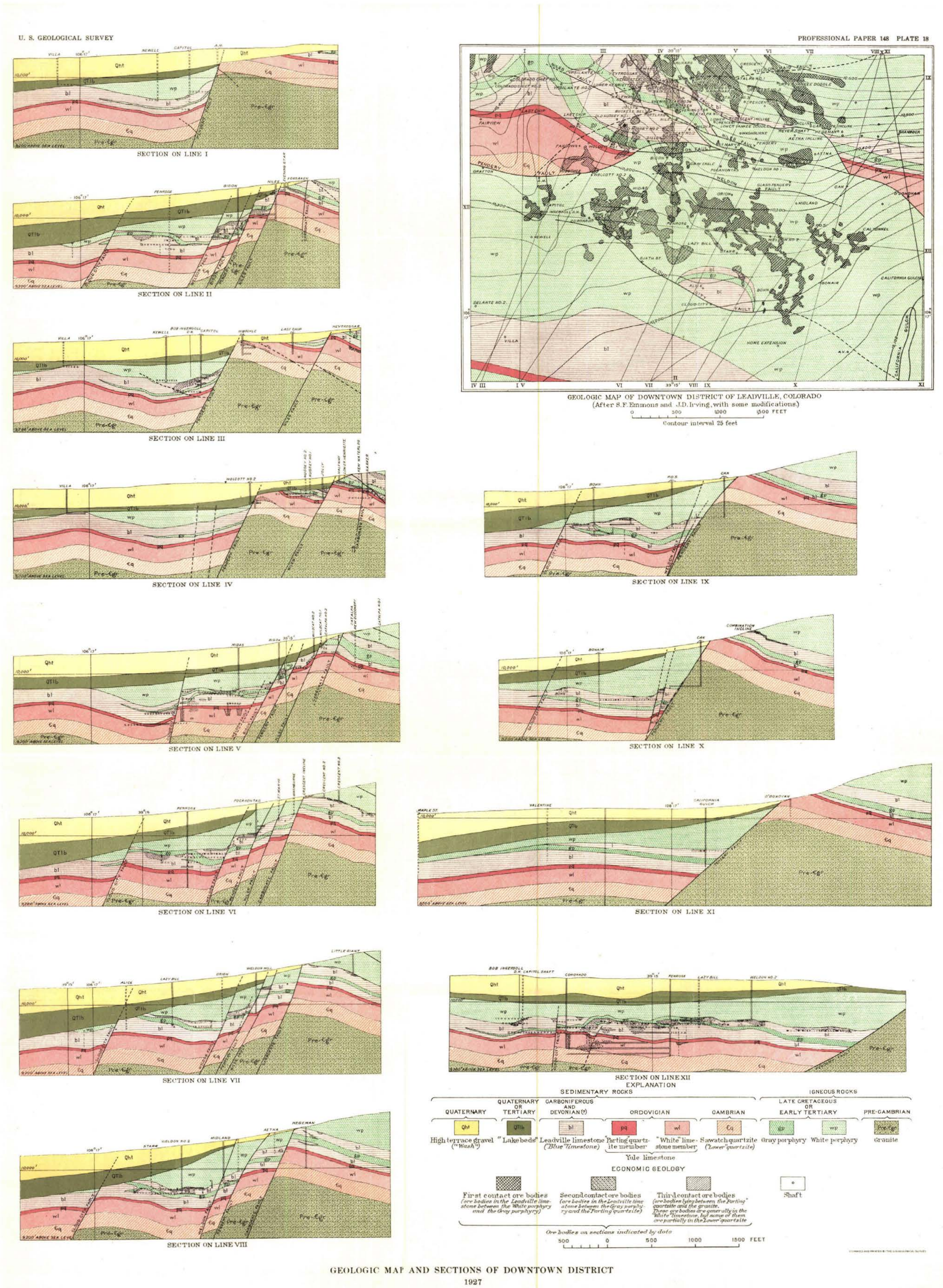

U. S. GEOLOGICAL SURVEY
PROFESSIONAL PAPER 148 PLATE 18
SECTION ON LINE I
SECTION ON LINE II
SECTION ON LINE III
SECTION ON LINE IV
SECTION ON LINE V
SECTION ON LINE VI
SECTION ON LINE VII
SECTION ON LINE VIII
GEOLOGIC MAP OF DOWNTOWN DISTRICT OF LEADVILLE, COLORADO
(After S.F. Emmons and J.D. Irving, with some modifications)
Contour interval 25 feet
SECTION ON LINE IX
SECTION ON LINE X
SECTION ON LINE XI
SECTION ON LINE XII
EXPLANATION
SEDIMENTARY ROCKS
IGNEOUS ROCKS
QUATERNARY
QUATERNARY OR TERTIARY
CARBONIFEROUS AND DEVONIAN(?)
ORDOVICIAN
CAMBRIAN
LATE CRETACEOUS OR EARLY TERTIARY
PRE-CAMBRIAN
High terrace gravel ("Wash")
"Lake beds"
Leadville limestone ("Blue" limestone)
Parting quartzite member
"White" limestone member
Yule limestone
Sawatch quartzite ("Lower" quartzite)
Gray porphyry
White porphyry
Granite
ECONOMIC GEOLOGY
First contact ore bodies (ore bodies in the Leadville limestone between the White porphyry and the Gray porphyry)
Second contact ore bodies (ore bodies in the Leadville limestone between the Gray porphyry and the Parting quartzite)
Third contact ore bodies (ore bodies lying between the Parting quartzite and the granite. These ore bodies are generally in the White limestone, but some of them are partially in the Lower quartzite)
Shaft
Ore bodies on sections indicated by dots
GEOLOGIC MAP AND SECTIONS OF DOWNTOWN DISTRICT
1927

PLATE 18.

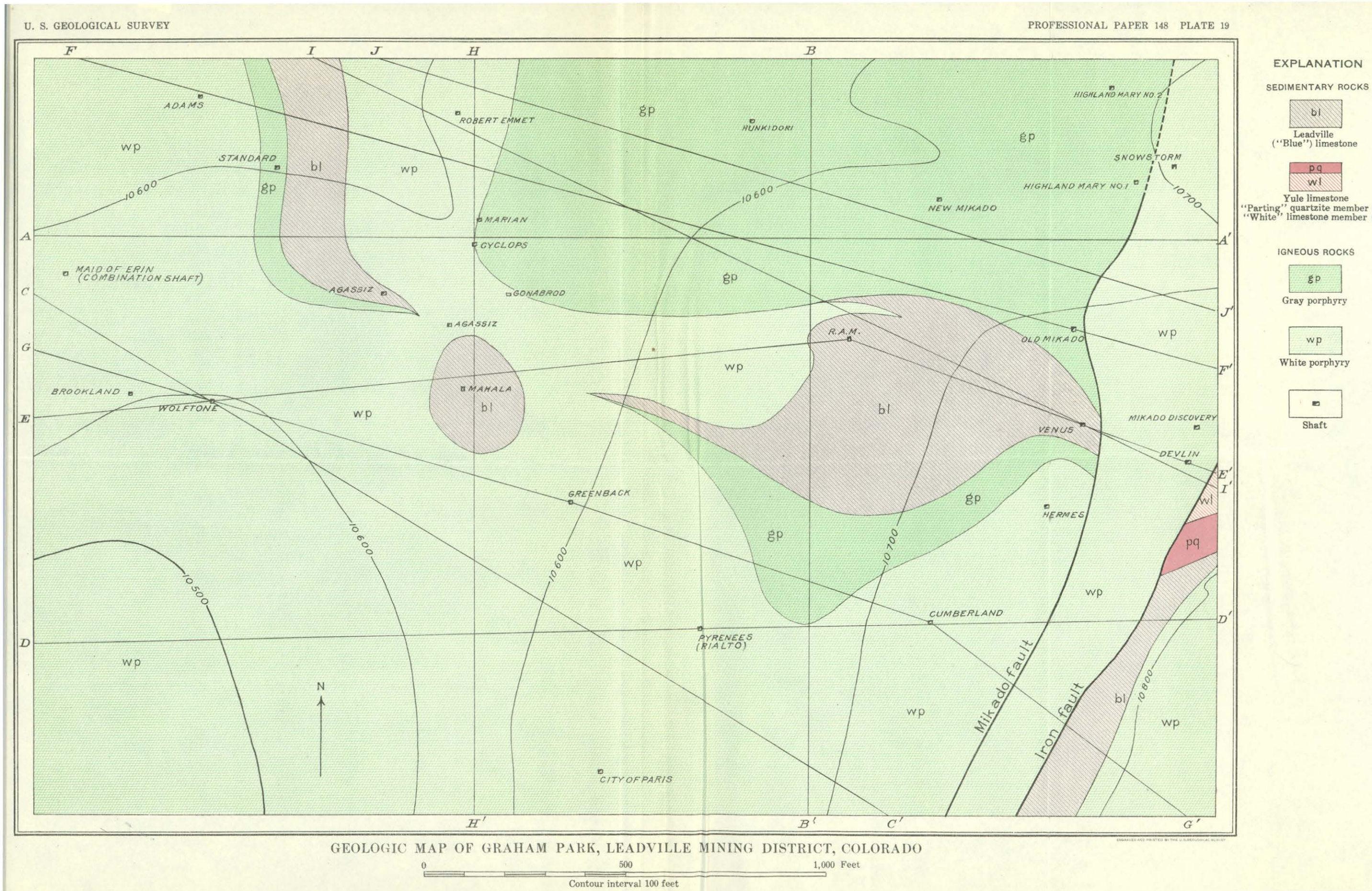
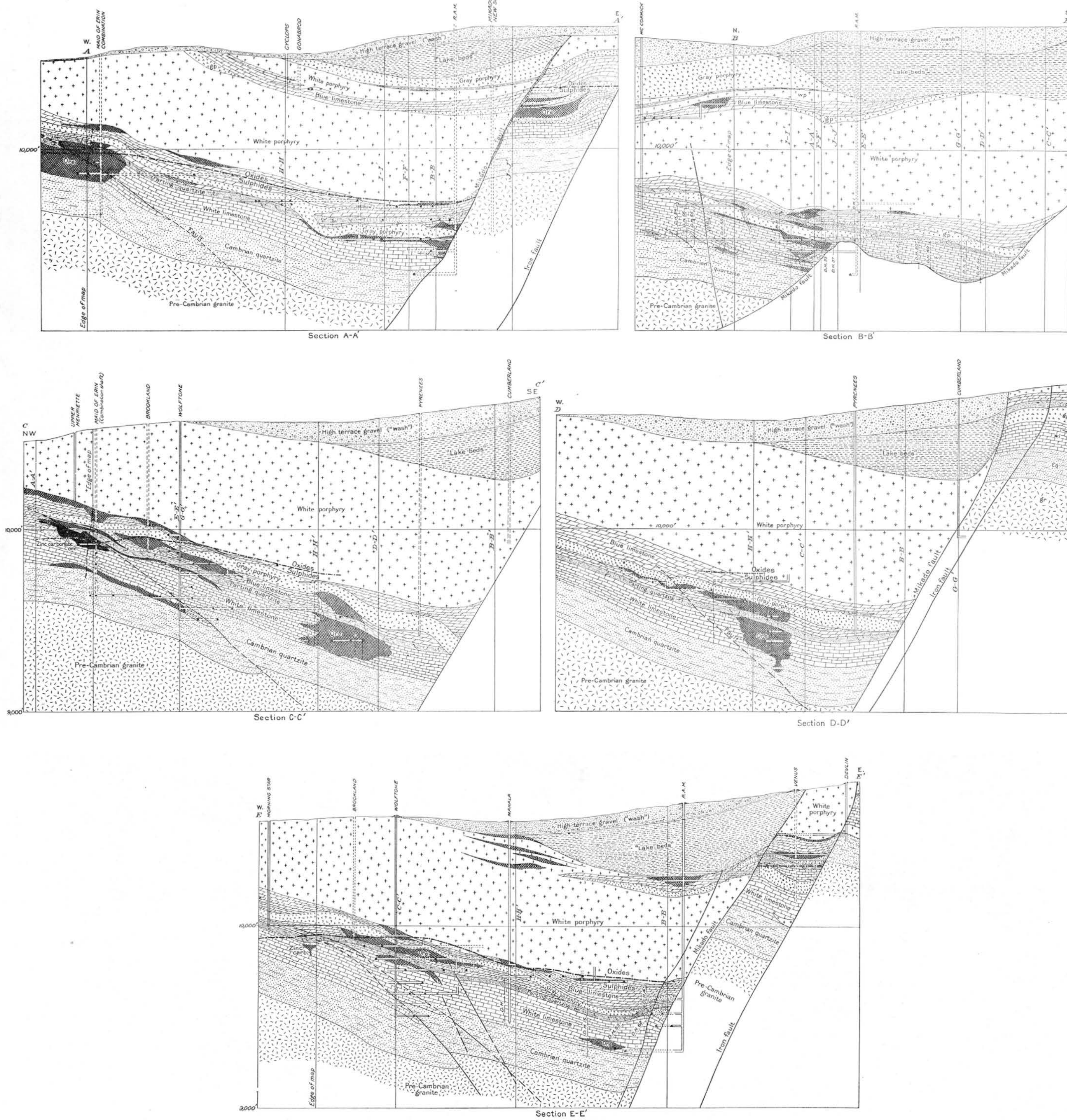

U. S. GEOLOGICAL SURVEY
PROFESSIONAL PAPER 148 PLATE 19
EXPLANATION
SEDIMENTARY ROCKS
Leadville ("Blue") limestone
Yule limestone
IGNEOUS ROCKS
Gray porphyry
White porphyry
Shaft
Mikado fault
Iron fault
ADAMS
STANDARD
ROBERT EMMET
RUNKIDORI
HIGHLAND MARY NO. 2
SNOWSTORM
HIGHLAND MARY NO. 1
NEW MIKADO
MARIAN
CYCLOPS
MAID OF ERIN (COMBINATION SHAFT)
AGASSIZ
GONABROD
R.A.M.
OLD MIKADO
MAHALA
BROOKLAND
WOLFTONE
VENUS
MIKADO DISCOVERY
DEVLIN
GREENBACK
HERMES
CUMBERLAND
PYRENEES (RIALTO)
CITY OF PARIS
GEOLOGIC MAP OF GRAHAM PARK, LEADVILLE MINING DISTRICT, COLORADO
Contour interval 100 feet

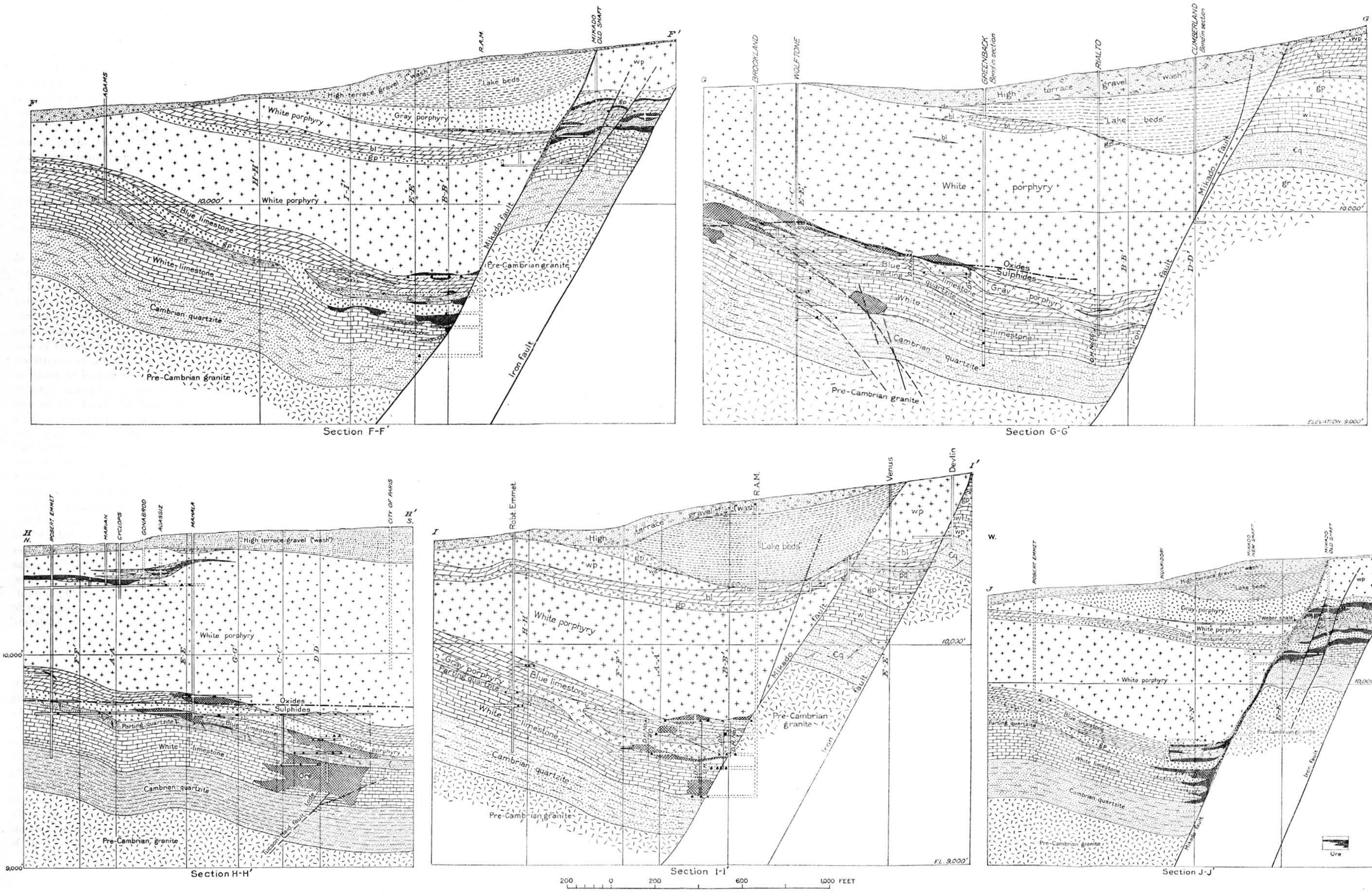
PLATE 19.



GEOLOGIC SECTIONS IN GRAHAM PARK

For lines of sections and explanation of symbols see Plate 19

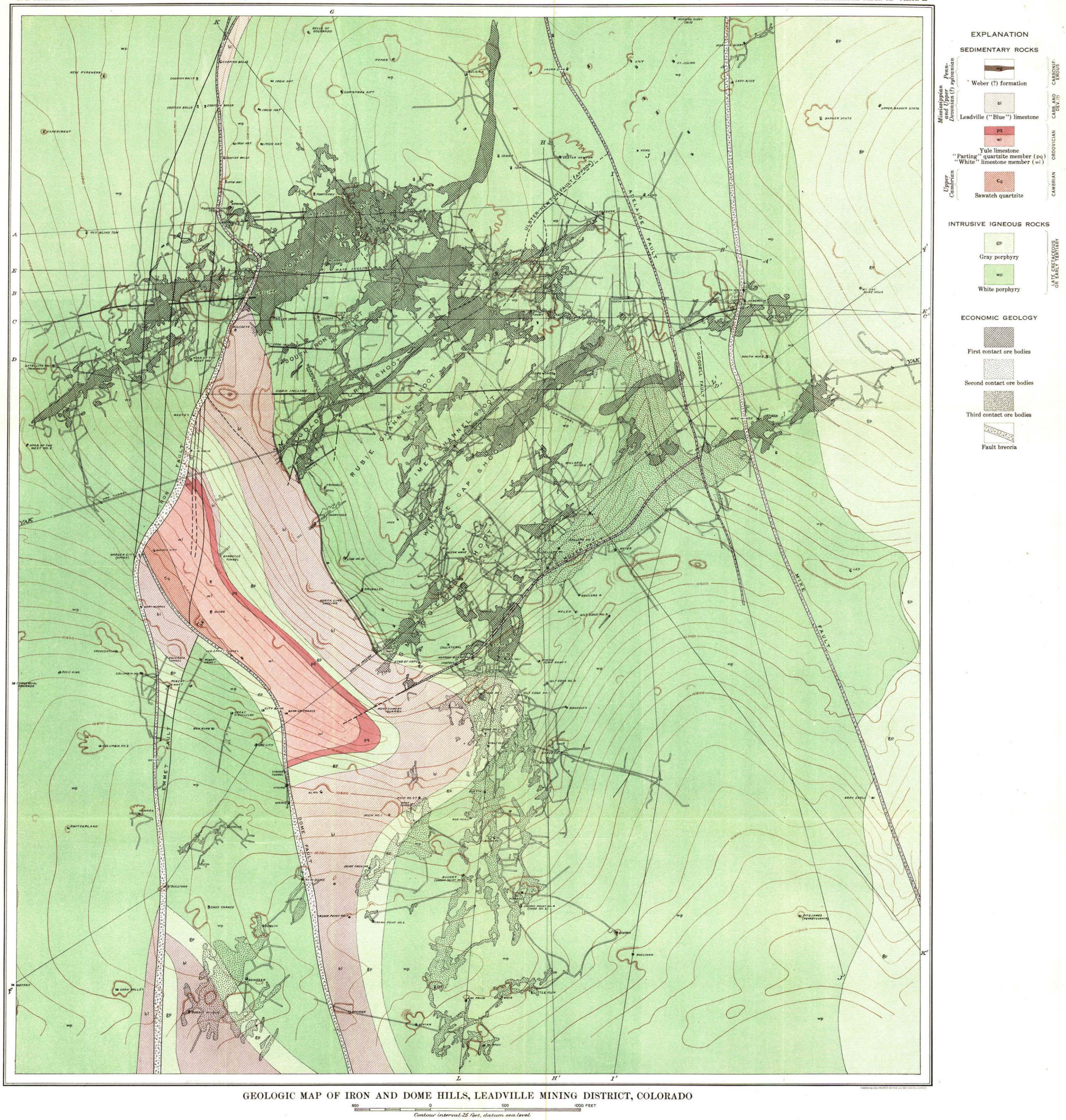
PLATE 20.



GEOLOGIC SECTIONS IN GRAHAM PARK

For lines of sections and explanation of symbols see Plate 19

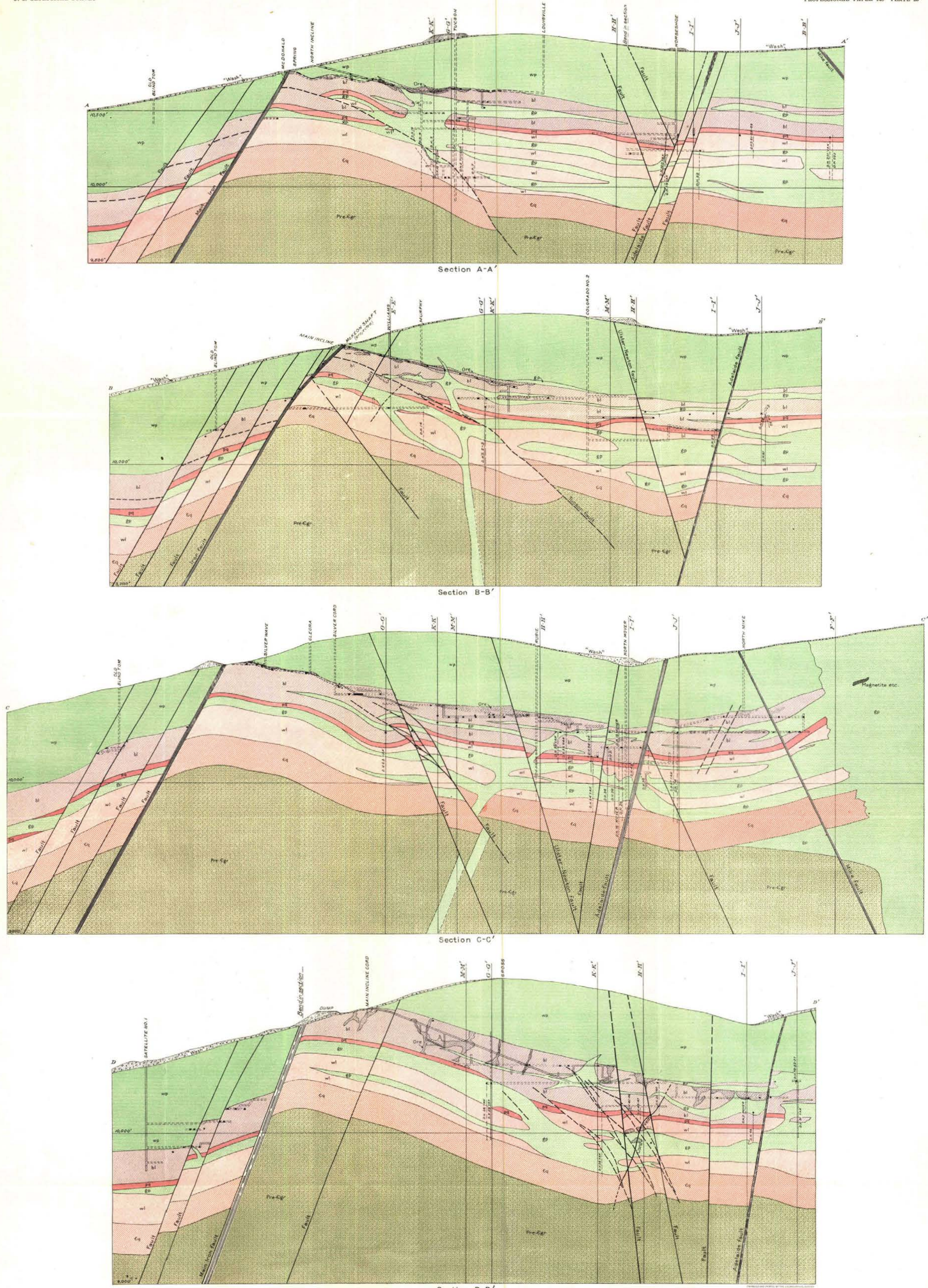
PLATE 21.



GEOLOGIC MAP OF IRON AND DOME HILLS, LEADVILLE MINING DISTRICT, COLORADO

1927

PLATE 22.



GEOLOGIC SECTIONS ALONG LINES A-A' TO D-D', PLATE 22, IRON AND DOME HILLS, LEADVILLE MINING DISTRICT, COLORADO

500 0 500 1000 FEET

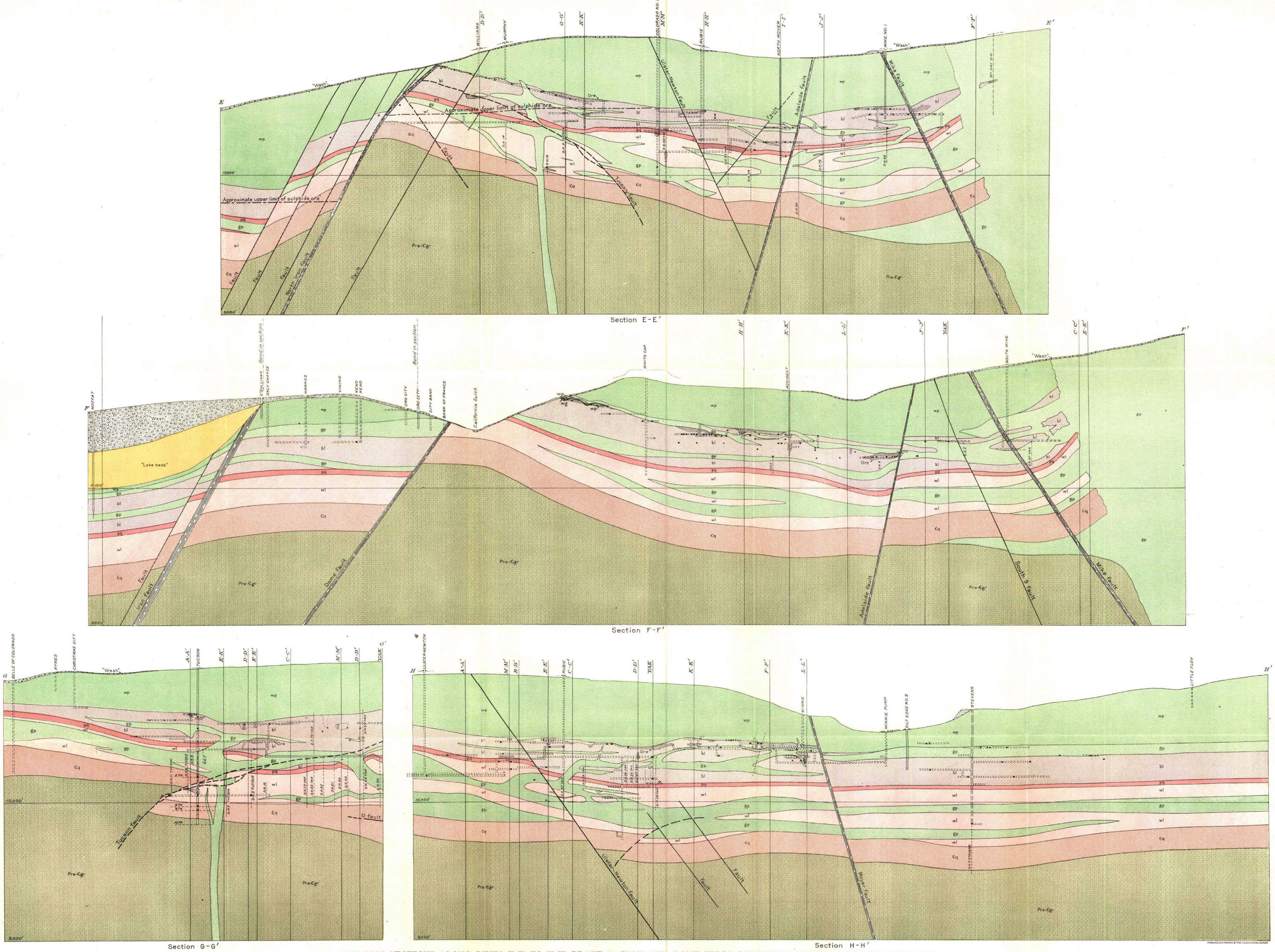
EXPLANATION OF LETTER SYMBOLS

wp, White porphyry bl, Blue limestone gp, Gray porphyry pq, Parting quartzite wl, White limestone €q, Cambrian quartzite Pre-€gr, Pre-Cambrian granite

For full explanation of letter symbols, see Plate 22

1927

PLATE 23.



GEOLOGIC SECTIONS ALONG LINES E-E′ TO H-H′, PLATE 22, IRON AND DOME HILLS, LEADVILLE MINING DISTRICT, COLORADO

500 0 500 1000 FEET

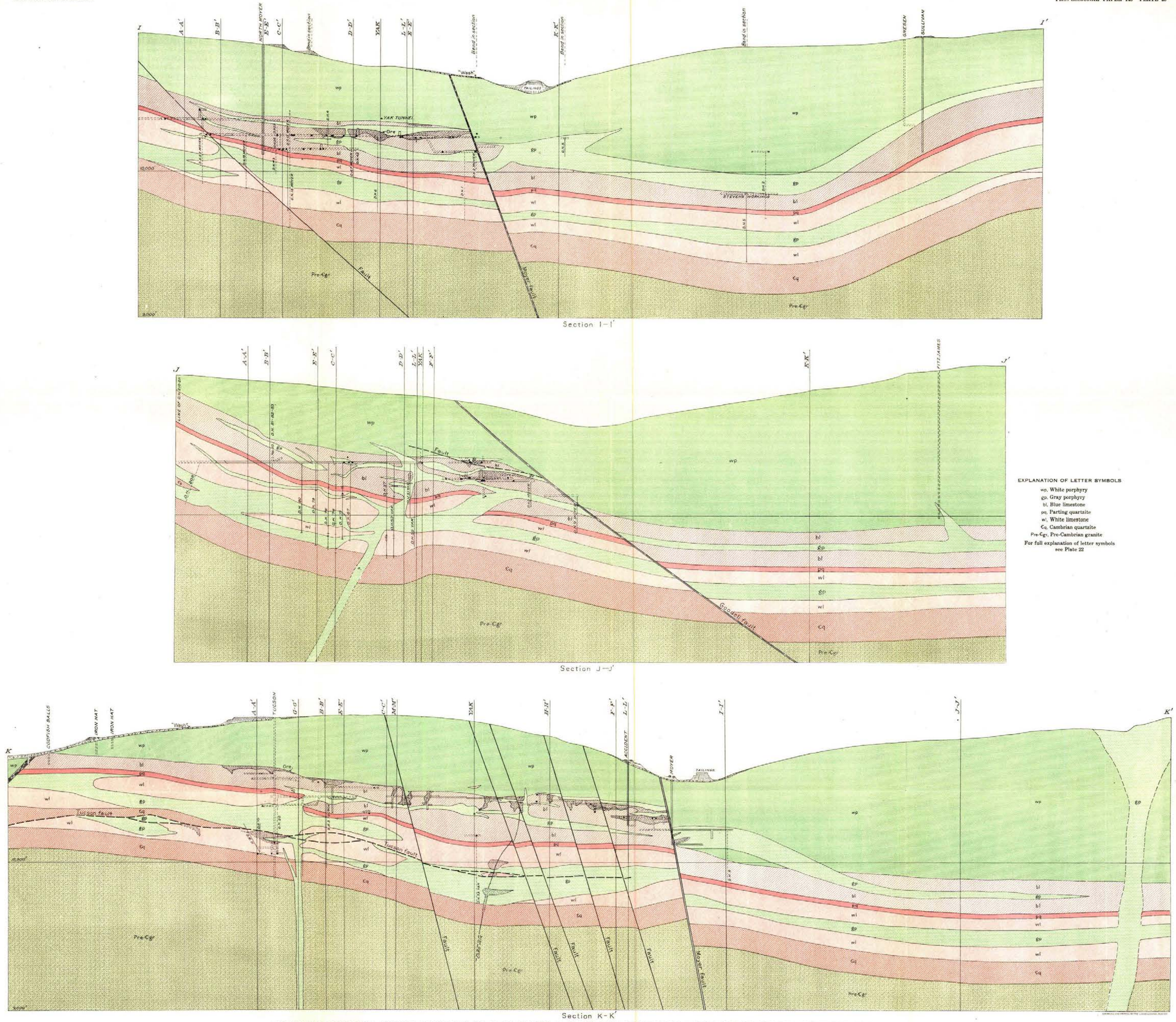
EXPLANATION OF LETTER SYMBOLS

wg, Weber grits wp, White porphyry bl, Blue limestone gp, Gray porphyry pq, Parting quartzite wl, White limestone Єq Cambrian quartzite Pre-Єgr, Pre-Cambrian granite

For full explanation of letter symbols, see Plate 22

1927

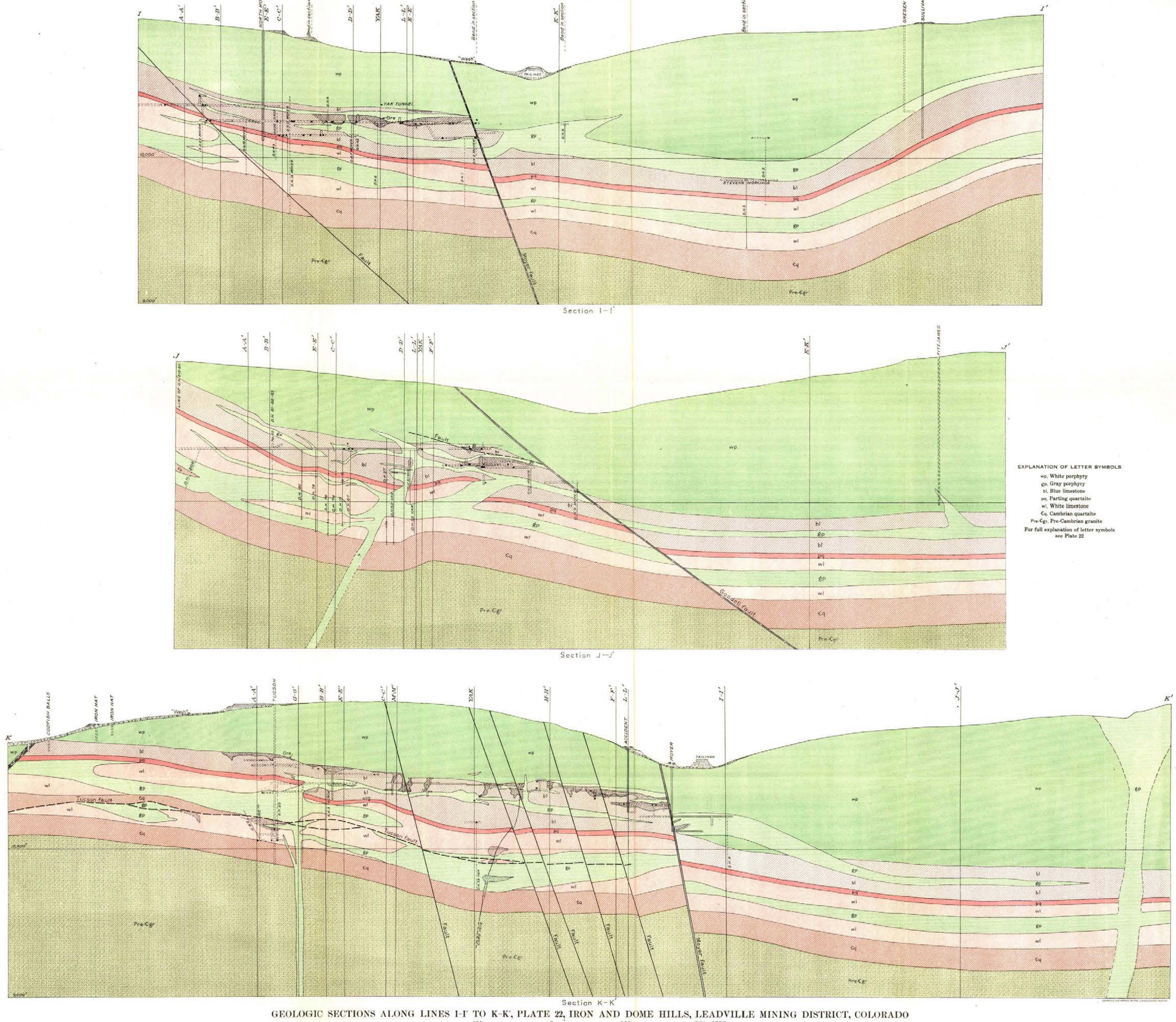
PLATE 24.



GEOLOGIC SECTIONS ALONG LINES I-I' TO K-K', PLATE 22, IRON AND DOME HILLS, LEADVILLE MINING DISTRICT, COLORADO

1927

PLATE 25.



GEOLOGIC SECTIONS ALONG LINES I-I' TO K-K', PLATE 22, IRON AND DOME HILLS, LEADVILLE MINING DISTRICT, COLORADO

500 0 500 1000 FEET

1927

PLATE 26.

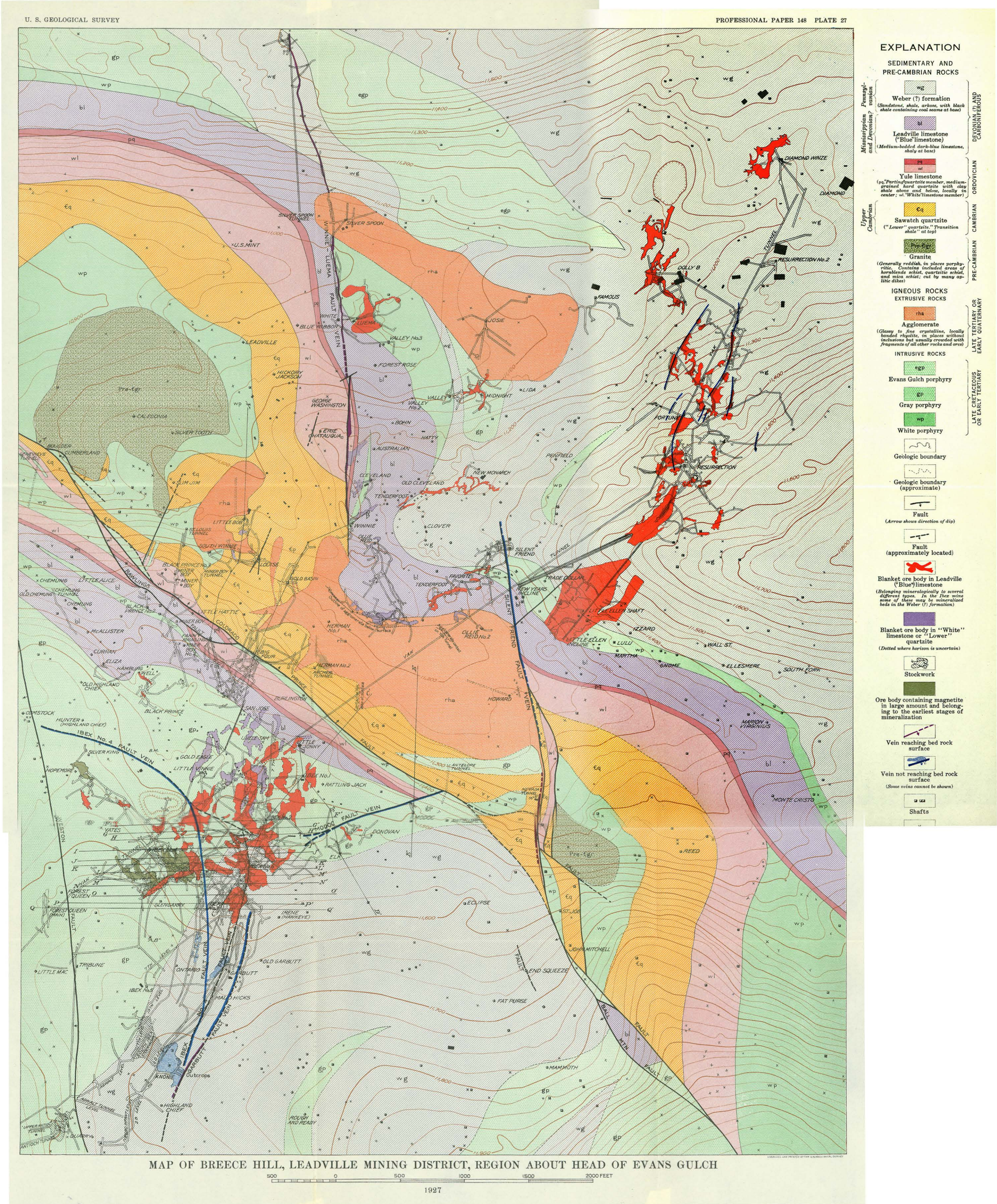
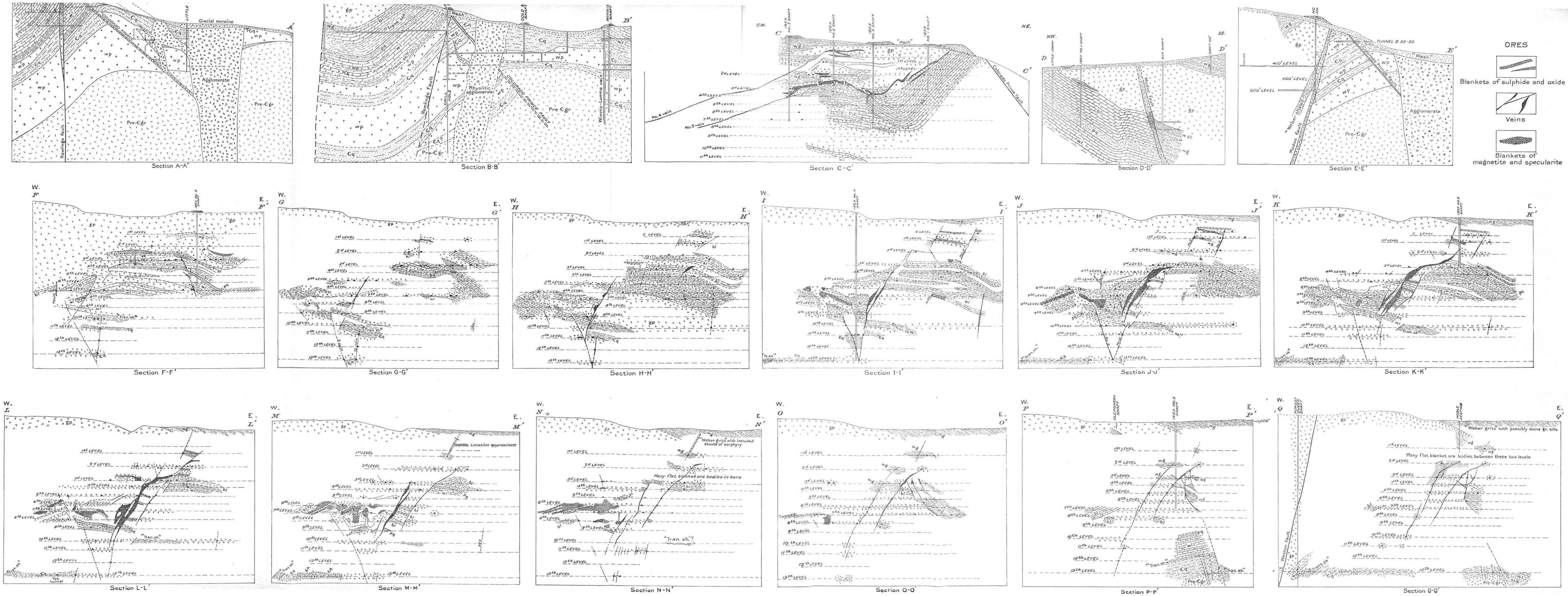
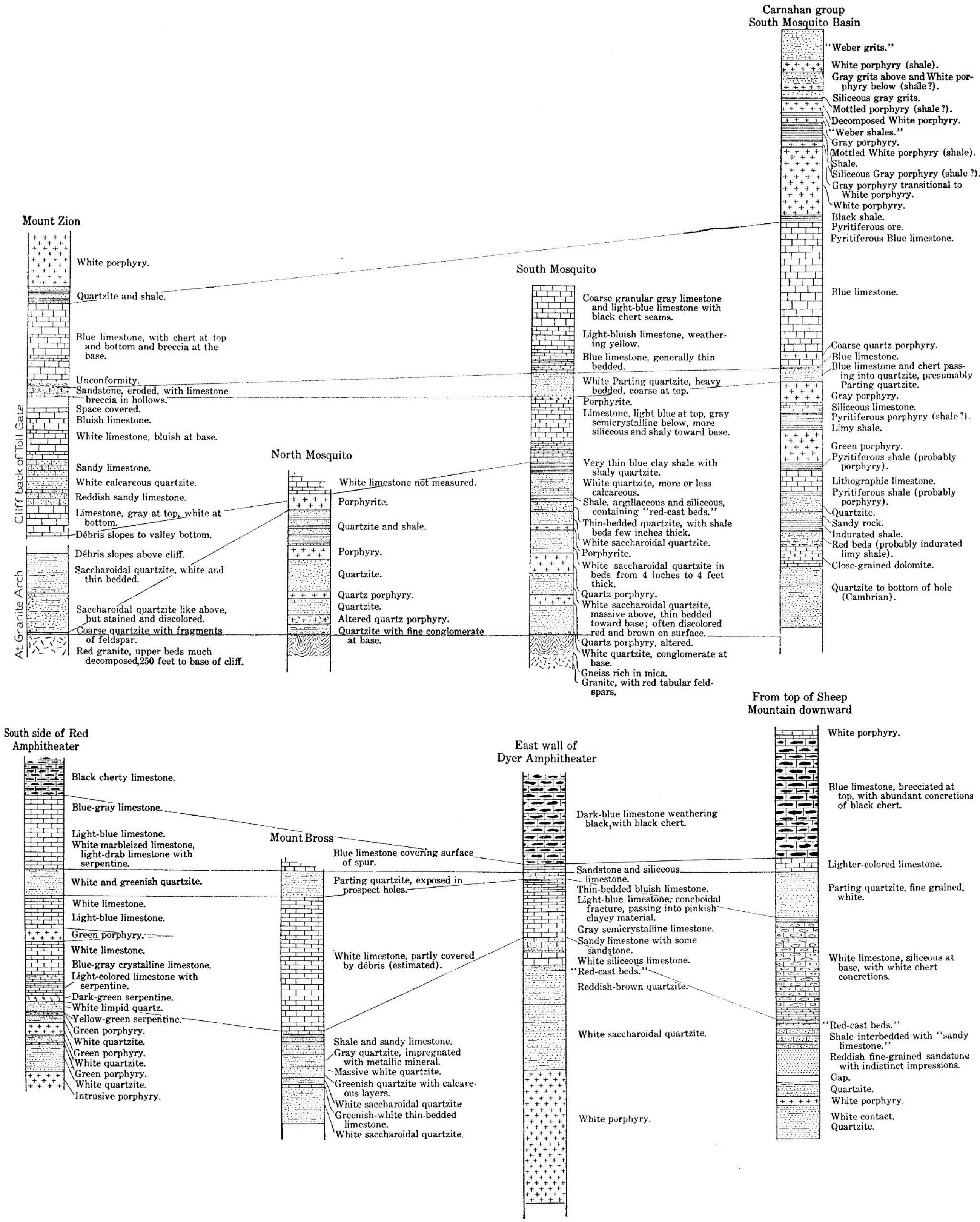

U. S. GEOLOGICAL SURVEY
PROFESSIONAL PAPER 148 PLATE 27
EXPLANATION
SEDIMENTARY AND PRE-CAMBRIAN ROCKS
Weber (?) formation
Leadville limestone ("Blue" limestone)
Yule limestone
Sawatch quartzite
Granite
IGNEOUS ROCKS
EXTRUSIVE ROCKS
Agglomerate
INTRUSIVE ROCKS
Evans Gulch porphyry
Gray porphyry
White porphyry
Geologic boundary
Geologic boundary (approximate)
Fault
Fault (approximately located)
Blanket ore body in Leadville ("Blue") limestone
Blanket ore body in "White" limestone or "Lower" quartzite
Stockwork
Ore body containing magnetite in large amount and belonging to the earliest stages of mineralization
Vein reaching bed rock surface
Vein not reaching bed rock surface
Shafts
MAP OF BREECE HILL, LEADVILLE MINING DISTRICT, REGION ABOUT HEAD OF EVANS GULCH
500 0 500 1000 1500 2000 FEET
1927

PLATE 27.



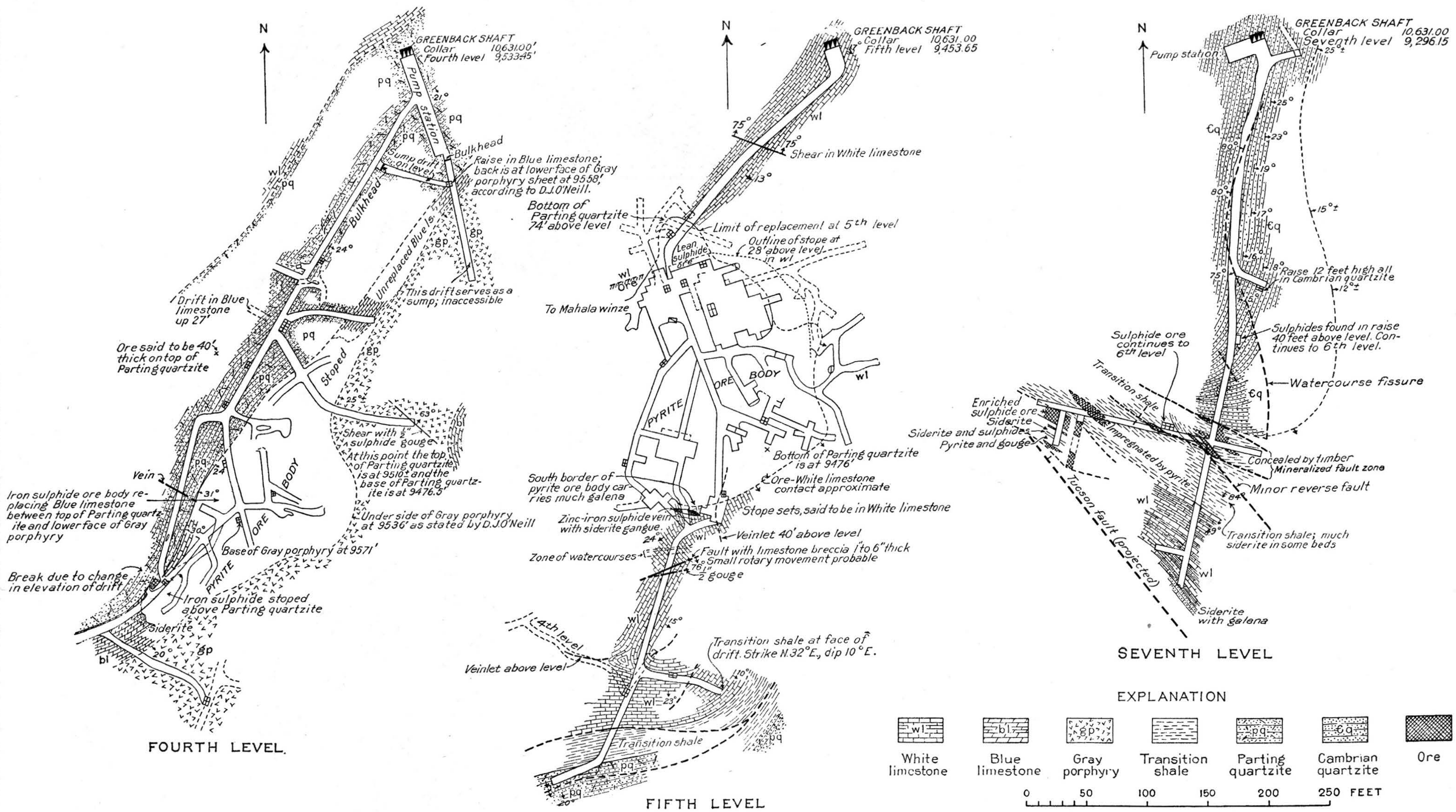
Section A-A'
Glacial moraine
Agglomerate
Pre-Є gr
Rawlings fault
Section B-B'
Rhyolitic agglomerate
Winnie-Luema vein
Section C-C'
Section D-D'
Section E-E'
ORES
Blankets of sulphide and oxide
Veins
Blankets of magnetite and specularite
Section F-F'
Section G-G'
Section H-H'
Section I-I'
Section J-J'
Section K-K'
Section L-L'
Section M-M'
Section N-N'
Many flat blanket ore bodies in here
Section O-O'
Section P-P'
Section Q-Q'
Many flat blanket ore bodies between these two levels

PLATE 28



COMPARATIVE STRATIGRAPHIC SECTIONS IN MOSQUITO RANGE

PLATE 29.



PLANS OF FOURTH, FIFTH, AND SEVENTH LEVELS OF GREENBACK MINE

By F. A. Aicher

PLATE 40.

INDEX TO SHAFTS AND TUNNELS

ALPHABETICALLY ARRANGED

Reference letters are large black skeleton letters near center of 1-minute squares
Asterisk (*) signifies that name is printed on map

INDEX TO SHAFTS AND TUNNELS

ARRANGED BY NUMBERS

Reference letters are large black skeleton letters near center of 1-minute squares
Asterisk (*) signifies that name is printed on map

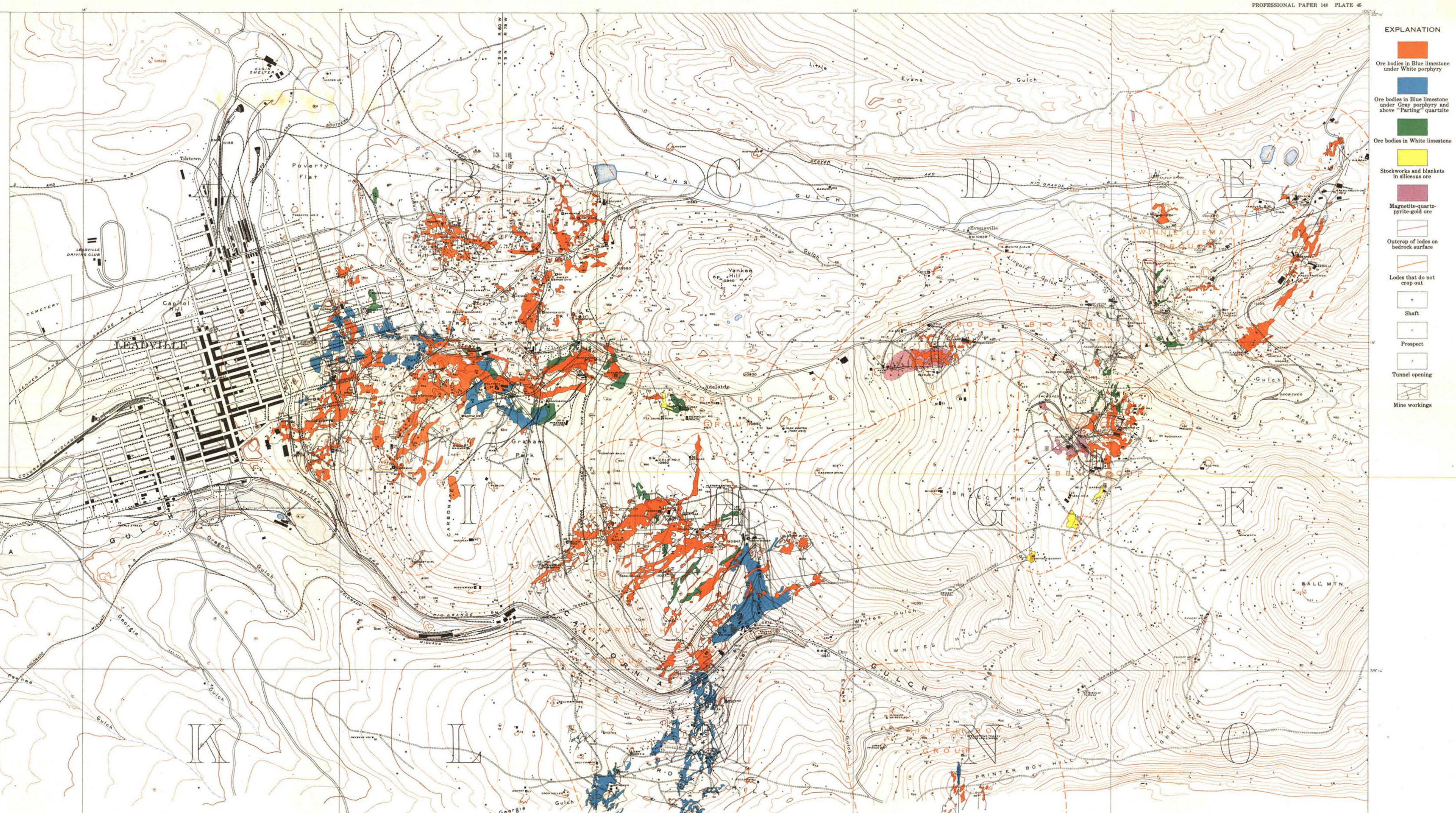


PLATE 45

R.B. Marshall, Chief Geographer.
Sledge Tatum, Geographer in charge.
Topography by E.P. Davis and S.E. Taylor.
Control by R.B. Robertson, C.H. Semper, and S.E. Taylor.
Surveyed in 1911.

MAP SHOWING ORE BODIES IN LEADVILLE MINING DISTRICT, COLORADO

Scale $\frac{1}{9600}$

0 — 1/8 — 1/4 — 1/2 — 3/4 — 1 Mile

1000 — 500 — 0 — 1000 — 2000 — 3000 — 4000 Feet

200 — 100 — 0 — 500 — 1000 Meters

Contour interval 25 feet

Datum is mean sea level.

1927

Geology and Ore Deposits Of the West Slope

Of the Mosquito Range (Behre, 1953)

Professional Paper 235

ORE DEPOSITS
Mineralogy of the Ores
LIMITS OF STUDY

The present report deals primarily with the mineralogy of the ores of the outlying region, beyond the Central Leadville district treated in Professional Paper 148. The mineralogy of the central district was very fully discussed in that report. In the marginal region, only a few mines were accessible and little mineral collecting could be accomplished. The following discussion is probably not complete but will afford a basis for comparison with the central part of the district and with similar deposits elsewhere.

BASIS FOR CLASIFICATION

A classification has been followed that is essentially economic and chemical, and hence most useful to the miner. All minerals that yield the same metal in common metallurgical processes are grouped together, and in the detailed description of the minerals, the lead minerals are discussed first, then the zinc minerals, and so on. A classification more in favor among mining geologists is that based on genesis; this is given below in brief tabulated form. According to this classification, based largely on the work of Lindgren (1933, pp. 207–212) and subsequently followed by most mining geologists here and abroad, the formation of minerals in ore deposits is determined largely by the temperatures during deposition; variations in depth and in distance from a magmatic source especially affect the temperatures during deposition; variations in depth and in distance from a magmatic source especially affect the temperatures of the depositing solutions and the pressures under which they lose their mineral content. Certain minerals may be regarded as geologic thermometers, and their temperature of formation may be roughly estimated; their pressure of formation, however, is not so readily subjected to quantitative interpretation. Deposits are classed as contact-metamorphic (pyrometasomatic); deposits formed at high temperature (about 300º–500º C.) and pressure (mesothermal); and deposits formed at low temperature (50º–200º C.) and pressure (epithermal). In recent years there has been a tendency to sub-divide the epithermal deposits still further, recognizing a very shallow origin for some to which the name telethermal has been applied (Graton, 1933, pp. 193–195). Although it is not possible in all cases to distinguish telethermal from epithermal ores in the marginal region at Leadville an attempt is made in the following pages to apply this distinction. In the table (p. 3) the ore minerals are classified in this way.

CLASSIFICATION BY GENESIS AND DEPTH ZONES

The list on page 3 includes only those minerals that have been observed by the writer or described by others as coming from the marginal part of the Leadville district. Gangue minerals are listed only if they were introduced by the mineralizing solutions; minerals that are a part of the country rock and fortuitously present as inclusions in veins or replacement bodies are not discussed.

PARAGENESIS AND ZONAL ARRANGEMENT OF MINERALS

The paragenesis of the ore and gangue minerals in the marginal parts of the Leadville district is in general closely similar to that of the central Leadville district (Emmons, Irving, and Loughlin, 1927, pp. 211–217). Mineral paragenesis and zoning have been briefly summarized by Loughlin and Behre (1934, p. 223). **Figure 63**, somewhat modified from Loughlin and Behre, shows the general relations between the various minerals and the different zones. It is more comprehensive than the following discussion, as this concerns only the ores of marginal districts around Leadville. The diagram shows which minerals appear in each zone, but actually the zones are not as sharply bounded as the diagram suggests, because of complicating structural factors; for example, mineral deposits formed along faults have linear or elongate-elliptical outlines in contrast to those of circular outline formed around a center from which the mineralizing solutions radiated. Besides, mineralization was largely confined to limestones and was virtually lacking in pre-Cambrian rocks; these two types of rocks represent opposite extremes in susceptibility to mineralization. Faulting and erosion have produced very irregular patterns for the limestones and pre-Cambrian rocks, so the ideal symmetry of zoning may be greatly modified or even obliterated by the presence of barren or poorly mineralized pre-Cambrian rocks in the midst of an otherwise normally zoned area. Finally, an outlying magma cupola at depth was apparently a source of the ore for a local and isolated center of a mineralization discordant with zoning as worked out for the central part of the Leadville district.

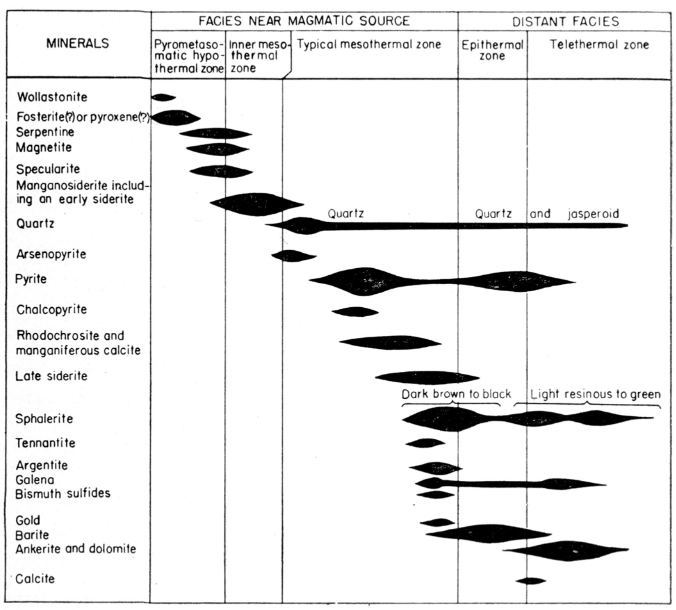


Figure 63. Paragenesis of ores in Leadville district; horizontal lengths of figures show extent of deposition of minerals; closeness of vertical position indicates nearness of period of deposition.

The chief departures from a simple zonal plan are in the most productive part of the Leadville district (Loughlin and Behre, 1934, pp. 241–242). Thus, along the Tucson fault, about 1¼ miles west of the Breece Hill stock, which overlies the presumptive center of mineralization, the largest bodies of high-temperature manganosiderite are located. An isolated center of mineralization has been found near the Mansfield, Lillian, and First National mines, and the mesothermal ores of this center have the effect of overlapping those of the Breece Hill stock to the north and making an unexpected southward bulge in the mesothermal zone south of the Rex, Mansfield, Brian Boru, and neighboring workings.

Megascopic and microscopic examinations of the ores reveal few exceptions to the sequence indicated by figure 63. The chief exceptions are in the sequence and paragenesis of the sulfides. In the central part of the district sphalerite commonly occurs in masses on which chalcopyrite is deposited, but in the marginal parts of the area (as, for example, in the Hellena mine) the relatively rare chalcopyrite forms inclusions in the sphalerite. In mesothermal ores some galena is coated with crusts of crystalline pyrite or is crossed by minute veinlets of it, reversing the normal order; indeed in prospects in the floor of Evans Gulch, pyrite and galena seem to form a late facies of ore, as compared with earlier generation of pyrite, from which they are separated in sequence by sphalerite.

Commonly sphalerite is deposited later than galena as veinlets of dark sphalerite, or as crustified veinlets whose central part is also sphalerite. Examples of this inverted sequence are seen in ore from the Lower Ontario tunnel and the First National mine. Some specimens from the First National mine showed two generations of galena, the earlier having almost the texture of steel galena, whereas the latter is coarsely crystalline and well terminated.

Such reversal or inversion of the normal order is assignable to "resurgence" (Spurr, 1923, pp. 288–291). This term is applied where, after the deposition of a series of minerals, a new influx of solutions like the original one repeats a part or all of the sequence. Resurgence may be induced simply by renewed supply of the mineralizing solutions, or by the opening of fresh and wider channel-ways through which solutions of a given temperature can approach nearer the surface than hitherto because of rapidity of flow; this process is to be especially anticipated at Leadville where, as has been shown, several movements probably took place along a given fault during the period of mineralization. In a region that is barely reached by solutions, because of its remoteness from the mineralizing center, minerals that represent cool, distant facies are deposited first; then, as the magma that furnished the mineralizers approaches nearer the surface and the temperature in this region rises, other minerals typical of higher temperatures may be deposited upon those first formed and the normal sequence is thus reversed. Or, finally, the deposits from several centers may overlap in time so that those of a high temperature but more distant center cut or follow deposits from a nearer but cooler source.

Minerals of peripheral deposits classified as to genesis, alphabetically arranged

Zone	**Ore Minerals**	**Gangue Minerals**
1--Supergene (oxidized zone)	Anglesite Aurichalcite Azurite Calamine Cerargyrite Cerussite Chalcanthite Chrysocolla Goethite Gold (native) Hetaerolite Hydrozincite Jarosite Limonite Malachite Melanterite Molybdite Psilomelane Pyrolusite Sauconite Silver (native) Smithsonite Turgite Wad	Aragonite Calcite Chalcedony Gypsum Kaolinite Quartz
2--Zone of Sulfide Enrichment	Argentite Chalcocite Covellite Silver (native) (?)	
3--Lowest temperature veins and replacements (telethermal)	Galena Pyrite Sphalerite	Calcite Dolomite Jasperoid Quartz
4--Low temperature veins and replacements (epithermal)	Argentite Chalcopyrite Galena	Ankerite Barite Calcite

	Gold (native)	Dolomite
	Pyrite	Fluorite
	Silver (native)	Quartz
	Sphalerite	Siderite
5--Moderate temperature veins and replacements (mesothermal)	Argentite	Albite
	Arsenopyrite	Ankerite
	Bismuthinite	Barite
	Chalcopyrite	Calcite
	Enargite	Chalcedony
	Galena	Dolomite
	Gold (native)	Manganosiderite
	Hematite	Muscovite (or sericite)
	Lillianite	Quartz
	Proustite	Rhodochrosite
	Pyrite	Serpentine
	Silver (native)	Siderite
	Sphalerite	Talc
	Tennantite	
	Tetrahedrite	

COMPARISION WITH DEPOSITS IN CENTRAL LEADVILLE DISTRICT AND ELSEWHERE

In a general way the Leadville district illustrates the principal of zoning, as developed by Spurr (1923, pp. 253–291), Emmons (1924, pp. 964–997), and Loughlin and Behre (1934, pp.221–224). In the central part of the district near the Breece Hill plug, the ores were formed by the replacement of limestone. There the ores consist of magnetite and specularite, and small amounts of pyrite, chalcopyrite, galena, and sphalerite; the gangue minerals are serpentine, siderite or manganosiderite, and quartz. Small amounts of wollastonite, epidote, sericite, and quartz also occur here. Emmons, Irving and Loughlin (1927, pp. 147–148) interpreted this assemblage as representing two generations: (1) a group of pyrometasomatic minerals including wollastonite and olivine or an unidentifiable pyroxene now altered to serpentine; (2) a group of high temperature (hypothermal) minerals, deposited largely by replacement of earlier minerals of higher temperature and also by metasomatic replacement of the limestone. Small amounts of serpentine in the Altoona workings and near the Mansfield shaft and numerous dikes of Johnson Gulch porphyry in this area suggest that a plug similar to that of Breece Hill, but smaller, may lie not far beneath the surface. The inferred plug is indicated in dashed lines just west of the Mike fault on the map, but heavy cover and extensive hydrothermal alteration of the porphyry that is the surface rock here makes the form and even the existence of the plug uncertain. Its small size would account for the scant distribution of the pyrometasomatic minerals in this area and the meager evidence of hypothermal mineralization.

With the exception of this center of higher temperature and the local occurrence of actinolite in limestone lenses of Weber (?) formation near Lake Isabelle, the ore deposits found in the peripheral parts of the Leadville district are of mesothermal to epithermal aspect. The highly productive manganosiderite-pyrite-sphalerite-galena ores of the central part of the district and the barite-galena-sphalerite ores of the marginal parts, represented in the Hilltop and Continental Chief mines, may be regarded as hot and cool mesothermal facies respectively (Loughlin and Behre, 1934), or as mesothermal and epithermal facies respectively, as now believed by the writer. The following general facts favor the interpretation that the central Leadville mineralization is mainly mesothermal and the marginal mineralization is epithermal.

1. A comparison of diagnostic minerals, as listed by Emmons (1942, pp. 51, 63, 71), shows more minerals listed in zone 5 (table, p. 3) that are typical of deposits formed at moderate temperature than at high temperature. When due allowance is made for complications of structural control, the outer (zone 4) of the table on the previous page is evidently epithermal, as it surrounds a mesothermal zone from which it is separated by a relatively barren zone of one half mile or more.
2. Certain minerals in the mesothermal zone (zone 5) are especially characteristic of that or of cooler zones, rather than of the hypothermal zones. Outstanding examples are the silver and

copper sulfo-salts of antimony and arsenic, proustite, enargite (?), tennantite, and tetrahedrite, and also bismuthinite and barite. Argentite is also present but maybe secondary and hence is of doubtful significance.

3. Certain other minerals listed from zone 5 are more typical of epithermal than of mesothermal veins; examples are barite (where present it occurs as the dominant gangue), argentite and native silver. However, because of the scarcity of diagnostic minerals, some of which may even be secondary, this evidence is not conclusive.
4. Chalcopyrite, a mineral characteristic of mesothermal ores, is absent from zone 4. Its absence is conspicuous because its presence elsewhere in the district demonstrates the presence of copper in the mineralizing solutions nearer the source.
5. In the deposits of the outer zone (5) extensive blankets are conspicuously absent, which is suggestive of the effects of solutions weakened by loss of reactive agents and lowering of temperature.

Despite the above contention, there are areas distant from the central Leadville district in which typical mesothermal ores are conspicuous. One such place is the floor of Evans Gulch, near and north of the Best Friend mine, where pyrite is more abundant in the ore than is usual in typical epithermal deposits, such as those of the Continental Chief and Hilltop mines. Another and larger area extends from the Hellena mine and prospects near it, north to Printer Boy Hill, south to the crest of Long and Derry Hill, and westward at least as far as the Rex mine in Iowa Gulch. This distribution of minerals characteristic of higher temperatures, even though they do not represent hypothermal or the more intense mesothermal conditions, lends further support to the inference that a plug-like mass of intrusive rock lies close to the surface near the Mansfield shaft.

The mineral assemblage characterizing the more distant facies of the Leadville district, such as the deposits of the Continental Chief and Hilltop mines, is especially striking. Typical ore of this kind is found in dolomitic limestone and consists of barite in long bladed crystals that have extensively replaced the limestone, and of crystals of galena and sphalerite deposited on the barite in open cavities commonly present. The sphalerite is dark chocolate-brown (“marmatite”) to light olive-green or even a honey-yellow; the olive-green variety is most common in this facies. Such ore is said to contain as much as 4 ounces of silver to the ton, but in what form has not been determined. Pyrite and quartz on small amounts may be present. This mineral assemblage, the tabular ore bodies and similar replacement veins (see descriptions of the Continental Chief and Hilltop mines, pp. 62 and 88), the well-crystallized bladed habit of barite, its position in the mineral sequence before the sulfides, and the exceptionally light color of the sphalerite are sufficiently characteristic to merit the use of a type name for such ores. A convenient term derived from this region is the Sherman type of ore, after Sherman Mountain on or near which several such deposits are located.

Another areal relationship is evident in the marginal part of the Leadville district. Wherever rocks and structures were favorable, ore-forming solutions that traveled still farther from the source apparently formed deposits showing an even simpler mineral assemblage than that of the Sherman type. These is well shown in prospects about a mile south of Mitchell Ranch, and better still at the Ruby mine in the Weston Pass mining district, about 10 miles south of Leadville and near the crest of the Mosquito Range. At the Ruby mine the primary ore minerals are disseminated galena, light-colored or dark brown sphalerite, and small quantities of pyrite; the gangue consists of dolomite, calcite, and crystalline quartz, and white to light bluish-gray jasperoid (Behre, 1932, pp. 56–75). Such ores are generally lean in silver and do not contain barite; indeed, it might be contended that all the gangue minerals are such as might be derived from the country rock by mere solution and re-deposition—a process resembling lateral secretion and in which the solutions that brought in the ores served only as transporting media. It is probably significant that deposits conforming to this type are located on or adjacent to bedding planes or to faults essentially parallel to the bedding; such channel-ways would involve the maximum distances of travel for the mineralizing solutions and a very large amount of cooling, and hence would afford the most favorable opportunity for dissolving and re-precipitating gangue materials from the country rock.

Published descriptions of the deposits of the central part of the Alma district, on the eastern slope of the Mosquito Range about 11 miles east-northeast of Leadville (Singewald and Butler, 1930, pp. 295–308; 1931, pp. 289–406; 1933, pp. 89–131) and of Leadville (Loughlin and others, 1936, pp. 410–441) reveal virtually identical mineral zones at corresponding distances from the apparent mineralizing source if due allowance is made for differences in structural conditions in the two districts. As at Leadville, the Sherman type is definitely recognizable at Alma, and also those types characteristic of the higher-temperature zones.

The individual zones at Leadville as discussed here, and at Alma as described by Singewald and Butler, are recognized in many other districts and further comparisons are not necessary to the purpose of this report. One striking analogy, however, may well be pointed out—the general resemblance in mineralogy between the telethermal deposits at Leadville and the much-debated Mississippi Valley lead and zinc deposits. Even the structural features of the two regions, if attention is concentrated on the immediate neighborhood of the ore deposits, are not highly dissimilar, especially when it is recalled that ore deposition in the Mississippi Valley districts is in many instances strongly controlled by bedding planes as accessory channels and sites of deposition (Fowler and Lyden, 1932, pp. 232–233), whatever the course of the hypothetical trunk channels.

DESCRIPTION OF MINERALS

LEAD MINERALS

Anglesite.—The sulfate of lead ($PbSO_4$) is normally an oxidized product of galena and is common throughout the district though not present in large quantities. Its formation is generally attributed to direct oxidation of galena in place, but an alternate explanation has been offered (Butler, 1913, p. 10). Almost all galena collected from near the surface showed the characteristic gray coating, less than 1/16 in. in thickness, that indicates the oxidation of galena to anglesite in advance of the reaction with CO_2 to form the carbonate; on such material the anglesite is not in visibly crystalline form. Cerussite, the carbonate, usually forms a thicker white border, or successive and banded layers having an aggregate thickness greater than the shell of anglesite, and it is generally chalky or of a translucent milky white hue.

Cerussite.—The carbonate of lead ($PbCO_3$) is an alteration product from the reaction between carbon dioxide (CO_2) of the atmosphere, or that dissolved in the ground waters, and galena or anglesite. Many believed it is formed by the reaction of lead-rich waters and limestone. Characteristically, cerussite appears as coatings on nodules containing inner layers of anglesite and central nuclei of galena. It is found also in a dense siliceous matrix, called “hard carbonate.” Commonly it assumes crystalline form where deposited in cracks and vugs, evidently from descending solutions. In the central part of the Leadville district cerussite is a very valuable lead ore (Emmons, 1886, p. 546; Emmons, Irving, and Loughlin, 1927, p. 163) and occurs partly in the crystalline form, partly as massive coating like that described above, but largely as “sand carbonate.” The crystalline and “sand carbonate” forms are generally lacking in the marginal parts of the Leadville district. The nearest deposits where these minerals were abundant are those of the Izzard group properties from which much silver-rich carbonate ore was mined. The Peerless mine on Peerless Mountain is also said to have supplied some quantities of “hard carbonate” consisting of cerussite cemented with silica (Emmons, 1886, pp. 533–534). Megascopically crystalline cerussite is more abundant in the central than in the marginal part of the district. In the Mount Sherman area, small crystals of it line many of the vugs of cavernous smithsonite described below. Some of the high-level stopes in the Continental Chief and Hilltop mines are also said to have contained rich silver-bearing cerussite, largely coarsely crystalline.

Galena.—Sulfide of lead (PbS) is one of the most widespread primary ore minerals in the Leadville district. Because of the insolubility of its oxidation products, crystals of galena are highly resistant to chemical change even in the zone of strongest oxidation. In many deposits it is the only primary sulfide remaining after a long period of oxidation. Typically the galena occurs in cubes, but in a few places in the mesothermal ore bodies (for example, in the First National mine) twinned forms, suggesting those of

Neudorf in the Harz region in Germany (Palache, Berman, and Frondel, 1944, fig. on p. 201), encrust masses of carbonate ore.

Galena in typical cubic crystals is disseminated along the bedding in the limestones of the district forming ill defined and discontinuous but recognizable bands (**Figure 64**); this habit is especially characteristic of the ores more distant from their source.

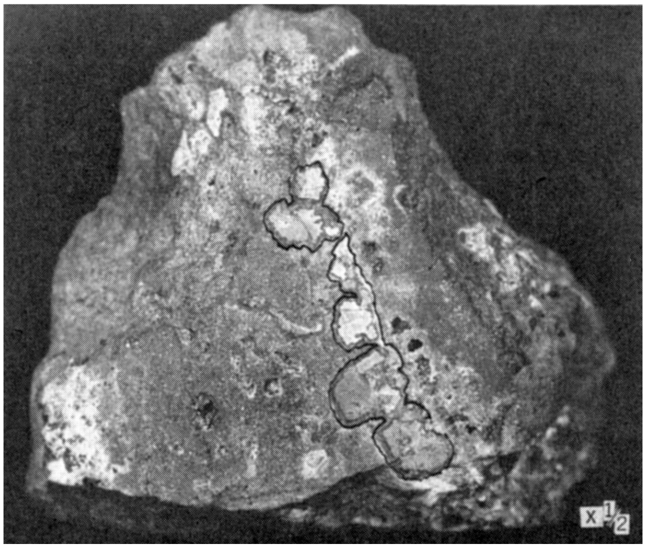


Figure 64. Partly oxidized galena in silicified limestone. X½ Prospect X-71, Horseshoe Mountain. Surface is polished. White galena, light-gray margins of galena, anglesite.

Among sulfide minerals, galena is one of the most delicate recorders of stress or deformation. Several features of the galena found in fissures are indicative of post-mineral movement. For example, in the Hellena mine steel galena occurs in the Hellena fault fissure. In the same mine some galena was fractured along its cleavage planes, and the fractures were later filled with thin films of quartz. Much galena (for example, that of the Continental Chief mine) shows curved cleavage planes, indicating at least stress and probably renewed movement. Somewhat similar features have been described from the Coeur d'Alene district in Idaho (Waldschmidt, 1925, pp. 583–584), though the crushing there appears to be more intense. Deformation of this kind usually occurs along twin lamellae or cleavage planes (Schneiderhöhn and Ramdohr, 1931, pp. 249 and 254), but in the ore from the Hellena mine the cleavage planes themselves are deformed.

In some of the shaly beds of the Weber (?) formation, galena as small, poorly formed cubes is intergrown with sphalerite, the two occupying positions similar to metacrysts in a schist. In the Hellena mine, where such relations were observed, the shale has been pushed aside, rather than replaced, for its laminae have been bent around the crystals.

Pyromorphite.—Pyromorphite [$(PbCl)\ Pb_4P_3O_{12}$] is a mineral characteristic of the oxidized zone in lead deposits. Several of the older accounts of mining in Iowa Gulch mention pyromorphite, and the ore of the Waterloo mine in Strayhorse Gulch is said to have contained considerable pyromorphite as shown by recalculation of analyses of "carbonate" ore (Emmons, Irving, and Loughlin, 1927, pp. 164–165). None was observed by the writer in mines or dumps of the marginal part of the Leadville district, however, and it seems to be characteristic of the central area, mainly because of the absence of sources of phosphoric acid in the primary minerals of the outer part.

ZINC MINERALS

Aurichalcite.—Aurichalcite, a basic carbonate of zinc and copper [$2(Zn, Cu)CO_3 \cdot 3(Zn, Cu)OH_2$] is a beautiful light-blue mineral commonly found, at least in small amounts, as radiating fibers near most of the smaller veinlets and replacement deposits on Sherman Mountain and in several of the larger workings. It occurs also in druses or vugs in oxidized zinc ore on some of the dumps of the First National and Julia-

Fisk groups. Its composition indicates that it is an oxidation product of zinciferous ores that contain some copper. Probably the copper was present in the primary ore in the form of chalcopyrite microscopically enclosed in sphalerite, as no megascopic chalcopyrite was seen. Observations reported in Professional Paper 148 indicate that aurichalcite is contemporaneous with calamine (the hydrous zinc silicate), but in specimens studied by the writer it appears to be slightly later.

Hemimorphite (Calamine).—Hemimorphite (H_2Zn_2-SiO_5) occurs in two forms—(1) in typical crystals, generally embedded in gouge or in clayey material of other than tectonic origin, and (2) in porous, bone-like yellow to brown masses (the "dry-bone" of the miners) ranging up to 2 feet in diameter, generally surrounding slightly tarnished galena and sparse barite. Significantly, the crystals are distributed through the rock, as though they were replacement products; the porous masses seem to be associated with open cavities.

Chalcophanite.—A dark-brown, drusy, botryoidal mineral, suggesting highly oxidized smithsonite but probably chalcophanite, was found in one of the higher stopes north of the incline in the "South workings" of the Continental Chief mine. The formula for chalcophanite is generally given as $(Mn, Zn)O \cdot 2MnO_2 \cdot 2H_2O$. The mineral seems to be rare in the marginal parts of the district but moderately common in the more highly mineralized areas.

Goslarite.—In the deeper parts of the oxidized zone, the heat or the dryness of the air has locally evaporated the water from solutions of zinc sulfate, yielding goslarite ($ZnSO_4 \cdot 7H_2O$) in long, needle-like crystals, attached most commonly to the walls of old, dry stopes and drifts.

Hydrozincite.—Though observed in only small amounts, hydrozincite ($2ZnCO_3 \cdot 3Zn(OH)_2$) is fairly widespread on the dumps of prospects on the western slope of Mount Sherman. It is a white, chalky soft coating occasionally seen on the surface of smithsonite and commonly associated with aurichalcite.

Smithsonite.—Smithsonite, the common carbonate of zinc ($ZnCO_3$), is abundant in all the oxidized zinc ores of Leadville. A dense variety so closely resembles partly weathered, rusty limestone that it was long used mistakenly for limestone flux. Some smithsonite is lighter in color, approaching white or light yellow. These varieties rarely occur as druses.

In Iowa and Empire Gulches and in the Hilltop and Continental Chief mines, the masses of deeply oxidized zinc ore commonly show an ocher-colored, dense meshwork in which are embedded corroded, shattered, or regularly cubical crystals of galena, still mostly unoxidized. In the midst of these masses is fine-textured, highly honeycombed, much more cavernous ore, which is commonly a light olive-gray (**Figure 65**). This honeycombed ore, like similar masses of hemimorphite, is called "dry bone ore" by the miners. Both the highly honeycombed ore and the denser surrounding meshwork are varieties of smithsonite. The honeycomb structure is ascribed to preservation of smithsonite that filled cracks in limestone fragments, the limestone itself having been subsequently dissolved, much as has been assumed in the case of the development of boxwork silica (Lindgren, 1900, pp. 170–171, pls. 28, 30). This explanation seems valid, especially if it be assumed that the densest, mesh-like parts of the smithsonite represent earlier vein filling, implying two periods of fracturing and of smithsonite deposition. However, the curvilinear forms of the honeycombed plates do not resemble normal fractures.

Smithsonite is an ore mineral of the greatest importance even in the marginal district; indeed, in the high altitudes of the marginal Leadville region the drainage is excellent and the ground-water table so low that most of the deposits are in the zone of oxidation, and smithsonite is very abundant. The Hilltop mine is said to have produced mostly smithsonite ore. In the Continental Chief mine, nearly all zinc has come from smithsonite ore and only the deepest levels contained much sphalerite; here local sphaleritic ores are crossed by smithsonite veinlets.

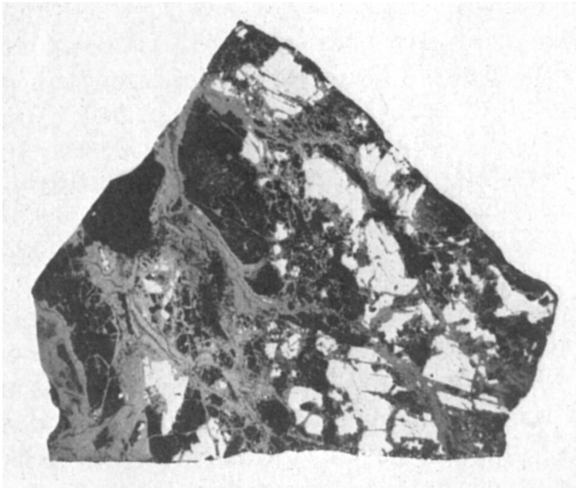


Figure 65. Oxidized ore consisting of galena (polished, white) and limestone (black), crossed by veinlets of gray smithsonite. X½ Continental Chief mine.

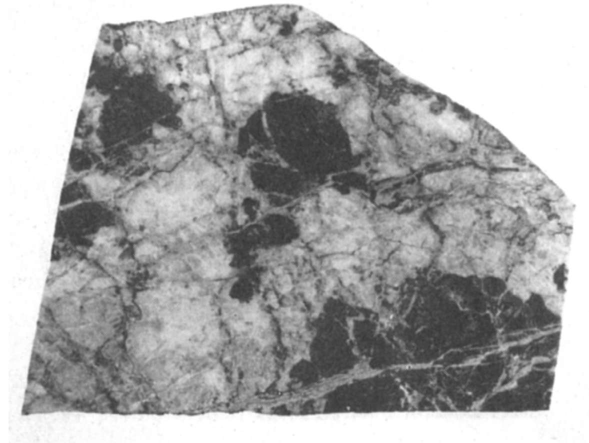


Figure 66. Sphalerite (black) crossed by stringers of smithsonite. X½ Deepest workings, Continental Chief mine.

Sphalerite.—Sphalerite, or zinc blende (ZnS) (**Figure 66**) is the only important primary zinc mineral. The common crystal forms are highly varied. In the mesothermal ores the sphalerite is commonly intergrown with pyrite or with galena, though rarely in such a way as to suggest contemporaneity between galena and pyrite. Generally in such ore the galena and sphalerite are intimately intergrown, suggesting contemporaneous formation, but some pyrite inclusions have been found in sphalerite, oriented as though they had resulted from unmixing. Somewhat rarely, in vugs, the sphalerite crystals are well terminated. Sphalerite of the mesothermal zone is dark-brown to black, with a high, resinous luster and is commonly called "marmatite". Analyses cited by Emmons, Irving, and Loughlin (1927) show a range in iron and manganese content of 12.1 to 17.8 percent; the iron is generally ascribed to the presence of FeS in isomorphous combination with the ZnS, as thin sections show no crystalline iron sulfide.

Near the margins of the district the sphalerite has a quite different appearance. Galena is the only common associate and, as the sphalerite generally lacks the intimate intergrowth with other sulfides seen in the central part of the Leadville district, the crystals are commonly euhedral. Moreover, the sphalerite is generally much lighter in color than the typical marmatite of the central Leadville district; it is for the most part light olive-green. It is transparent in thin-sections, not translucent or nearly opaque, as is commonly the case in the darker variety. Whatever the cause of the green color, it is generally retained even after the sphalerite has been converted to smithsonite. Sphalerite of this facies and galena commonly grow upon bladed barite crystals, filling the space between them.

Sauconite (zinciferous clay).—In the intermediate stopes northwest of the new incline of the Continental Chief mine, there is a firm, brownish, banded clay with conchoidal fracture, apparently the end product of hydrothermal alteration and oxidation of the Leadville dolomite. The percentage of zinc present sufficed to induce local prospecting, but zinc content was small and recovery too difficult to yield a profit. For a detailed discussion of the nature and origin of such clays, the reader is referred to Loughlin (1918, pp. 24–28) and Emmons, Irving and Loughlin (1927, pp. 160–162, 264–270) and to a later article by Ross (1946, pp. 411–424).

COPPER MINERALS

Azurite.—Azurite, the blue basic copper carbonate ($2CuCO_3 \cdot Cu(OH)_2$), is seen as thin coatings on some baritic lead or zinc ores, such as those found in the Dyer mine on Dyer Mountain and in the smaller workings on Mount Sherman between the Continental Chief mine and Hilltop Pass.

Chalcanthite.—Chalcanthite ($CuSO_4{\cdot}5H_2O$) is rarely seen at Leadville on account of the relatively high humidity in this district as compared with the desert or semi-arid climates in which this mineral typically forms. Miners have found it occasionally, however, as stalactites attached to timbers and walls, especially during the winter, the season of lowest humidity inside the mines. It has not been observed by the writer in the course of these studies.

Chalcocite.—Chalcocite (Cu_2S) is commonly a product of secondary sulfide alteration, where chalcopyrite or other copper sulfides are present in the primary ore. Considerable quantities of chalcocite occur in the central part of the Leadville district, especially where primary copper sulfides are important constituents of the ore, but even in the South Ibex (Venir) mine, where copper is not abundant, thin films of sooty chalcocite, called "copper skin" by the miners, are plentiful.

In the marginal parts of the district here described, chalcopyrite and other primary copper minerals are rare, and most of the mining has been carried on in the oxidized zone, so that chalcocite is not commonly seen. A small quantity appeared in ore from the Hellena mine, presumably from the 5th level. It is of no economic importance.

Chalcopyrite.—The scarcity of chalcopyrite ($CuFeS_2$) in ores of both the marginal and the central areas of Leadville is striking, considering the wide variety and the intensity of mineralization. Inclusions of chalcopyrite in sphalerite are fairly widespread, but make up so small a part of the total mass of the ore as to be inconspicuous in most hand specimens. Chalcopyrite in relatively high proportions is found in Swanson's stope and in other ore shoots near it in the Ibex mine; here it is generally in close association with pyrite, occurring partly in definite veins and partly in irregular masses of highly varied size within the pyrite. It is especially conspicuous near the central and larger parts of the stope, as the ratio of zinc to copper increases marginally. Emmons, Irving, and Loughlin (1927, pp. 165–166) stated that generally chalcopyrite is richer in silver than the associated pyrite and that silica (mostly quartz) is the commonly associated gangue. Where chalcopyrite occurs with galena and sphalerite in the outlying areas it is partly older than the sphalerite, but invariably older than the galena.

In the marginal district, the ores here classified as mesothermal contain some chalcopyrite; Mr. E. P. Chapman (Personal communication, 1934) gave it as a conspicuous constituent of the rich ores in Printer Boy Hill. It is inconspicuous in ores of the Hellena mine and small amounts of it appear with pyrite in the dump of Prospect C-103, south of the Best Friend group in Evans Amphitheater. In such occurrences, the chalcopyrite is too intimately intergrown with gangue and other sulfides, especially sphalerite, to have well-terminated crystals. In the still more distant (epithermal) facies, as seen on Sherman, Dyer, and Peerless Mountains, chalcopyrite was nowhere actually found in the ore, but the widespread presence of stains of malachite and azurite point to widely disseminated but low percentages of primary copper minerals, most probably chalcopyrite.

Chrysocolla.—Chrysocolla is a bluish-green, amorphous, hydrous copper silicate ($CuSiO_3{\cdot}2H_2O$), and, like other copper minerals in this area, is widespread but does not occur in large proportions. It is present in oxidized ores, having essentially the same distribution as the copper carbonates, but is less common than malachite.

Covellite.—A bright peacock-blue iridescence found locally on sphalerite, especially in the more central part of the Leadville district, suggest thin coatings of covellite (CuS). This mineral, which is commonly associated with chalcocite, is generally formed during secondary sulfide enrichment—in part, at least, as a first step in the formation of chalcocite.

Enargite.—Enargite (Cu_3AsS_4), a sulfarsenate of copper, has been reported from several of the workings on the north and south sides of Iowa Gulch in the neighborhood of the Hellena mine, but ore found on the dumps showed none, and underground studies in the Hellena mine, but ore found on the dumps showed none, and underground studies in the Hellena mine brought none to light. C. J. Moore (unpub. rept., 1902) recovered small amounts of enargite in the lower Little Troubadour tunnel, but specimens for examination are no longer available.

Malachite.—Malachite is a green mineral, widely distributed in the oxidized ore of the marginal part of the district. It is a close relative of azurite and the two differ mainly in chemical composition and in color; malachite has the formula $CuCO_3{\cdot}Cu(OH)_2$ and is the more highly hydrated and basic of the two common carbonates. In the epithermal ores it commonly appears in tiny botryoidal masses or acicular crystals on blades of barite but it is not present in commercial quantities.

In one of the workings on the Garbutt property, malachite formed so rapidly on the floor of a stope drift that a coating two inches thick accumulated in three years. The source seems to have been oxidized copper sulfate solution. The product is a highly cavernous, bright-green copper carbonate with scattered tiny white areas, evidently representing a kaolin-like compound.

Tennantite and tetrahedrite.—Gray copper ore—tennantite ($Cu_8As_2S_7$) and tetrahedrite ($Cu_8Sb_2S_7$)—has been reported by miners operating in Iowa Gulch or on the slopes to the north and south; the two minerals are so similar that decision as to their presence and their exact identification must await the examination of better material. Tennantite, however, has been definitely identified in ores of the Lillian mine. No sulfo-salts of copper were found in hand specimens or polished sections of any of the other ores from the marginal parts of the Leadville district.

SILVER MINERALS

Alaskite.—The bismuth-bearing mineral alaskite ($Ag_2S{\cdot}PbS{\cdot}Bi_2S_3$) was found in a single specimen (Chapman, 1941, p. 269) from the Lillian mine on Printer Boy Hill, associated with gold that is believed to be secondary. The alaskite is in small residues in nodules of oxidized ore.

Argentite.—Argentite (Ag_2S), found in various districts both as a primary mineral and as the product of secondary sulfide enrichment (Emmons, 1917, pp. 274–275) has been reported by C. J. Moore from the Ella Beeler mine (unpub. rept., 1909). It is probably also present, though not identifiable in the specimens available, in the silver-rich galena and its oxidized products found in the Hellena, First National, Belcher, and other mines of the mesothermal zone, and in the Continental Chief, Hilltop, and similar ore bodies of the marginal, epithermal zone. In such ore, the argentite is probably present as tiny inclusions, though some of the silver, as in other similar districts, may also occur in other forms, such as freibergite or native silver (Finlayson, 1910, p. 727; Singewald and Butler, 1931, p. 405; Sandberg, 1935, p. 501, fig. 6). In the oxidized ore argentite also occurs in small specks in the cerussite (Emmons, Irving, and Loughlin, 1927, p. 167). Its presence as a primary mineral in the marginal parts of the Leadville district is inferred from the high silver content of some of the ore.

Cerargyrite.—Cerargyrite (AgCl) is a product of oxidation. Though seldom very conspicuous, it is widespread at Leadville and accounts for most of the high silver content of oxidized ore. Cerargyrite occurred at the Peerless Maude and Hilltop mines in large quantities. How much of the “horn silver” of the older miners was true cerargyrite (AgCl), and how much was a salt of other halogens, such as bromyrite (AgBr) and iodyrite (AgI), is not known. All the “horn silver” seen by the writer was true cerargyrite.

Many miners designate malachite as “chloride,” especially where it occurs as thin films, evidently regarding it as a high-grade silver ore.

Hessite.—Chapman (1941, p. 268) has reported finding hessite (Ag_2Te) in association with bismuth minerals in ore from the Greenback, Tucson, and Louisville mines and in some specimens of doubtful origin. It may be present in the deposits of Printer Boy Hill.

“Lillianite” and related minerals.—The problematic mineral “lillianite” was discussed in detail in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, p. 170), together with the minerals “kobellite,” and “schapbachite.” These minerals appear to be related both to bismuthinite (Bi_2S_3) and to galena (PbS), and intermediate forms from Leadville have been described by Chapman and Stevens (1933, pp. 680-685; 1941, p. 274) who showed that the “lillianite” of the Lillian and Greenback mines (the latter in the central Leadville district) is really an intergrowth of bismuthinite and argentite. Chapman and Stevens agree with the work of Emmons, Irving, and Loughlin (1927, p. 170) who arrived at a similar conclusion but regarded galena as another admixed ingredient, and mentioned “schapbachite” as having essentially the same composition. Though mineralogically interesting, the “lillianite” and its relatives in the marginal part of the Leadville district are of economic importance only on Printer Boy Hill.

Proustite.—Light ruby silver, proustite (Ag_3AsS_3), is reported from the lower tunnel of the Little Troubadour group. None was found on the dump, and its relation to the associated minerals is not known.

Silver, native.—Native silver in wires and in thin leaflets is reported from several deposits in the marginal parts of the Leadville district. Its common association with fissures in sulfide ores suggests that it was formed by precipitation from solutions as they ascended or descended along bodies of base-metal sulfides. Minute inclusions of silver (?) are found in galena as already indicated above.

GOLD MINERALS

Gold, native.—Native gold was commonly found in many mines located in the central part of the Leadville district. In the marginal parts it generally occurs where bismuth is found (Chapman, 1941, p. 272), notably in the mines of the Lillian group. It appears to coat earlier sulfides, or to occupy their cleavage cracks; rarely it is disseminated, as in the Lillian mines. These relations are similar to those at Gilman, Colo. They seem to indicate that gold, like the silver-bismuth compounds previously referred to, appeared late in the mineral sequence; in fact, Chapman has recognized a bismuth-gold stage very late in the precipitation of the metallic minerals.

Some of the ore once worked on the upper levels of the Hellena mine appears to belong to this stage and to have been very rich in gold, but this is exceptional. In the more distant ore deposits, such as those of the Iowa and Empire Amphitheaters, no free gold was recognized in the ores; that which was present was probably in the form of minute inclusions in galena, pyrite, or blende, and remained residually concentrated upon oxidation. Presumably as the result of downward enrichment and transportation in chloride solutions, native gold also occurred in fissures in the pre-Cambrian rocks on the lower slopes of East Ball and West Sheridan Mountains. Placer gold has been worked on a small scale in the outlying parts of the Leadville district, but production has been far less than in California Gulch. The placer deposits derived from Iowa and Empire Gulches have been carried by glacial action to places nearer the axis of the Arkansas Valley.

IRON MINERALS

Goethite and turgite.—Goethite and turgite probably occur in the oxidized zone of all of the deposits, wherever pyrite, siderite, or even dark-colored zinc blende were present among the primary minerals. They are not readily distinguished, but turgite ($2Fe_2O_3{\cdot}H_2O$) is commonly reddish or nearly black, whereas goethite ($Fe_2O_3{\cdot}H_2O$) and its near relative, limonite (generally written 2 $Fe_2O_33H_2O$), are generally brownish or yellowish.

The hydrous iron oxides are especially conspicuous in oxidized “contact” or “blanket” deposits. They are also characteristic as a stain on silicified limestone near faults. In some instances they have been transported, presumably in the colloidal state, and occupy tiny fissures in the country rock. They are especially noticeable along small gold veins in the areas of pre-Cambrian rocks.

Hematite.—Hematite (Fe_2O_3) is uncommon at Leadville as an associate of ore except where relatively high temperature mesothermal, hypothermal, or contact-metamorphic minerals occur; it is especially typical of deposits formed at high temperatures. This is confirmed by the presence of specularite in the contact metamorphic ores at the Ibex mine, described by Emmons, Irving, and Loughlin (1927, p. 150).

Scattered masses of magnetite and rock containing cloudy aggregates of fine, dusty hematite particles occur in the ground between the Mansfield shaft on the west, the First National shaft on the east, the crest of Printer Boy Hill on the north, and the bottom of Iowa Gulch.

The reddish colors in the oxidized parts of many of the “blanket” deposits are caused by the presence of turgite, rather than of hematite.

Jarosite.—Jarosite ($KFe_3S_2O_{11}{\cdot}6H_2O$) is reported by Emmons (1886, pp. 549–550) to occur abundantly in an almost continuous layer under the rich ore bodies of Carbonate Hill. In a stope northwest of the incline on an intermediate level of the Continental Chief mine, partly oxidized galena is embedded in material unctuous to the touch, ocherous in color, and composed in part of tiny plates. No analyses were made, but the physical properties of the mineral suggest that it is jarosite.

Figure 67. X½ Typical baritic ore, Canterbury tunnel.

Figure 68. X½ Veinlet of rhodochrosite crossing from shattered granite into margin of sulfide ore. Hellena vein, east face, 5th level, Hellena mine.

Limonite.—Limonite, with which goethite and turgite may also be classed loosely, is characteristic of the oxide zone and develops as a result of the oxidation of ore minerals rich in iron. Its presence in large amounts along fissures strongly indicates locally intense mineralization. In regions where the country rock is homogenous and not stratified, heavy, more or less linear, stains of hydrated iron oxide may be the only indication of fissuring and possible ore deposition.

Locally in the mine workings, hollow stalactites of limonite hang from the walls and timbers. They were formed by descending waters carrying iron from overlying bodies of pyrite, ferruginous sphalerite, ore siderite, or possibly even from limonite.

Magnetite.—Magnetite (Fe_3O_4) appears in minor amounts in the area to the east of Mansfield shaft. Here, like the hematite previously described, it replaces the limestone, forming lenses of dense black rock or crystals in vugs. A few specimens show well-formed octahedral crystals. Magnetite, like hematite, indicates mineral deposition at relatively high temperatures

Melanterite.—Melanterite ($FeSO_4 \cdot 7H_2O$) is formed wherever pyrite or other sulfides containing iron become oxidized. It is light gray, yellowish, or light greenish, and transparent or translucent. Where the air is hot and not humid, it loses its water and dries to a chalky powder.

Pyrite.—Pyrite (FeS_2) is the commonest of the sulfides. It occurs as one of the chief constituents of the ores and in a variety of forms. At Breece and Printer Boy Hills it represents deposition of iron at temperature below that at which the hematitic and magnetitic bodies were formed. Pyrite is found crustified with other minerals in veins, densely intergrown with galena or sphalerite or both in veins and replacement bodies, and disseminated in limestones, sandstones, quartzites, and porphyries (**Figure 69**). It is especially plentiful in the basal shales of the Weber (?) formation, in the form of concretions; these concretions, however, are probably of syngenetic, sedimentary origin. Some of the porphyry bodies of the Leadville district were locally so rich in pyrite as to be designated the "pyritiferous porphyry" and regarded as a distinct rock type in the earlier work of Emmons. In itself the pyrite has no economic value but some gold is believed to be associated with it. Its most common associate among the gangue minerals is quartz.

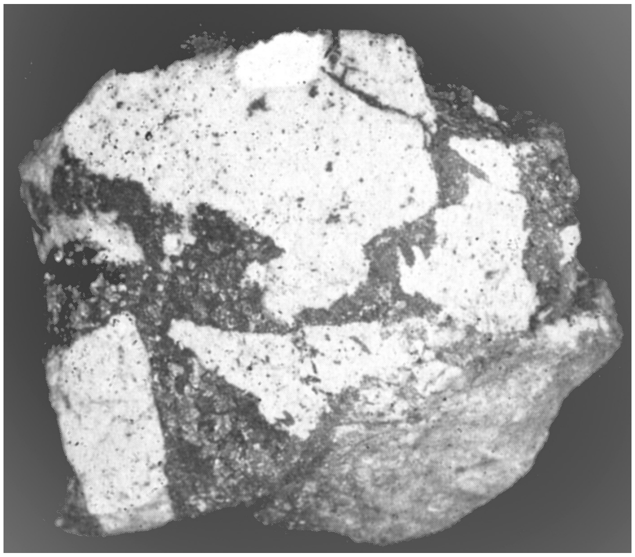


Figure 69. Breccia of white porphyry, cemented and partly replaced by pyrite. X½ Dump of Julia-Fisk shaft.

The pyritohedron is the most commonly observed form where crystals are well formed, though the cube is also common. Leadville is famous among mineralogists for its large, well-formed crystals of pyrite, which during the earlier years of wireless telegraphy sold at a premium because of their use in crystal radio sets. Some pyrite crystals measure 3 or 4 inches on an edge.

In contrast to the widespread occurrence of pyrite, marcasite has not been found in the Leadville district. This is significant, as Allen, Crenshaw, and Johnston (1912, pp. 169–236) have shown that pyrite tends to form from alkaline solutions at higher temperatures whereas marcasite is characteristically crystallized from acid solutions at lower temperatures; even in the deposits of lowest temperature of the greater Leadville region, such as those at Weston Pass (Behre, 1932, pp. 65–66), the rare iron sulfide is found only in the form of pyrite. As various kinds of mineralogic and geologic evidence in this area point to deposition at comparatively low temperature, and as no very complex structures exist, it may reasonably be assumed that the pyrite was deposited from alkaline to neutral rather than from acid solutions. The alkalinity of these solutions was probably maintained by reaction with the large amount of calcium-magnesium carbonate present in much of the sedimentary country rock.

MANGANESE MINERALS

Pyrolusite and psilomelane.—The Leadville district has long been an intermittent source of manganese ores, most of which consist of the minerals psilomelane ($H_4Mn_2O_5$) and pyrolusite (MnO_2), and possibly also the mineral cryptomelane KMn_8O_{16}, the complex formula of which is generalized (Fleischer and Richmond, 1943, pp. 273–274). Most of the output came from the central part of the district, particularly from mines on Carbonate Hill. In the region here described, however, little of either mineral could be identified, though certain bodies on Long and Derry Hill are said to have contained much manganiferous ore (Emmons, 1886, p. 509), including nodular masses of needlelike pyrolusite crystals. Several prospects on Rock Hill near the Nisi Prius were also manganiferous, as were the Florence tunnels, the highest large workings southwest of the crest of Printer Boy Hill, here included as part of the Lillian group.

A small amount of crystalline psilomelane has been found in pre-Cambrian granite between the northern peak of West Sheridan Mountain and Upper Long and Derry Hill.

Wad.—The impure, earthy manganese dioxide was, is found in at least small amounts almost wherever hydrated iron oxides occur. It is especially conspicuous in the oxidized “blanket” or “contact” deposits.

MINERALS OF THE RARER METALS AND METALLOIDS

Arsenopyrite.—Arsenopyrite (FeAsS) has hitherto been reported from only two mines, the Moyer and Tucson. Considerable arsenopyrite was found, however, on the dump of the First National shaft, together with pyrite, small quantities of chalcopyrite, and manganosiderite. These minerals occur in vugs in a slightly cavernous block of dolomitic Leadville limestone. The arsenopyrite forms euhedral crystals 0.1 in. (2.5 mm) in longest dimensions; the conspicuous striated facies of m(110) yield pseudorhombohedrons with twinning. These crystals are largely intergrown with pyritohedrons of pyrite, and both sulfides are encrusted with manganosiderite. Chapman also has described manganosiderite that is later than arsenopyrite, and recognizes two generations of bismuth minerals, one earlier than the arsenopyrite, the other later.

Arsenopyrite is ordinarily formed at moderate to high temperatures. Its presence in the First National mine suggests that this region is nearer the source of mineralizing solutions than the region to the south and east.

Bismuth-bearing minerals.—Bismuth-bearing minerals have been reported in considerable amounts from several mines in the Leadville district, generally as intergrowths with argentite and galena, and various names have been applied to these intergrowths (Emmons, 1886, pp. 169–170). Chapman (1941, pp. 265–267) has recognized a widespread bismuth stage in mineralization, later in age than the main period of sulfide deposition. The minerals of the "bismuth period" are of economic interest because among them are silver compounds, native silver, tellurides, and native gold. Minerals of the "bismuth period" include the tellurides hessite (Ag_2Te) and altaite (PbTe), tennantite and chalcopyrite, aikinite ($Cu_2S{\cdot}2PbS{\cdot}Bi_2S_3$), and galeno-bismutite ($PbS{\cdot}Bi_2S_3$) as the most prominent primary minerals, and argentite and native silver among the supergene derivatives. These minerals are conspicuous in the ore bodies of the Garbutt and other mines on Breece Hill; on the south side of Printer Boy Hill; in the Cord, Whitecap, Louisville, and Tucson mines on Iron Hill; in a drift on the Silent Friend claim east of South Evans Gulch; and in the Greenback mine at Graham Park. Gold is associated with hessite in the Tucson mine.

Although the preceding statements apply to the district as a whole, Chapman (1941, p. 269) devoted special attention to the ores of the Lillian mine, in which he found gold in association with alaskite ($Ag_2S{\cdot}PbS{\cdot}Bi_2S_3$), a mineral related to bismuthinite.

Molybdite.—Though the primary mineral, molybdenite (MoS_2), the chief source of molybdenum, has not been found in the Leadville district, its oxidation product molybdite (MoO_3) occurs in most deposits that have been thoroughly oxidized. The molybdite appears as a fine yellow powder commonly associated with galena, suggesting that the primary sources are probably minute inclusions of molybdenite in the galena crystals.

GANGUE MINERALS

Gangue minerals are those which do not yield a useful metal in noteworthy quantities and also the carbonates of iron and manganese because these minerals are not here worked as sources of metals. There are also numerous other minerals in the rocks of the region. As fragments of such rocks are frequently present as inclusions or "horses" in veins or as relict parts of the original country rock in replacement deposits, they might be regarded as gangue minerals associated with the ores. In the following section, however, only such minerals will be listed as appear to have been formed together with the ore minerals, and are therefore essentially a product of the mineralizing processes.

Albite.—In the alteration of the Iowa Gulch porphyry, some of the feldspar was replaced by a highly sodic plagioclase, probably albite. Albitization was strongest in the greenish-gray alteration facies of the rock. This change appears to be correlated in turn with the mineralization of the district; areally, however, there is no correlation. Locally bodies of mineralized and of albitized rocks overlap, but this coincidence is not conspicuous. This sort of alteration has occurred in all of the porphyries, as already reported by Singewald (1932, pp. 25, 27–29); its results are generally most conspicuous in the groundmass. As albitization was not confined to fracture zones, Singewald regards it as essentially deuteric rather than hydrothermal. The two steps in rock alteration implied by his viewpoint are not sharply separable regionally by field inspection.

Aragonite.—Like calcite, the mineral aragonite has the composition $CaCO_3$. It occurs in some of the veins that appear to be later than those containing ore, but some of it may have been contemporaneous with them. Great blocks made up wholly of acicular crystals of aragonite are found in the western slope of the 12,065-ft. knob northwest of Empire Hill, evidently from a nearby but unrecognized fissure.

Barite.—In the ores here classed as epithermal, barite ($BaSO_4$) is the most characteristic and widespread gangue mineral. It fills open veins and occurs in tabular crystals as much as an inch long. In some ore the space between these crystals is occupied by sulfides, commonly galena and sphalerite. Even more characteristic, however, is the tendency for barite to replace limestone in or near ore shoots. In places the feeding fissure is still outlined by the barite crystals; elsewhere it is completely sealed and the barite blades penetrate outward into the limestone in such a way as to destroy the fissure boundaries, yielding a type of replacement that may well be designated "baritization" (**Figures 67, 70, 71**).

The common association of barite with lead and zinc sulfides is especially characteristic of the epithermal and telethermal groups of ore deposits. Barium sulfide is soluble but barium sulfate is not, suggesting that although the precipitation of barite may be attributed in part to a reduction in temperature and pressure it may also be due to a slight oxidation of the mineralizing solutions. The formation of oxidized (sulfate) minerals in deposits predominantly sulfidic has been discussed at some length in earlier papers and was considered in detail by Butler (1919, pp. 581-609). However, Butler's conclusions may not apply to this area; instead, the oxidation of barium sulfide may have been caused by the admixture of descending cool waters.

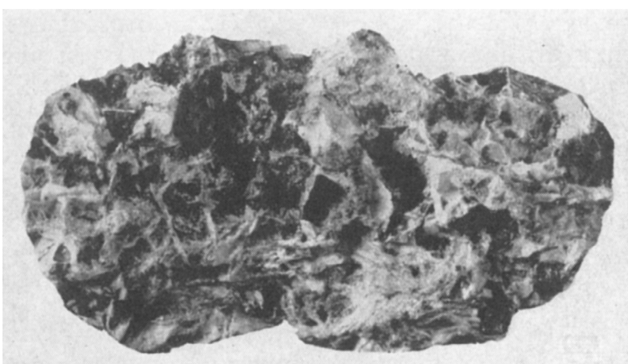


Figure 70. Baritic ore, showing a meshwork of barite blades (white) encrusted with galena (black) and smithsonite (light gray). X½ Continental Chief mine.

Figure 71. Barite blades disseminated in limestone. X½ Stope under head of incline. Continental Chief mine.

Calcite.—Calcite ($CaCO_3$) is one of the widespread gangue minerals in the oxidized ore but is commonly not abundant. Dogtooth spar crystals (scalenohedrons) are most abundant, with some rather sharp-pointed rhombohedrons. Efforts to correlate these crystal forms with different conditions of deposition failed because of the scarcity of well-terminated crystals. Commonly the calcite crystals are found in partly leached masses rich in limonite and manganese dioxide.

A late change in virtually all the porphyries is there impregnation and partial replacement by calcite. As might be expected, this change has especially affected the plagioclase feldspars.

*Chalcedony and jasperoid.—*Finely granular quartz and cryptocrystalline silica, comprising chalcedony and jasperoid, are alteration products of the groundmass of porphyries in or near some of the ore bodies. Silicification in the calcareous country rocks, especially near the top of the Leadville dolomite, has produced a rock resembling quartzite. The microscope reveals it to be a finely granular quartz-rich rock, containing some cryptocrystalline silica. Such alteration apparently antedated ore deposition slightly, for the ore is found to extend to the siliceous rock and there stop, or it encroaches into the silica on a small scale along tiny cracks. Excellent examples of this type of siliceous barrier against mineralization are seen in the Evelyn mine.

*Dolomite.—*Dolomite, $(Mg{\cdot}Ca)CO_3$, is a more common gangue mineral than calcite. It is most abundant in the "zebra rock," which is commonly, though not invariably, found in the neighborhood of mineralized masses. The forms most commonly seen are rhombohedrons, which may be distinguished from those of calcite by the curved faces; the calcite effervesces freely in cold dilute acid whereas dolomite effervesces only if the mineral is powdered.

*Epidote.—*The presence of epidote $(HCa_2(AlFe)_3SiO_{13})$, especially as an alteration product of ferric or calcareous minerals, has been noted in the description of the porphyries. It is inconspicuous to the unaided eye, but is easily recognized under the microscope by its light-greenish color. Epidote is generally associated with either calcite or quartz or both. It may be regarded as either a deuteric or a hydrothermal mineral, the evidence resembling that presented by Singewald (1932, p. 23) in his discussion of secondary albite and associated minerals. Probably some of it is hydrothermal and may properly be considered a gangue mineral.

*Fluorite.—*A few cubes of fluorite (CaF_2) were found at the mine cabin in Miller's adit (Prospect C-91); presumably they had been found underground in one of the local prospects. This is the only report of fluorite from the Leadville district.

*Gypsum.—*Several miners reported finding small gypsum $(CaSO_4{\cdot}2H_2O)$ crystals in the mines of Iowa Gulch, but the writer was not able to confirm its presence by personal observation. The occurrence of gypsum in the oxidized zone in a region where the country rock is limestone and the ore minerals are sulfides is not astonishing.

*Kaolin or kaolin-like minerals.—*Clay minerals are common in the "contact" bodies. Clays are extensively developed as gouge in fault zones, for example, along the Hellena fault. The clays are commonly iron stained, and some, as in the Nevada tunnel, contain noteworthy quantities of gold.

*Manganosiderite.—*Among the carbonates, manganosiderite $[(Mn, Fe)\ CO_3]$ indicates a higher temperature of formation than calcite or dolomite. It has been found in large amounts in ores at Leadville that clearly represent a more intense phase of mineralization than is characteristic of the marginal parts of the district where manganosiderite occurs only in some of the mines east of the Mansfield shaft and north of the Hellena mine, notably the Julia-Fisk and the First National (**Figure 72**); these mines are where temperatures during ore deposition may have been slightly higher than those in adjacent areas.

In the marginal districts around Leadville, crystallized manganosiderite commonly occurs as pseudo-cubic rhombohedrons and as flat scalenohedrons. Both crystal habits were observed in specimens from the First National and Julia-Fisk shafts but the flat scalenohedrons are somewhat more common and the surfaces of the normally white or light-gray mineral have been slightly oxidized and possess a coating of black, sooty manganese oxide. Large masses replacing the limestones are common in the central part of the district.

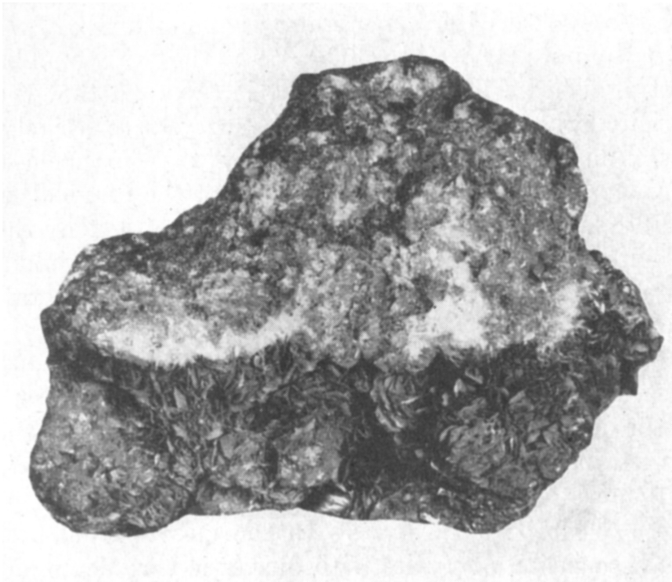


Figure 72. Oxidized manganosiderite (dark) in bladed crystals encrusting earlier carbonate (white). X½ Dump, First National shaft.

Muscovite and sericites.—The difference between muscovite [$(HK_2Al_3(SiO_4)_3)$] and sericite is not chemical or mineralogic but genetic. Sericite is a white mica produced by replacement or dynamic metamorphism, and muscovite, which is chemically identical, is the primary mineral. According to this definition, the rocks of Leadville district that have undergone alteration contain sericite. The early White porphyry, as already described, contains a conspicuous amount of sericite, partly as replacement of orthoclase and plagioclase phenocrysts, and partly as a felty aggregate in the groundmass. The optical properties of this mineral are those of sericite, but are also very much like those of paragonite ($H_2NaAl_3(SiO_4)_3$), and the two cannot be distinguished with certainty. It is observed that the sericite replaces the feldspar phenocrysts selectively, attacking plagioclase more strongly than orthoclase. Although it is not clear to what extent the plagioclase has already been albitized, the strong attack of the sericite on the plagioclase feldspars suggests a preponderance of potash in the earlier stages of the mineralizing solutions.

Quartz.—Quartz is the most widespread and the commonest of all of the gangue minerals. Though present in the deposits here regarded as epithermal, such as the "West Workings" of the Continental Chief mine, it is still more characteristic of mesothermal ores such as those of the Hellena mine. In the mesothermal ores the association of pyrite with quartz is very common; in the epithermal deposits the associated minerals are galena and sphalerite, and rarely barite. Quartz, chalcedony, and jasperoid are also found together in silicified porphyries and sedimentary rocks, especially in the upper beds of the Leadville dolomite. The forms most commonly observed are prisms, generally long and slender. They are especially well developed in vugs. Crustified veins are singularly rare and comb quartz is therefore inconspicuous. Where quartz replaces the country rock it occurs in densely packed anhedral grains. Quartz in this form occurs in the Leadville dolomite and in one type of altered early White porphyry. A similar form is not uncommon in some of the cerussite ore, yielding "hard carbonate," which may contain as much as 20 percent lead; such ore was produced in the Peerless Maude mine.

Rhodochrosite.—Rhodochrosite ($MnCO_3$) is apparently similar to manganosiderite in genesis but seems to form at somewhat lower temperature. It is readily distinguished from the white or light-gray manganosiderite by its pink color. Emmons, Irving and Loughlin (1927, p. 176) reported the presence of rhodochrosite in a few of the mines of the central Leadville district, in the Mammoth mine in Evans Gulch, and in workings of the Ella Beeler and Clear Grit groups in Iowa Gulch (Singewald, 1932, p. 176). A discontinuous but well-marked vein of it was found in the Hellena workings on the third level. The largest body of rhodochrosite lay in the gouge of the Hellena fault, some distance away from the other vein minerals, so that its paragenetic relations could not be determined. The fracture that it filled was crustified. Elsewhere a thin seam of it bordered an irregular veinlet of blende and pyrite (figure 68), suggesting that the rhodochrosite antedated the sulfides. In the absence of distinct crustification, the possibility must be recognized that the vein matter was torn from the wall of the fissure, and this marginal opening, formed subsequent to sulfide deposition, was then filled with rhodochrosite.

Rhodonite.—Rhodonite ($MnSiO_4$) has been reported from only one mine, the Ella Beeler, where it is described as having formed narrow parallel bands alternating with other minerals (Emmons, Irving, and Loughlin, 1927, p. 173). The mineral is commonly formed at considerably higher temperatures than generally prevailed during mineralization.

Serpentine.—A small quantity of serpentine, mostly opaque white but ranging to very light gray, occurs in the upper workings of the Altoona adit. Magnetite, which occurs in association with the serpentine of the Penn mine and the old Breece iron mine, is not present in the upper Altoona workings in the immediate neighborhood of the of the altered dolomite (Emmons, Irving, and Loughlin, 1927, pp. 173–174). In prospects to the east and northeast of the Altoona adit, however, more highly silicified rock is associated with magnetite and cloudy aggregates of hematite.

Siderite.—Siderite ($FeCO_3$) was not identified in any of the deposits in the marginal parts of the Leadville district. Mineralogically it closely resembles dolomite, manganosiderite, and ankerite; as dolomite is widespread, siderite may possibly have been mistaken for it. Dolomite-like material (possibly ankerite) was found in the Hellena mine, stained yellowish-brown, as though it contained some ferrous iron which, upon oxidation and hydration, was converted to limonite. In this locality the mineral is not in contact with the sulfide ore, and hence its paragenetic relations could not be established.

Forms of Ore Deposits

The ore deposits of the marginal parts of the Leadville district resemble those in the central part, except that the irregular masses of the contact-metamorphic facies described by Emmons, Irving, and Loughlin (1927, p. 177) are missing. The marginal ore bodies occur in two dominant forms—replacements of the "blanket" type, and fissure fillings.

REPLACEMENT DEPOSITS OF THE BLANKET TYPE

Replacement deposits generally are parallel to the bedding and thus tend to be tabular ore bodies having two long and one short dimension; hence they are called "blankets." They are most common at the contact of different kinds of rocks—a limestone and quartzite, or a sedimentary rock and a porphyry sill. Because of this juxtaposition of two kinds of rock, deposits of this category are often called "contact" ore bodies; it should be noted, however, that the use of this term does not connote that one of the rock-types involved is igneous.

Blankets or "contact" ore bodies are commonly flat above, as though a rising solution had been impeded or "ponded" by an impermeable barrier. These deposits taper downward to a point in vertical section; commonly their lowest projections follow fissures that appear to be the channels along which the ore-forming solutions traveled. In dimensions they vary greatly; those of the marginal parts of the district are smaller both vertically and horizontally than those of the central part. Some of the individual stoped blankets in the Continental Chief mine were 200 by 50-ft in plan and 12-ft high; in the same mine the Ice Palace stope is 220 by 105-ft in plan with a maximum height of 37-ft. These are two of the largest stopes of the marginal districts around Leadville which were accessible at the time of the field work, but some of the stopes of the Hilltop mine were even larger. In the Continental Chief and Liddia mines, the caprock is a dark-gray shale that lies between the Leadville dolomite and the sill of early White porphyry. In some of the smaller prospects south of the Mitchell Ranch the ponding body is a quartzite layer at the top of the Leadville dolomite. Rarely, the blanket is in the Manitou dolomite, and in that position, sills of Parting quartzite are the common ponding body. By far the most common caprock, however, is the sill of early White porphyry just above the Leadville dolomite.

FISSURE FILLINGS AND ASSOCIATED REPLACEMENT VEINS

Typical fissure veins may be developed in any kind of rock, if only the fracture gapes enough to admit the ore. Such ore bodies vary greatly in their dimensions. Commonly a fissure vein is marked by discontinuous ore shoots following an unpredictable pattern that is dependent on many factors. As is well known, the walls of a fault having a zigzag pattern involving two different directions in ground plan or vertical section may, after movement has taken place, match closely where the course of the fault follows one direction but gape widely in the other. This condition yields alternate wide open stretches and narrow tight stretches; in such faults, the ore shoots are generally confined to the wide sections.

Fissure veins are not limited to faults of large displacement. Indeed, at Leadville, wherever most faults of large displacement are of compressional origin and especially wherever they have relatively low dips, these fissures are generally the tightest and least productive of the premineral openings. On the contrary, related but smaller fissures are of greater economic importance. The relatively small number of low angle reverse faults are of interest largely because their presence serves as a clue for favorable localities. Mineralization seems to be more extensive where the dip steepens on such veins.

Although vein deposits are typically fissure fillings, at least a moderate amount of replacement takes place at the borders of many fissures, even in the marginal districts around Leadville. There are good examples in the larger stopes of the Continental Chief mine. In the central Leadville district replacement fissures grade into replacement bodies of the blanket type. Such features are discussed in more detail below.

Dimensions of lodes in fissure and associated replacement veins vary greatly. The Hellena vein has been mined from the Hellena shaft at mine levels to a depth of 800-ft, and for a distance of 600-ft along the strike of the vein in this mine alone. If it is an extension of the vein worked in the Green Mountain and Sunday mines, its horizontal dimension is at least 4,000-ft, but it is not uniformly mineralized. Mineralized ground is less extensive along the main Mosquito fault in the Best Friend and adjacent workings; there it is 1,000 to 1,200 ft in length and has a known depth of about 800 ft. This size is more typical for the fissure veins than is the great Hellena vein.

TRANSITIONAL FORMS

The “contact” or “blanket” deposits are believed to have been formed by solutions fed from below (pp. 30–31), so it is natural that the feeding fissure should end against any contact, at least locally. In many places the original channel has been obliterated by subsequent mineralization; where it has not, as in some of the mines of the central district, the original fissure can still be traced across the main blanket ore body. The vein differs mineralogically as well as structurally from the associated blanket, generally containing ore richer in precious metals as though precipitation of these metals had been the last stage in fissure filling and had resulted from interaction between the precious-metal solutions and the base-metal sulfides making up the blanket. Such ore bodies are thus a combination of fissure filling and blanket-like replacements.

Many of the fissure veins are bordered by replacement bodies of such extent that the replacement rather than fissure filling was clearly the dominant mode of origin of the deposit. This is more particularly true if the rock traversed is a limestone or dolomite that is readily replaced. In such rock “selective replacement” has commonly been operative, some beds having been extensively replaced whereas beds above and below were less so. The vein then is bordered on one or both sides by small blankets at one or several horizons, but commonly the extent of a steeply inclined tabular ore body is along the vein itself (See Continental Chief mine, p. 59–64, figures 86–87.)

In many ore bodies the longest dimension is clearly outlined by the vein, but the width and thickness differ with the degree to which wallrock has been replaced. For example, the main ore body of the Hilltop mine was stoped almost continuously for a distance of 1,450-ft; but it averages only 30-ft in width and thus was obviously determined by a fissure. The width of the fissure, however, is not regular; the fissure was swollen here and contracted there. Moreover, the upper surface of the deposit, like that of most “contact” deposits, was capped by a sill of early White porphyry or a basal quartzite bed of the Weber (?) formation. The ore body was thus intermediate between a true “contact” deposit and a fissure vein. Several of the smaller mines also exhibit this pattern in their stopes.

Texture and Finer Structure

In a general way a primary ore in the marginal parts of the Leadville district may be classified under one of five heads: (1) densely granular replacement ores, (2) lean replacement ores, (3) coarsely crystalline replacement ores, (4) breccia ores, and (5) crustified fissure ores.

Densely granular ores contain sulfides in most concentrated form. These ores occur in rich replacement bodies and in vein fillings. A conspicuous mineral in ores of this type is pyrite, but dark-colored blende, and finely granular but cubical galena are also present. The average grain diameter is only about 1/25 in. (1 mm), and the minerals are so closely interlocked, and even intergrown, that fine grinding would be necessary to obtain zinc and lead concentrates from this type of ore. Some of the sphalerite grains enclose minute blebs and grains of chalcopyrite too small in size and quantity to be separated. Finely granular quartz may be present in large percentages and greatly dilute the sulfides.

Most lean replacement ores are not generally worked. They are well represented in some of the lower levels of the Ibex mine, where sphalerite has replaced shale of the Ibex mine, where sphalerite has replaced shale of the Peerless formation. Commonly ores of this type contain a larger proportion of zinc blende, in comparison with the other sulfides present, than do the densely granular ores. The grains of blende are disseminated through the rock in small, irregular masses and in separate crystals averaging about 1/10 in. (2.5 mm). Lean replacement ores tend to be monomineralic: pyrite tends to occur in the Parting quartzite or in Cambrian sandstone, the blende or galena in the various limestones. Ores of this kind require less crushing in order to free the desired sulfides and are generally amenable to tabling (or other forms of gravity separation, as distinguished from flotation) because intergrowths between minerals are less intimate.

Coarsely crystalline replacement ores are characterized by bladed barite, galena, and zinc blende, and rarely pyrite. Mineral grains are all fairly large, with minimum sizes for the sulfides of approximately 0.5-in. (12.5-mm) in most localities; these figures do not apply, however, to the oxidized minerals derived from the primary ores. Intergrowth is negligible and gravity separation without fine crushing is possible for much of the ore. Such ore occurs only in limestone or dolomite.

Typical breccia ore occurs in the Hellena fault in the Hellena mine. Fragments of the country rock are embedded in dense, finely crystalline ore composed of intimately intergrown lead and zinc sulfides, and rich in pyrite (**Figure 73**). Many cubes of galena in the Hellena ore are almost 1 in. (25 mm) in diameter, but most of the sulfide grains are much smaller. Pyrite and zinc blende may be present in large proportions. Milling is made difficult by the fineness and intergrowth of the sulfide grains, and by the abundance of quartz.

Figure 73. Breccia ore from Hellena vein. X½ From 4th level, Hellena mine. Fragments are altered porphyry embedded in mixed sulfides.

Crustified fissure ore consists of quartz, dolomite, rhodochrosite, and other gangue minerals, associated with any of the three common base-metal sulfides. Commonly, the veins are so small that selective stoping or underground cobbing can not be applied to eliminate the waste before hoisting. Most fissure veins at Leadville are bordered by noteworthy replacement zones across which the ore becomes more pyritic and fine-grained; beyond this rather densely pyritic zone the sulfide content becomes progressively less and finally disappears. Such ores commonly have the highest content of precious metals, and generally also of copper in or very close to the fissure vein.

Origin of the Primary Ore

Emmons, Irving, and Loughlin (1927, pp. 209–219) presented a careful outline of the origin of the ore. They discussed the deposits in the outlying areas to the extent warranted by the scant evidence available to them. The present report considers the origin of these outlying deposits more thoroughly, and summarizes the discussion of these earlier authors.

In Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 562–584) Emmons modified his views concerning the source and direction of movement of the mineralizing solutions. As a result of his earliest work at Leadville, Emmons thought that the ores are essentially the products of lateral secretion—that they were dissolved by circulating (probably descending) waters from the adjacent country-rocks, especially the porphyries, and deposited at favorable places. Emmons maintained (1) that the primary ores were chiefly sulfides, (2) that they were formed mainly by replacement of the country rock, rather than by cavity filling, and (3) that they were derived, at least in large part, from the adjacent porphyries. This theory was based on (1) the finding of at least minute quantities of the elements and minerals making up the ore and gangue in virtually all the rocks of the region (suggesting that these rocks might have been the source of the ore); (2) the absence of evidence (for lack of deeper workings) that the ore extended to great depths or appeared especially along channels that might be presumed to extend very deeply (an observation that seemed to favor a connection of ore genesis with near-surface agencies); and (3) the great extent of “contact” ore bodies, resulting in an overemphasis upon their genetic significance and a failure to recognize the importance of veins or ore channels along which the ore minerals were transmitted to the “contacts.”

Later studies led Emmons and Irving to a complete change from the earlier ideas. The account given in Professional Paper 148, a further revision by Loughlin, is thus in full accord with the modern concepts of the genesis of ores of this general type. According to these ideas, the ore-forming solutions moved outward in part perhaps from local deeper centers, but chiefly from the Breece Hill plug (now recognized as composed of Johnson Gulch porphyry, the latest member of the Gray porphyry group). Temperatures were high, and solutions or gaseous emanations were active in this plug and immediately adjacent to it. Here were deposited the ores formed under contact-metamorphic conditions, or at least at temperatures high in the ranges within which veins and replacements form. Farther out from the plug, the temperatures of the ore forming solutions were lower, and in this region the higher ranges of mesothermal (moderate temperature) conditions prevailed. The ores here were sulfides, sulfo-salts, and certain high-temperature carbonates, in particular manganosiderite. Locally, where the fractures remained open to especially great depths, the solutions had relatively easy and rapid passage from the depths where they originated to the zone of deposition. In such open channels the gradient for a given length of channelway was less abrupt and conditions of deposition approximated those nearer the Breece Hill plug, despite greater distance from the source of the solution. Trunk channels of this deep type were in the broken ground along reverse faults, such as the Tucson-Maid, and some of the normal faults, such as those of the Garbutt and Winnie-Luema systems. Structural features still further modifying this relatively simple pattern are discussed on page 27.

Still farther away from places where the high mesothermal conditions prevailed, the solutions had been cooled even more and typical mesothermal ores were deposited; this is the stage represented in Iowa Gulch near the Hellena, Lillian, Ella Beeler, Mansfield, and Rex properties, and also along the northern edge of the area mapped—north and east of the Chicago Boy property, and in the floor of Evans Amphitheater.

At still greater distances from the Breece Hill center the ore and gangue minerals are those characteristic of epithermal (low-temperature) conditions, as recognized today by geologists. The solutions yielded deposits of lead, zinc, and iron sulfides, with silver (probably in the form of primary argentite and possibly of native silver) with a gangue of carbonates and barite.

At distances ranging from 3 to 10 miles from Breece Hill, ores of the coolest or telethermal zone are present, such as those of the Ruby mine at Weston Pass and several prospects west of Empire Hill. In these ores silver content is relatively low, pyrite is rare, and barite is lacking.

The relatively open channels mentioned, notably along the Tucson-Maid fault, resulted in the deposition of certain minerals farther from the source than might have been expected. Although the temperatures indicated are generally as high and the mineralization not as intense as along the Tucson-Maid fault, a similar effect was produced around the intrusive plug near the Mansfield and Rex shafts, and it may be inferred that this small plug is related to a local center of rather intense mineralization from which the ores of the First National, Julia-Fisk, Hellena, Lillian, and Rex mines were derived. Thus, at least two probable centers of high-temperature mineralization are recognized in the Leadville district, and the picture becomes more complicated than the idealized picture of the regularly circular and concentric zoning.

The zoning pattern seems to point to sources of mineralization geographically near and probably beneath the large Breece Hill plug and the smaller plug near the Mansfield mine; possibly, also, to a third source beneath the general area of the First National mine (pp. 73–74). This idea—that the ore-depositing solutions at Leadville rose from deep sources from which the intrusives of the Gray porphyry group were also derived—was first urged by Blow (1890, pp. 173–181) as the result of careful analysis of the facts observed in the Iron Hill area; it was accepted in large part by Emmons and Irving (1907, pp. 60–72), then engaged in a restudy of the district.

The studies here reported have demonstrated an age sequence for the intrusives of the Gray porphyry group, in which the latest is the Johnson Gulch porphyry. This porphyry is the only one among the Gray porphyry group that appears largely as dikes, and is also the type constituting the two stocks mentioned above. Advance toward the surface by stocks of fair-sized horizontal cross-section involves considerable upthrusting and probably some stoping and assimilation of the country rock (Barrell, 1907, pp. 152, 156–157). This statement is not intended to face the much-discussed question whether the quantity of assimilated material is sufficient to change the composition of the intruding magma, as some have maintained (Grout, 1932, pp. 224–230), but merely to accept the most reasonable solution of the mechanical problem of making room for the advancing magma. Transgressive porphyry stocks of the Johnson Gulch type are manifestly more directly connected with deep magma reservoirs than the sills which form so much more conspicuous a part of the total of the “Laramide” intrusions. Moreover, the stocks and dikes were intruded at a time much closer to that of ore deposition than the sills. The mineralizing solutions are believed to have been derived at depth from the same source as the Johnson Gulch porphyry.

The physical and chemical nature of the solutions from which the ores were deposited is of interest. The exact temperature of the solutions cannot be ascertained, but may be inferred from two lines of evidence. The temperatures of deposition of mineralogically similar ores may with reason be assumed as having the same general range. By an ingenious method, Newhouse (1933, p. 748) has shown that the lead-zinc-carbonate or lead-zinc-barite veins of Henry County, Kentucky, were formed at 70º–95º C; those of the similar lead-zinc deposits of southwestern Wisconsin at 80º–105º C; and those of the lead-zinc-carbonate-barite deposits of the Joplin district, in Missouri, at about 90º–135º C. The similar epithermal ores of the Leadville district were probably formed at temperatures of the same range.

Criteria for inferring the chemical nature of the mineralizing solutions are far better than those suggesting temperature of deposition. Questions regarding the chemistry of these solutions have long been debated. Bowen (1933, p. 119) argues for the presence in predominant quantities of HCl, HF, H_2S, CO_2, H_3BO_3, H_2SO_4 and other acids or their related ions, together with those bases that form volatile compounds with the acids mentioned. These views are confirmed by observations made at volcanoes by Zies (1929, pp. 4–5), by Georgalas, Liatsikas, and Reck (1936, pp. 78-79), and by others and by theoretical reasoning developed by Niggli (1929, pp. 14–27), Fenner (1933, pp. 77–80, 83-84), Bowen (1933, pp. 119–120, 124–127), and Ross (1928, pp. 880–881, 885). However, most traces of the strongly acid elements disappear after ore deposition, and they are not well represented in the minerals of the veins and replacement deposits with the exception of fluorite and barite; this is largely because many of the acid ions, such as chlorine and its relatives, react with country rock, forming for example, soluble chlorides, such as $CaCl_2$, which are carried far from the sites of ore deposition. The only available direct evidence for the former presence of halogens is offered by inclusions in the minerals themselves.

Newhouse (1932, pp. 430–431) was able to analyze the inclusions in galena and sphalerite from several districts, among them Leadville. The galena from Leadville, like that of the other districts studied, contains inclusions that carry the elements sodium, calcium, and chlorine, in strong concentrations. These inclusions are thought to represent remnants of the original solutions, caught by the sulfides as they were precipitated and crystallized, and clearly suggest that the mineralizing solutions were rich in chlorine and possibly also sodium. The calcium is probably best attributed to the action of the solvents on the limestone. In this process the chlorine itself may have been the solvent, or an agent acting to retain the salts of the metals in solution (presumably as sulfides) much as hydrochloric acid is used to increase the solubilities of certain metallic sulfides in chemical analysis.

Thus, both theory and observation indicate that the mineralizing solutions carried acid ions and the metals now present in the ores (especially lead, zinc, iron, and copper), whereas prominent acid radicals were the chloride and sulfide ions. Whatever their exact composition, the temperatures of the mineralizing solutions that formed the ores in the marginal parts of the district were too low to permit volatilization of the chief acid constituents at the pressures then existing; hence the solutions were liquid and aqueous, and the ore minerals were not deposited by mere loss of acid gases from solution. These solutions rose along fractures leading from cupolas or plugs connected with one or several igneous sources. The fractures were thrust several igneous sources. The fractures were thrust faults, steeply dipping reverse faults, and premineral normal faults. In places where the faults were “tight” and did not serve as effective channels, the adjacent shattered zones or accessory tension fissures furnished channelways essentially parallel to the major faults themselves. Some movement of the solutions took place along bedding planes, especially where these planes permitted flow in an upward direction, toward places of lower pressure.

The solutions tended to lose their less soluble constituents as they moved laterally and upward, and came into contact with cooler rock farther from the source cupola or plugs and nearer the surface. However, this tendency to precipitate was not due solely to reduction of temperature. The abundant dolomitic limestones of the region and descending ground water, rich in calcium and magnesium bicarbonates dissolved from the country rock, reacted with the acids in the solutions. These reactions had the effect of dissolving the limestones and at the same time neutralizing the high acidity upon which the solubility of the metallic sulfides probably depended. The relatively insoluble sulfides were then deposited along the channelways (forming the fissure veins) or in the minute openings produced by solution of the limestone (forming replacement bodies which at Leadville take the form of "blankets" or "contact" deposits).

That deposition is largely a chemical process resulting from such reactions is amply demonstrated by the following fact: many of the noteworthy ore bodies at Leadville are developed only where a feeding fissure crosses soluble limestone beds. This seems to show not merely that the solution served to attack and corrode the country rock, but also that both the solution and the country rock were generally essential to the reaction that resulted in the precipitation of the metallic sulfides. If the action of the solution had been purely corrosive and precipitative, not all of the openings developed would have become filled with minerals as they are now. In order to account for the present lack of unoccupied openings it must be assumed that solution and deposition took place essentially simultaneously and were parts of a single process.

One more kind of evidence as to the nature of mineralizing solutions is available. It has been pointed out by Singewald (1932, pp. 27–29) that the distinction between deuteric changes, produced during the consolidation of the intrusive porphyries within the porphyries themselves, and hydrothermal alteration is not readily made. In the alteration of the porphyries, albitization generally took place during an early stage of alteration, especially in the early White porphyry; silicification and sericitization were more conspicuous, later changes. The preponderance of sericitization over albitization suggests that the hydrothermal solutions gradually changed in composition, with a relatively high concentration of potassium during the later stages of the process. The alteration of calcic, sodic, and purely silicic minerals by the substitution of potassium must have increased the amount of calcium, sodium, and silicon in the solutions. To the extent that silica was liberated, this process increased the acidity of the solution and its ability to deposit quartz.

A striking feature of the mineral deposits is the absence of extensive replacement bodies of quartz and other forms of silica in immediate association with the sulfides of the lower-temperature facies. The filling of fissures with quartz and sulfides was common, but the processes of silicification by replacement and the deposition of sulfide ores generally appear to have been mutually exclusive; jasperoid forms the margins of many ore shoots but usually contains only negligible quantities of metal. Gold and silver, however, may be present in silicified country rock. Lead and zinc ores are lacking in highly silicified rock except for deposits of silica and oxidized lead as in the so-called "hard carbonate" found at the Peerless Maude mine. Emmons, Irving, and Loughlin (1927, pp. 224, 229) ascribed the "hard" character of this oxidized ore to the original presence of large amounts—approximately 25 to 40 percent—of silica in the primary lead ore. Most of this silica appears to have been jasperoid and supports the theory that the original sulfide ore was deposited at relatively low temperatures.

Carbonates are conspicuous gangue minerals, despite evidence that the solutions were moderately acid. Among the acid ions listed by Bowen (1933, p. 119), $CO_3^{=}$ and Cl^{-} are present in large quantity in mineralizing solutions of the type here discussed. The alkalies, K and Na, are believed to have been present, as suggested above, whereas the alkaline earths, Ca and Mg, if present, were not conspicuous. Under these conditions the calcareous and dolomitic country rock should have been dissolved in the form of the bicarbonates, aided by the excess acid. Carbonates of the alkaline earths could be dissolved in the form of the bicarbonates, aided by the excess acid. Carbonates of the alkaline earths could be dissolved from lower horizons by rising hot solutions containing either acids or alkaline carbonates, as suggested by Hewett (1931, p. 67), Loughlin and Behre (1934, pp. 252–253), and others. There is strong evidence of this origin for the crystalline dolomite and rarer calcite found as gangue in the veins, and probably also for the small quantities of siderite and manganosiderite in the outlying deposits. Although the carbonate radical may have been derived from the mineralizing solutions, at least the positively charged ions in the carbonate minerals (Ca, Mg, Fe, and Mn) probably came in large part from the country rock. This is suggested by the moderately close agreement in composition between country rock and gangue minerals in the outlying areas. This is suggested by the moderately close agreement in composition between country rock and gangue minerals in the outlying areas. Thus, siderite and quartz are most abundant where the country rocks are ancient siliceous schists and granites, and quartz unaccompanied by carbonates is abundant where quartzites and sandstones preponderate. In dolomites and limestones, dolomite and calcite are the chief gangue minerals.

The characteristic association of barite, galena, and sphalerite in the epithermal zone as here described merits at least a tentative explanation. One deposit of this facies occurs at such great distance from the Breece Hill plug as to nullify any appreciable increase in temperature assignable to the Breece Hill intrusion itself. The depth of barite-galena-sphalerite ores below the surface at the time of formation is estimated at not more than 3,000 ft, where, probably, the temperature was not more than 30º C higher than at the surface—too little to change appreciably the solubilities of the minerals mentioned. The mineralizing solutions may be assumed to have contained $PbCl_2$, $ZnCl_2$, and $BaCl_2$, with an excess of negatively charged sulfur ions. As it approached the surface, the solution would cool and thus tend to deposit at least the sulfides, and there would probably be continuous reaction of chloride ions with the carbonate country-rocks and with descending solutions rich in Mg, Ca, and CO_2; this condition in turn would increase the deposition of PbS and ZnS through neutralization of chloride ions. Moreover, oxidation by descending waters would tend to convert the sulfides to sulfates, and in this process barium sulfide would be the first of the metallic sulfides to oxidize, because of its higher potentiality as indicated by its position in the electromotive series. The barium sulfide that was not oxidized in this way moved to higher horizons. The fact that it antedated the precipitation of the base-metal sulfides constitutes ample proof that the solutions were not sufficiently cooled and neutralized to precipitate galena and sphalerite until after the early oxidation of the barium sulfide. Thus was developed the association characteristic of the epithermal facies in the Leadville district.

Factors in the Localization of Ore

The geologic study of the outlying parts of the Leadville district had two principal purposes—to aid the individual mine operator to develop ore already discovered on his property, and to help find new ore deposits by revealing areas that merit exploration. Detailed descriptions of the mines given in a later section of this report should further the first objective; a discussion of the factors localizing the ore deposits should contribute toward the second. The following discussion deals in general terms with causes for localization of the ores. Three factors appear to be of paramount importance in ore localization: large structures, such as folds and faults that directed the flow of solutions, the nearness of intrusive rocks (that served as sources or ponding agents for the solutions), and the permeability, solubility, and other pertinent properties of the particular country rock in which the ore was deposited.

STRUCTURAL FEATURES

FOLDS

Ore deposition in the Alma district was favored by an anticline, at least in the Mount Lincoln area (Singewald and Butler, 1933, p. 106; Loughlin, Butler, Burbank, Behre, and Singewald, 1936, pp. 439–440), but in the Leadville district folds (other than small wrinkles caused by drag along faults) do not appear to have had any appreciable influence in the localizing of mineralization. Certain apparent exceptions prove, on closer examination, to conform to the rule. Ore in small quantities was found widely distributed in the western limb of the broad syncline extending approximately due south from the Mitchell Ranch, but it was localized along bedding faults. Some mineralization also took place in the western limb of the Empire syncline, but here too it is chiefly localized on eastward-trending faults. Ore occurs on the northern slope of Upper Long and Derry Hill, in what has been described as the Long and Derry syncline, but localization of mineralization here appears to have been due more to the local faulting than to folding. Much the same circumstance applies to the conspicuous ore deposits in the eastward-dipping monocline east of the Pilot-Mike fault complex, as exposed on the southern slope of Printer Boy Hill and on the northern slope of Long and Derry Hill, but without exception the ore bodies there are either in fault fissures or in blankets leading out from these fissures.

Two general observations may be made regarding the relations between folds and ore deposits throughout the Leadville district. One of these is the fact that country rocks of pre-Cambrian age are not favorable for mineralization. With the present degree of dissection, prominent anticlines are likely to bring pre-Cambrian rocks either to or near the surface, with a corresponding erosional thinning of the overlying favorable sedimentary rocks; hence anticlines are largely barren in the marginal, less mineralized parts of the Leadville district. This condition probably explains why as much ore occurs in association with synclines as with anticlines at Leadville, despite the expectation, for theoretical reasons (Newhouse, 1931, pp. 241–245), of the contrary.

The second general observation is related to the fact that most of the folds are actually drag-folds along the larger faults. Whether such faults were preceded by the folds or caused them is a matter of conjecture but, as the faults are generally the chief sites of mineralization, the ore deposits are best discussed as related to them.

FISSURES AND FAULTS

In general, large bodies of ore are not found between the walls of the faults having the largest displacement. The South Dyer, Weston, Ball Mountain, Iowa Gulch, and Mike faults which are of premineral age, at least in part, and which have large throws, are generally barren. The Liddia and Mosquito faults contain small amounts of ore and only the Sunday and Hellena veins among the larger fractures are extensively mineralized.

Considerable difference of opinion exists as to which of the major faults truly antedated mineralization. Some of the faults hitherto regarded as postmineral (Emmons, Irving, and Loughlin, 1927, pl. 39) are now known to be premineral, although they have also been subjected to postmineral movement. Conspicuous among them is the Mosquito fault, but the South Dyer fault also was regarded, at least in part, as of postmineral age. No evidence was recognized that proved the South Dyer fault to be postmineral, but in the Mosquito fault ore minerals have been found to be slickensided, and this fact has been cited to prove that deposition took place before the fracture was first opened. In this connection it should be recalled that ore deposition rarely heals a rock fracture completely and that both sulfides and quartz are conspicuously brittle. Faults are commonly the sites of renewed movement and at Leadville many striations on fault surfaces cross one another, proving repeated movements. In the Hellena mine, evidence was found that is interpreted is indicating oppositely directed motion along the minor fault east of the shaft that contains a shale “dike” (p. 67). Both in the present study and as reported in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 77–79), the Weston fault was found to have a reversal of downthrow in different parts of its course, indicating two periods of displacement, the later directed oppositely to the earlier one. A similar explanation would reconcile also the disagreement in the interpretations of the Mosquito fault, described as postmineral in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 80–81), but as possibly premineral as well by Butler and Vanderwilt (Butler and Vanderwilt, 1931, pp. 332–334) and by the present author. In short, a premineral fracture, once opened, remains a plane of weakness even if cemented with ore. If the region is subjected to renewed stresses, such a fissure is very likely to be reopened after partial ore complete cementation by ore. This process of recurrent opening and shattering probably accounts for the larger ore bodies found in some premineral reverse faults, such as that along the Hellena fault in the Hellena mine. As a consequence ore bodies may occur even in major faults.

More favorable places for mineralization, however, are the minor fractures that are either parallel or accessory to the major ones. Because of their great displacements and lengths, the master faults are presumed to be more continuous and to extend to the great depths from which the mineralizing solutions came. The accessory or parallel faults, however, contribute an irregular and discontinuously shattered zone bordering the larger planes of movement. Along such zones the mineralizing solutions can easily rise, even though the main fault itself is closed by gouge or has its opposite walls too tightly pressed against each other to serve as a channelway. This relationship between the major breaks and the more open accessory fractures probably accounts for the mineralization in fissures such as those near the Mosquito fault developed by the Best Friend, Dixie, and Kemble mines in Evans Amphitheater. The numerous ore bodies mined in Iowa Gulch east of the Mike-Pilot fault complex on the slopes of Long and Derry and Printer Boy Hills are further examples of the same sort.

Intense mineralization, such as that of the central Leadville district, yielded workable deposits even in slightly fissured ground. On the other hand, where the mineralizing solutions appear to have been farther from their source, less active, and less concentrated (as in the marginal parts of the Leadville district), they yielded ore in workable quantity only where the ground was considerably fractured. Examples are the intermediate stopes of the Continental Chief mine, where the Leadville dolomite is greatly shattered by sub-parallel fractures, and the deposits on the southern slope of Printer Boy Hill east of the Mike-Pilot fault complex. A favorable locality for ore deposition is where fissures pass from one kind of rock to another; for example, in the northern head of Iowa Amphitheater, small fissures that extend from the Leadville dolomite to the overlying shale of the Weber (?) formation or early White porphyry sill generally contain ore below the contact. A decrease in permeability or brittleness from below upward appears to have localized the ore. Repeated observations have shown that dolomite shatters more easily and recrystallizes with greater difficulty when under stress than does limestone, a fact which may explain, at least in part, the well-known association of ore bodies with dolomite, rather than limestone in many districts (Hewett, 1931, pp. 28–31).

The nature of the fractures is significant in another connection. In many places where the shattering is moderately intense, individual fractures are vertically short and stop after having crossed only one or two narrow beds, thus limiting the vertical extent of mineralization. The vertical extent or continuity of the fractures varies greatly with the kind of rock. Even within a series of dolomite layers, some beds are broken by short, discontinuous joints, whereas others are crossed by fissures that afford excellent channels are crossed by fissures that afford excellent channels for ore-forming solutions to pass continuously from bed to bed. This difference seems to be due in part to differences in the size of particles and the degree to which they interlock: the more closely spaced and finer the particles (or, as it is usually put, the more dense the texture) the less continuous the fractures. This contrast is well shown at the foot of the incline in the Continental Chief mine, where the fissures are conspicuously discontinuous in a dense, equigranular dolomite, though the next higher and more coarsely granular beds are broken by regular, continuous fissures.

A second factor in the continuity of the fractures is the continuity or thickness of shale partings between the beds of dolomitic limestone. In parts of the Dyer and in the lower part of Leadville dolomite, calcareous beds are separated by thin shaly members; each stratum when put under stress separates from its neighbor and the rock becomes broken by joints, fissures, or small faults that stop at the partings. In such rock, mineralizing solutions cease their flow at the partings or they follow tortuous zigzag paths upward, losing their mineralizing action at relatively deeper levels than would be the case if the channelway were a single, more nearly vertical fracture.

That deposition is likely to be richer at intersections of fissures has been demonstrated in many mining districts. In the marginal deposits at Leadville such structures generally consist of a well-defined, essentially continuous major fissure, intersected by minor ones (feather fractures). The acute angles where the two intersect are promising areas of replacement, presumably because the mineralizing solutions attacked the rock in the acute angle more strongly and found a smaller volume here that needed to be removed; moreover, the wedge in the acute angle was doubtless rendered more permeable by many minute cracks. An excellent example is seen in the Hilltop mine at the intersection of the northwest-trending fissure that yielded the Lind stope with the main fissure on which the Leavick drift and corresponding stopes were driven (p. 89, figure 98).

No discussion of the relation between ore deposition and fissuring would be complete that did not take into account the extensive bedding-plane faults that permitted mineralization to extend laterally parallel to gently dipping beds for appreciable distances from steeply dipping trunk channels. The slippage of beds upon one another has a beneficial effect in producing openings that may be followed by mineralization (Behre, 1937, pp. 512–529). Though difficult to recognize, such planes of movement prove their true nature as faults by passing vertically into typical normal or reverse faults that cut the bedding. In the Continental Chief mine small faults of this type pass upward with essentially vertical dips through the uppermost beds of the Leadville dolomite, but curve sharply as they rise to the base of the overlying black shale of the Weber (?) formation and disappear into the parting plane separating shale above from dolomite below; the contact between dolomite and shale is locally slickensided. The Bowden fault, observed in the Ibex mine, rises across the steeply dipping beds in the northeast limb of a syncline but passes into the bedding as it crosses the axis and enters the gently dipping southwest limb. In the Greenback-Mikado workings a branch of the Tucson-Maid thrust can be followed upward along a thick gouge and breccia zone to a level where it gradually curves and passes into a bedding plane. Such faults serve as channelways to mineralizing solutions because of their openings along the planes of bedding, and they also induce the formation of accessory faults and fissures along which gash veins may be formed. Despite considerable "healing," there is much evidence that the feeding fissures of some of the larger blankets are bedding-plane fractures or faults.

Where veins of late mineralization cross replacement ore bodies a striking relationship exists as to relative richness: the replacement deposit (frequently a blanket) commonly consists of sphalerite-chalcopyrite-galena ore of only moderate grade, whereas the intersecting fissure is far richer, with an especially high content of gold and silver. In such examples the facts admit two possible interpretations. The ore may all have arisen from trunk veins, mineralization spreading laterally to yield the blankets and, at a late but gradational stage, depositing the richer ore that borders and fills the vein channel. Alternatively there may have been the following sequence of events: (1) the formation of the blanket by replacement, (2) shattering, and (3) deposition of the richer ores, the precious metals having apparently been precipitated by reaction between the base-metal sulfides and late rising solutions, or a similar relation could result from enrichment of veins by descending meteoric water. Emmons, Irving, and Loughlin (1927, pp. 184, 206–207) cited examples favoring the first of these interpretations. One of the most striking deposits is that in the Golden Eagle workings where both blankets and veins were formed during one period. Studies of Swanson's stope in the Ibex mine (p. 104, figure 100) show that the vein and blanket ores are contemporaneous, but here too the vein and blanket differ somewhat in composition; the vein is richer in copper and in gold despite the absence of any evidence of secondary enrichment, whereas the blanket contains a far higher proportion of zinc to other metals.

The trend of the ore-bearing fissures is fairly constant locally. In general, both premineral and postmineral fractures strike N. 0º–30º E. A few of the major faults (the Mike, Weston, and Ball Mountain faults) strike north-northwest, but most smaller mineralized fractures have strikes between the limits indicated. There are, however, some conspicuous exceptions. At the Continental Chief mine, in the head of Iowa Amphitheater, the strikes of 77 premineral fissures average N. 40º E.; of 77 observed fissure strikes, only 10 are in the northwest quadrant of the azimuth circle (figure 82). Farther south along the western slope of Mount Sherman the direction is more nearly N. 60º–75º E. Near the Hellena and Lillian mines, it is approximately due north. Intelligent prospecting requires recognition of the regional trend, with the intention of driving exploratory tunnels as nearly as possible at right angles to the prevailing fissure strikes. It is emphasized, however that it would be most unwise to assume that the strike of fissures will be constant for long distances; stresses vary considerably from place to place, even within a small area, especially if the rocks are not everywhere identical.

Gouge has a definite effect upon mineral deposition, acting much like a semipermeable membrane by "straining out" some constituents, but allowing others to pass through it. The fissures thus exert a differential effect on mineralization in ways other than as channels. For example, in the southern crosscut at the east end of recent workings of the Nevada Tunnel, gold in amounts up to 3 ounces per ton has been found in a dense, clayey gouge of sheared granite, deeply stained with brown iron oxide; locally the metal is visible in this gouge, and also in the sheared granite "horses" within the gouge zone. Whether this gold is primary or secondary in origin is uncertain; the oxidized state of the iron suggests that the gold is secondary, but the gold in the relatively unaltered granite inclusions at least appears to be primary.

NEARNESS TO INTRUSIVE BODIES

In the central part of the Leadville district high-temperature deposits surround the obscure intrusive stock of Breece Hill plug, is interpreted as indicating that the mineralizing solutions traveled laterally and upward from the same center as the Breece Hill plug, following the edges of the newly consolidated plug and spreading outward from it along available fault zones. Thus the Breece Hill plug may be regarded as marking the source of the mineralization.

No igneous masses in the marginal part of the Leadville district are clearly associated genetically with the ore. However, there is evidence that the Mansfield shaft was sunk in a plug of Johnson Gulch porphyry, which cuts the early White porphyry sill at the top of the Leadville dolomite. This plug is not clearly delimited at the surface because all of the rock in the vicinity is greatly bleached and altered (p. 67). From the Mansfield plug the ore-forming solutions apparently moved outward, in part following along the great Mike fault that lies to the east, and in part radiating in all directions through the sill of early White porphyry and the underlying Leadville dolomite. The great heat coming from this nearby irregular plug appears to have favored the serpentinization, local deposition of crystalline masses of magnetite, and impregnations of fine dusty hematite. These minerals are conspicuous in the Altoona workings and the adjacent area and extend as far east as the First National shaft. The plug of Johnson Gulch porphyry or a similar, more deeply buried, intrusive is believed to account for the arsenopyrite and manganosiderite found on the dump of the First National shaft.

The various porphyry sills were intruded before the crosscutting plugs and were obviously not so closely related to the ore-forming solutions. Certain of the sills are very closely associated with large ore bodies, but this association is a structural feature to be considered below.

EFFECT OF PONDING AGENTS

Upward or lateral progress of solutions may be impeded or completely halted by impermeable rock masses. This stagnation generally favors deposition of the contained mineral matter in pre-existing openings; similarly, ponding commonly affords a better opportunity for replacement. Conspicuously effective ponding barriers at Leadville are clay gouge in faults (already discussed above), porphyry sills and dikes, and shaly layers; locally silicified limestone strata and quartzitic beds have also been effective. Where such ponding layers are parallel to the beds, the replacement bodies developed are the "blankets" or "contacts" so typical of the district. In general, the most common ponding agents are sills of the Gray porphyry group or of the early White porphyry. In the central part of the Leadville district porphyry sills are abundant, especially in the Leadville dolomite. Sills are so numerous in some localities, including one or two shaly beds that also act as barriers, as many as ten or eleven "contacts" are recognized (Emmons, Irving, and Loughlin, 1927, p. 190). However, such occurrences of multiple "contacts" are confined to the central part of the district; neither intrusive sills nor deposits of the blanket type are so plentiful in the marginal parts here described.

In the marginal parts of the Leadville district, the sill most commonly serving as a ponding agent is the great mass of early White porphyry that lies above the Leadville dolomite. This well exposed in the vicinity of the Dyer mine and in the numerous prospects on the east wall of the Iowa Amphitheater. The sill can be readily traced westward far down Iowa Gulch: it is recognized on the southern slope of Printer Boy Hill and on the northern slope of Long and Derry Hill, west of the Hellena mine, and near the Mansfield shaft. In the northern part of the area mapped, from Little Ellen Hill and Evans Gulch northward, the chief ponding sills exposed in shallow workings are of Evans Gulch porphyry, as best seen on the southern slopes of Prospect Mountain. However, most of the higher-grade ore and the larger ore bodies in the northern area are those developed beneath the same sill of early White porphyry (here greatly thinned) above the Leadville dolomite; others occur beneath a thick sill of Johnson Gulch porphyry, wherever this lies directly above the top of the Leadville dolomite.

In the central part of the Leadville district the ponding agent is very commonly one of several shaly beds in the Peerless formation, as may be seen on the 7th and lower levels of the Ibex mine. In mines of the Mikado Greenback group, shaly beds in the Parting quartzite act as ponding agents; where mineralization was intense in this ground, even the Parting quartzite itself is replaced to some extent by ore minerals. In the marginal parts of the district, however, the most generally effective shaly barrier is that at the very top of the Leadville dolomite, consisting of 5 to 35-ft of Pennsylvanian shale that locally lie between the base of the thick early White porphyry sill of Mount Sherman and the top of the dolomite. It is well exposed in the Continental Chief and Liddia mines, and may be present elsewhere, though it was not generally noted in earlier descriptions.

In many places one or several of the beds in the topmost 35-ft of the Leadville dolomite have been silicified, and such silicified rock is locally a constant guide horizon. One such area, in which the top 15 to 20-ft of the limestone are affected, is that near the crest of Sheridan Mountain; exposures are especially good on the southwestern slope. A second area of good exposures is near the Hilltop mine and still another is the region about 0.8 miles south of the Mitchell ranch. In all of these localities the altered rock is strongly quartzitic. Despite careful field work, it has not been possible everywhere to determine whether the rock is the result of silicification of a limestone or is a true quartzite, such as is not uncommon in the lowest part of the Weber (?) formation, and was produced by the metamorphism of a clean but fine-grained quartzose sandstone. Mineralizing solutions have been ponded locally by such quartzites or pseudo-quartzites in the three localities mentioned above, though not on a scale that is now of commercial importance.

NATURE OF THE COUNTRY ROCK

Aside from the importance of fissures, the outstanding feature in the control and localization of ore deposition is the presence of limestone, especially the upper part of the Leadville dolomite, which is the predominant ore-bearing rock. The ore channels were better developed in the sedimentary rocks than in the igneous and metamorphic rocks of late Cretaceous or early Tertiary and of pre-Cambrian time because the bedding planes in the sedimentary rocks served as solution channels and helped to orient fissure formation. Although the preceding statement applies to the clastic rocks of the Cambrian, Ordovician, Devonian, and Pennsylvanian deposits as well as to the limestones and dolomitic limestones, the clastic rocks contain only a small proportion of the ore deposits. Such a discrepancy between calcareous rocks and all the others must have a basic reason; further, the cause seems to be mainly chemical, for the physical differences, if any, are not apparent. The upper part of the Leadville dolomite is more cherty than the lower part, but there is no obvious correlation of the chert with the degree of mineralization.

Repeated tests with dilute hydrochloric acid were made to detect chemical differences between the lower and upper beds of the Leadville dolomite in view of their contrast in degrees of mineralization. Such studies were especially detailed in several localities where exposures are good, particularly in the Evans, Dyer, Iowa, and Empire Amphitheaters.

Finally, a series of samples were systematically collected from the Leadville and Dyer dolomites. Sampling was started at the top beds of the Leadville dolomite, as exposed beneath the lowest sill of early White porphyry on the crest of West Dyer Mountain, and continued downward to the top of the Parting quartzite in the northwestern wall of the Dyer Amphitheater. The specimens were collected at actual stratigraphic intervals averaging about 11-ft, the lowest being 11-ft above the Parting quartzite. The Leadville dolomite here has a normal thickness of 154-ft, but the Dyer dolomite member of the Chaffee formation is far thicker than average, attaining a total of 94-ft. Analyses showing the bases (CaO, MgO, and FeO) present in the carbonates of the limestone, together with the insoluble residues, are recorded in the following table:

Systematic sampling of Leadville dolomite and Dyer dolomite member of Chaffee formation, West Dyer Mountain
[E. T. Erickson, U.S. Geological Survey, Analyst]

1. Sample No.	2. Stratigraphic height above base of formation (feet)	3. Insoluble constituents (percent)	4. Soluble CaO (percent)	5. Soluble MgO (percent)	6. Soluble FeO (percent)	7. Molecular ratio of CaO	8. Molecular ratio of MgO	9. Molecular ratio of FeO	10. Ratio of molecular ratio of CaO to molecular ratios of MgO and FeO
				Leadville Dolomite					
1	154	0.39	32.47	19.84	.80	.578	.491	.011	1.151
2	143	.24	31.01	19.85	.65	.552	.491	.009	1.104
3	132	.66	31.20	20.15	.41	.556	.499	.006	1.101
4	121	44.64	17.19	11.68	.41	.306	.289	.006	1.037
5	110	.52	31.95	21.31	.32	.569	.528	.004	1.070
6	99	.46	30.81	21.27	.28	.549	.527	.004	1.034
7	88	.67	31.20	20.27	.41	.556	.502	.006	1.094
8	77	.61	30.91	19.05	.37	.569	.472	.005	1.193
9	66	.72	30.80	19.72	.46	.549	.488	.006	1.111
10	55	1.04	32.16	18.49	.32	.573	.458	.004	1.240
11	44	.64	29.11	20.75	.32	.519	.514	.004	1.002
12	33	2.30	30.19	20.91	.32	.538	.518	.004	1.031
13	22	5.84	29.53	18.89	.32	.526	.468	.004	1.114
14	11	5.75	29.27	18.07	.28	.522	.448	.004	1.155
				Dyer Dolomite					
15	94	6.82	29.75	17.27	.41	.530	.428	.006	1.221
16	88	8.23	29.30	18.13	.37	.522	.449	.005	1.150
17	77	13.22	27.42	16.69	.97	.489	.414	.013	1.145
18	66	15.48	27.57	15.51	1.01	.492	.384	.014	1.236
19	55	29.21	21.19	13.52	1.16	.378	.335	.016	1.077
20	44	5.96	29.78	19.21	.60	.531	.476	.008	1.097
21	33	4.78	29.59	18.99	.46	.527	.471	.006	1.103
22	22	5.73	29.47	17.08	.51	.525	.423	.007	1.221
23	11	18.65	25.57	15.21	.62	.456	.377	.009	1.181
24	Parting Quartzite	---	---	---	---	---	---	---	---

In the Leadville district much of the dolomite in the dolomitic limestones contains ferrous iron in place of some of the magnesium. The recalculations of the analyses listed in columns 7, 8, and 9, of the above tabulation are simple molecular rations computed by dividing the percent of a given oxide as reported in an analysis by the molecular weight of the oxide. If for a certain analysis the sums of molecular rations of magnesia and ferrous iron oxide are less than the calcium oxide ratio given in column 7, this would suggest that the calcium oxide was not all used up in dolomite molecules but that a surplus exists which appears in the rock as calcite. The result of dividing the molecular ratio of calcium oxide available by the sum of the molecular ratios of magnesium oxide and ferrous iron oxide, as expressed in column 10 thus furnishes a relative measure of this surplus calcite indicated for the several stratigraphic horizons analyzed.

These calculations are subject to some qualifications. First, it is well known that dolomite may contain some calcite in solution within the dolomite space lattice; this calcite, though appearing in the calculations, is not as readily subject to attack by mineralizing solutions as ordinary calcite; generalizations concerning the susceptibility of a given bed to replacement, if based upon calculations such as the above, would be vitiated if this factor were ignored. Second, it is here assumed that the three basic ions are present only in the carbonate minerals, calcite and dolomite. Instead, they may be present in part in silicates or other compounds, not detectable without careful mineralogic and petrographic study. If one or another of these basic ions were liberated in quantity from a silicate during solution of the specimen for analysis, a false impression would arise regarding the ratios of the ions in the carbonate minerals assumed to be present. These possibilities do not seem likely but they compel a recognition of the somewhat tentative nature of the conclusions, which follow.

In all the samples of the Leadville and Dyer dolomites, the ratio of CaO to MgO-plus-FeO is close to that of dolomite, as indicated in column 10, regardless of the percentage of insoluble material. In detail there is considerable variation, but assuming that the sampling is representative (and every effort was made to keep it so), there is no part of the section in which the ratio of CaO to MgO-plus-FeO is markedly greater than in any other part. Perhaps the lower part of the Leadville dolomite and the upper part of the Dyer dolomite together constitute the only significant exception, though the ratio is high in certain other samples irregularly distributed in the section. Calcite, in contrast to dolomite, does not seem to be unusually abundant in the upper part of the section sampled, even though that is where mineralization is most extensive. The three samples from the highest part of the Leadville dolomite contain no more calcite than samples 8, 9, and 10, from near the base of the formation, and no more than the average of samples from the Dyer dolomite. Indeed, the average ratio of the molecular ratio of CaO to the sums of the molecular ratios of ferrous oxide and magnesium oxide is higher in the Dyer dolomite than in the Leadville.

On this basis alone, in short, there is proportionally more calcite in the Dyer than in the Leadville dolomite. As calcite is more soluble and presumably more readily replaced by ore than dolomite, its percentages in the different beds have evidently had little to do with the localization of ore bodies.

At certain places in the central Leadville district large quantities of ore have been mined from the lower part of the Leadville dolomite and from the Dyer and Manitou dolomites, but even so, the dominance in number and size of the ore bodies in the upper part of the Leadville dolomite is very distinct (Emmons, Irving, and Loughlin, 1927, pl. 45). This dominance is even more striking in the outlying areas: in these outlying areas substantial quantities of ore from replacement deposits have come only from strata in the uppermost part of the Leadville dolomite. This statement applies to such relatively large mines as the Hilltop, Continental Chief, and Dyer. In other mines credited with large output, such as the Hellena, Clear Grit, and Lillian, the ore shoots occurred along fissures with which no noteworthy blanket deposits have been found to be related, either because the wall rocks are siliceous or because gouge along the margins of the fissures has prevented solutions from spreading into the limestone or dolomite walls.

The lower part of the Leadville dolomite and the Dyer dolomite as a whole contain more insoluble material than do the uppermost beds of the Leadville, and may therefore have been left comparatively impermeable, especially in places far removed from faults. No porosity tests were made on the samples, as the degree of porosity both in the purer and the less pure beds is obviously very low.

The Manitou dolomite as a whole contains greater percentages of calcite and of insoluble material than the Leadville dolomite and about the same percentages as the least pure samples of the Dyer dolomite (Emmons, Irving, and Loughlin, 1927, pp. 28–29). Its many shaly partings render it still less subject to continuous open fracturing than are the other two formations.

The quartzites and sandstones in the outlying areas have been wholly unproductive, even though the sandstones appear to be more porous than the carbonate rocks. In a few places within the central area, quartzite and sandstone have been replaced by small ore shoots where local shattering and other structural conditions rendered the rock unusually susceptible to attack. No matter how porous the siliceous rocks may be as a whole—including the pre-Cambrian rocks, Sawatch quartzite, Parting quartzite member of the Chaffee, and the Weber (?) formation—they are not extensively replaced under the conditions that commonly prevailed in the Leadville region. Some fissure veins in these rocks, particularly the pre-Cambrian, have been mined for their precious-metal contents, but their ore shoots are too small to justify mining for the base metals.

In brief, chemical data indicate that although the carbonate rocks were far more readily replaced than any of the siliceous rocks, there was no preference for beds containing relatively high or low percentages of calcite, and the large replacement bodies are essentially restricted to the uppermost part of the Leadville dolomite throughout the marginal areas by the structural conditions.

Secondary Changes in the Ores

GENERAL NATURE OF SECONDARY CHANGES

After an ore deposit has formed by rising solutions, and the process of primary mineralization is completed, the ore and gangue minerals are likely to undergo changes. These primary minerals may be acted upon by descending cold waters containing oxidizing agents (such as oxygen and carbon dioxide) and by salts of metals leached from higher parts of the same primary ore body. New, secondary minerals are formed: oxides, carbonates and sulfates, native metals and certain sulfides. If the products are rich in oxygen, they are said to be oxidized minerals; if there is no increase in oxygen but new sulfides with a greater percentage of metals are formed, they are said to be secondarily enriched sulfides. Chemical conditions required by the process of secondary sulfide enrichment can exist only below the ground-water level prevailing at the time. In general, ground-water level will coincide with the boundary between the zone of oxidation and the zone of secondary sulfide enrichment but subsequent uplift or depression may change the position of the ground-water level. Minerals produced by oxidation may be brought below ground-water level and the products of secondary sulfide enrichment elevated above ground-water level. Oxidation products may be removed by glaciation or by stream erosion.

The secondary changes tend to separate iron and copper. The iron forms such insoluble compounds as limonite in the oxidized zone, and the dissolved copper is generally re-precipitated at depth as the secondary sulfides chalcocite and covellite. Similarly, one exposed to oxidation, zinc tends to migrate downward in solution, whereas oxidized lead minerals are relatively insoluble. Thus, two metals closely associated in the primary ore are likely to become separated in the process of secondary alteration.

SECONDARY CHANGES IN THE CENTRAL LEADVILLE DISTRICT

The nature and origin of the secondary changes in the ores of the central part of the district have been discussed in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 220–272). Oxidation was very extensive in the central Leadville district, and early production was mainly from oxidized ores. Manganosiderite yielded iron and manganese ores, but some primary iron pyrite, too, found use as flux in smelting. Siliceous pyritic ore rich in precious metals yielded siliceous gold and silver ores upon oxidation. Mixed sulfides were oxidized to form jarositic ores rich in lead and also to form various types of lead carbonate. Zinc blende was oxidized to zinc carbonates and silicates. Siliceous pyrite and chalcopyrite ores were oxidized to form copper ore (silicates and carbonates), and bismuth compounds yielded oxidized bismuth ores, but copper and bismuth ores are relatively scarce and of little economic importance in the Leadville district.

Iron and manganese ores of various grades were widely distributed, especially making up the so-called “vein material,” but have been largely exhausted. A few small bodies of high-grade manganese ores have been formed.

Most siliceous gold-silver ores form irregular bodies below lead carbonate ore shoots. On Carbonate and Fryer Hills much of the silver occurred as cerargyrite along joints or pore spaces. Some ores on Iron and Breece Hills were rich in gold but in deeper workings they commonly passed abruptly to sulfides low in precious metal content.

Oxidized lead ores include “hard carbonate” and “sand carbonate.” Hard carbonate is formed where there is enough iron oxide or silica to cement the grains of lead carbonate into a hard but generally porous rock. Sand carbonate consists of granular cerussite crystals, typically not firmly cemented. Sand carbonates are gray to brownish; hard carbonates are commonly reddish or brownish, though rarely gray. Both types of oxidized lead ore are generally silver bearing. Lead sulfate is of mineralogic interest but of no economic importance in the district. Jarositic ores consist of basic ferric sulfate with some lead in the molecule; they are ocherous, finely micaceous, and unctuous. They are generally lean in silver but rich in lead and gold. Jarosite is fairly common in the central part of the Leadville district but rare in the marginal sections.

Oxidized zinc ores are of four types: (1) gray carbonate ore, (2) brown carbonate ore, (3) brownish-black carbonate-silicate-oxide ore, and (4) dense zinciferous clay. The gray carbonate is the result of replacement of manganosiderite. The brown carbonate ore is highly varied in texture, porosity, and color; it represents partly a replacement, partly the filling of contraction cracks and other cavities containing zinc carbonate and silicate. The other two types of oxidized zinc ores lack economic importance.

Oxidized ore minerals in the central part of the district contrast greatly in vertical distribution. The primary lead and zinc minerals reacted differently to oxygen-bearing solutions. The zinc sulfide was oxidized to soluble sulfate and traveled downward in descending acid solutions to the point where, coming in contact with calcareous wallrock or with carbonate gangue minerals, the solution was neutralized and the zinc replaced the iron, manganese, or calcium in the carbonate gangue minerals, the solution was neutralized and the zinc replaced the iron, manganese, or calcium in the carbonates of the country rock or gangue. Lead sulfide, however, undergoes only a very slow conversion to carbonate or is altered, likewise slowly, to sulfate by direct combination with oxygen. As both carbonate and sulfate are nearly insoluble, little lead was removed by solution from the primary ore; replacement of limestone or gangue, resembling the replacement by oxidized zinc minerals, is relatively slight. Thus, after oxidation an original blanket body of primary mixed lead-zinc ore is likely to be divided into an upper body of lead carbonate with remnants of primary galena, a thin layer of iron oxide and clay, and a lower body of zinc carbonate, commonly with some calamine. In veins the arrangement is essentially the same, with the lead carbonate and galena medial and the oxidized zinc minerals marginal. In general, the zinc carbonate ores occur beneath the ground-water level, and in some places even beneath sulfide ores.

The depth of oxidation in the central part of the Leadville district is greatly varied, in part because of differences in the permeability of the country rocks. This variation of depth is increased by the fact that rocks of contrasting permeability lie at approximately the same level. The old surface of most of the lower parts of the district (other than the valley floors) is covered by Pleistocene glacial deposits. Because most of the oxidation antedated glaciation, the top of the sulfide zone is more nearly parallel with the bottoms of the moraines rather than with the present surface (Emmons, Irving, and Loughlin, 1927, pp. 248–249).

The processes of oxidation and secondary sulfide enrichment have been closely studied in many districts, and their chemistry is well understood. Leadville differs from many other rich mining regions in the scarcity of primary copper ore. Copper minerals oxidize near the surface to form soluble copper salts which pass down into the zone of more sluggish circulation and of reducing conditions where they tend to be precipitated as secondary sulfides. Copper is the most sensitive of the common metals in this behavior but the low amount of copper in the Leadville ores precludes its use as an index of secondary sulfide enrichment. Zinc rarely (if at all) occurs as a distinctive sulfide and likewise is a poor criterion for recognition of the secondary sulfide zone. Lead, on the contrary, resists oxidation and solution. As a consequence, in lead-zinc ores boundaries between the oxidation zone, the secondary sulfide zone, and the primary sulfides are not only very irregular, but also commonly hard to identify. The anomalous behavior of zinc carbonate, which is commonly carried below the level of sulfides, produces an additional complication.

Thus, with respect to zones of oxidation and secondary sulfide enrichment, the central part of the Leadville district differs from other larger mining districts of the United States west of the Front Range.

SECONDARY CHANGES IN MARGINAL DISTRICTS

GENERAL FEATURES

Most of the larger mines in the marginal districts around Leadville are in areas such as the floors and slopes of the Empire, Iowa, Dyer, and Evans Amphitheaters that have been subjected to vigorous glaciation. Other mines, such as the Hellena, are in deeply glaciated valleys. In all these areas erosion has removed most of the thoroughly oxidized ores, and the mines are too few to yield dependable general information on the secondary changes in the ores. Furthermore, the ores are uniform and simple; copper minerals, the most sensitive indicators of secondary sulfide enrichment, are lacking, and silver salts are rarely visible. In short, there is little basis for a trustworthy concept of oxidation and secondary sulfide enrichment in the ore.

Nevertheless, the general mineralogical relations do not differ greatly from those reported for the central part of the district. The primary ores are the same, though leaner and very largely lacking both copper and gold, with smaller quantities also of manganosiderite; zinc and lead predominate, much as in the central district, but pyrite is far less conspicuous. The mineral assemblage, therefore, bears considerable resemblance to that of the central Leadville district, and the limits of oxidation and secondary enrichment are poorly defined in the marginal deposits, just as they are in the central Leadville district.

Few observations in deeper mines could be made in the present study, but depth to which the oxidized zone extends is evidently as greatly varied in the marginal as in the central Leadville region. In the Hellena mine in Iowa Gulch the effects of oxidation are negligible, as might have been inferred from the heavy flow of water encountered at all levels. These effects are also virtually absent from the Best Friend and other mines in the floor of Evans Amphitheater and from most of the mines on the valley floor of Iowa Gulch west of the Hellena mine. Most of the higher slopes of Long and Derry and Printer Boy Hills, however, revealed extensive oxidation to various depths. In the Continental Chief, Hilltop, Liddia, Peerless Maude, and Dyer mines oxidized zinc ores predominated even in the deepest workings. The higher areas have been less affected by glacial erosion. As most of the oxidation of the ore antedated glaciation, the lower limits of the oxidized zone may have been completely stripped. Where, as in the Peerless Maude and Dyer mines, the ore deposits lie (presumably) only 500 feet or less below the topographic level from which oxidation proceeded downward in pre-glacial times, at least a part of the oxidized zone should still be preserved.

Another factor affects the present depth of oxidation. Structural features such as faults, dikes and impervious strata may produce irregularities in the depth of oxidation. Oxidizing waters can descend easily to unusual depths along faults, but are impeded by impervious beds or fault gouges.

Upon very strong evidence, the time of maximum oxidation has been placed in late Tertiary or early Pleistocene (Emmons, Irving, and Loughlin, 1927, fig. 83 and p. 272). Most faulting antedated the major oxidation so it is most unlikely that the present irregularities in the level of the bottom of the oxidized zone can be attributed to faulting and displacement of an oxidized zone having a previously uniform altitude.

OXIDATION OF SPECIFIC ORE MINERALS

Pyrite oxidizes readily through various ferrous and ferric sulfates to limonite and the related oxides, the commonest minerals of the oxidation group. Some of the pyrite, especially where as in the Continental Chief mine, lies near lead sulfides, forms small quantities of plumbojarosite. Manganosiderite is not widespread, but deposits of wad and other manganese oxides, (especially pyrolusite and psilomelane, or cryptomelane) are found. They are most common in the “contact matter” between two beds. The absence of large quantities of manganosiderite suggests that the manganese is also present in such minerals as hetaerolite ($2ZnO \cdot 2Mn_2O_3 \cdot H_2O$) and chalcophanite [$(Mn, Zn)O \cdot 2MnO_2 \cdot 2H_2O$], and in a brown zinciferous clay. Manganese in zinciferous clay was found in large quantities in one of the northwest stopes an intermediate distance down the incline in the east workings of the Continental Chief mine. Such manganiferous ores are common in the “contact” or blanket deposits. Large quantities, reported to contain much silver, occur in and near the Kenosha tunnel on Long and Derry Hill, and some has been produced from a tunnel situated about 1,000-ft east-southeast of the Himalaya mine. The dumps of the First National and Julia-Fisk groups show oxidized manganosiderite, but no production of manganese ore is recorded from these mines.

Films of oxidized copper minerals are common, but their conspicuous blue and green colors are likely to lead to overestimation of the quantity of primary copper minerals; in the marginal deposits they are almost wholly absent. Small quantities of malachite in minor prospects on the north slope of Mount Sherman are designated “chloride” (cerargyrite) by miners, but assays reveal very little silver.

Oxidized lead ores are conspicuous only locally, as on Printer Boy Hill, in the Peerless Maude mine and Peerless Mountain, and in several prospects situated about 1,000 ft north-northeast of the Liddia tunnel. Basic ferric sulfates containing lead (plumbojarosite) and rich in gold may have been mined to a small extent in the workings of the Lillian group on the south slope of Printer Boy Hill; presumably these sulfates resembled those described by Emmons, Irving, and Loughlin (1927, pp. 230–231) but their relations to the other ores are not known. Probably the absence of extensive deposits of oxidized lead ores in the marginal Leadville district is due to the effects of glaciation. Most of the ore deposits are in valley bottoms or on the walls of cirques, where the oxidized lead ores were swept away by glacial erosion. Remnants of the pre-glacial topography, such as the crest of Peerless Mountain, are most likely to retain deposits of oxidized lead ores.

In the outer parts of the Leadville district the zinc ores are by far the most conspicuously oxidized. Hetaerolite and chalcophanite (complex oxides of zinc and manganese) have been mentioned. Chocolate-colored zinciferous clay is found locally, especially in “contact” deposits, but zinc can not be extracted from it economically. By far the most common oxidized product from primary blende is smithsonite (“dry bone”) in chocolate, yellowish, or gray cavernous masses suggesting partly decayed bone. It constitutes the dominant zinc ore in the Continental Chief and Liddia mines. Specimens shown to the writer indicate that it was plentiful in the Hilltop mine, but that mine also contained considerable smithsonite or hydrozincite of a type described by the miners as a “chalky carbonate.” Near the ground water level the “dry bone” type of smithsonite commonly shattered and altered to smithsonite along the cracks. Remnants of galena, commonly enclosed in thin envelopes of oxidized lead minerals, are also preserved within the larger smithsonite masses. The caverns in the “dry bone” are commonly crustified with tiny crystals of calamine. In places small calamine crystals are enclosed in the smithsonite forming the walls of the cavernous “dry bone”. In most oxidized bodies calamine seems to have been the more recent and less plentiful of the two common oxidized zinc minerals though it is very widespread. In the oxidized marginal ores of the Leadville district there is some native silver, some in combination with halogens (especially in the chloride, cerargyrite), and some as a sulfide. None of these three forms is visibly abundant or known in quantity, but a few silver wires, scales, or leaves are found. Rich silver ores in iron-stained flinty material that represented silicified Leadville dolomite were worked in several prospects in Little Evans Gulch about 1,000 to 1,500 ft north and northeast of the Chicago Boy mine. The proportion of primary to secondary silver has not been determined. The high degree of iron staining of this ore and the occurrence of some of the silver in small, open fractures suggest that only oxidized silver or silver salts have been preserved.

Oxidized gold ores probably occur in what is described as “rusty” limonite in some oxidized veins, and also in iron-stained “contact” deposits. In numerous shallow fissures in the pre-Cambrian and Cambrian rocks gold has been found, commonly associated with considerable manganese stains; such small deposits are especially abundant in the pre-Cambrian rocks, and though the small bodies that were worked were rich, their aggregate output is not great. Examples are found in prospects on the slope of East Bald Mountain, just west of the mouth of Dyer Amphitheater. In general, however, gold ores in the marginal parts of the district are lean. The gold reported in the west workings of the Continental Chief mine was partly in oxidized quartzose ore. The ore along the Mosquito fault or its subsidiaries in the southern arm of the Evan Amphitheater is apparently primary, as alteration of the associated blende and pyrite is negligible.

“Contact” or blanket deposits in the marginal parts of the district are small (in contrast with the great ones of the central parts) but they are nevertheless very conspicuous because they are deeply stained brown or black. The deposits commonly contain cerussite, smithsonite, silver minerals, and (more rarely), calamine and gold. In the marginal region they apparently result from local alteration of pyrite, sphalerite, or mixed ores.

OXIDATION OF GANGUE MINERALS

Manganosiderite is oxidized to iron and manganese oxides, and the other carbonates slowly dissolve, leaving a cavernous rock favorable to the deposition of smithsonite and calamine. Most of the carbonates appear to contain at least small quantities of iron carbonate in isomorphous combination with the carbonates of magnesium, calcium and manganese; indeed, some of the mineral called dolomite may well be ankerite or siderite. Oxidation of the carbonates is therefore commonly accompanied by the formation of faint or conspicuous rusty coatings.

A special kind of oxidation process, commonly ascribed to the action of descending waters, is the solution of the cement between the grains of dolomite. The residue is a poorly consolidated or wholly free sand, called locally “dolomite sand.” Examples are common at Gilman and Red Cliff, Colorado (Henderson and others, 1934, p. 75), and also in the central Leadville district (Emmons, Irving, and Loughlin, 1927, pp. 36–37).

Quartz in the oxidized ore also is commonly stained brown as the result of the oxidation of pyrite, and made cavernous in appearance by the solution of grains of pyrite and blende. Barite is highly insoluble and remains unaltered except that its normal bluish white color is changed to a creamy hue.

SECONDARY SULFIDE ENRICHMENT

Secondary sulfide enrichment consists of the oxidation of primary sulfides near the surface, their solution in descending waters, and their reprecipitation as secondary sulfides at depth. It is important in copper rich deposits of the western United States, but not in the Leadville district where copper is negligible and lead and zinc are the dominant mineral constituents of the primary ores. Apparently, lead is rarely if ever reprecipitated as a sulfide at the ground-water level (Butler, 1913, p. 92; Emmons, 1917, p. 140). The theory of enrichment of zinc in ore deposits of the Leadville type on a large scale by secondary sulfide deposition is also not accepted by most observers and seems not to be supported by fact (Emmons, 1917, p. 271; Emmons, Irving, and Loughlin, 1927, p. 268). In some places silver is reprecipitated in commercial quantities, both as native silver and as argentite (Emmons, 1917, pp. 373–374). Gold, taken into solution as the chloride in the oxidized zone, may be precipitated as the native metal in the zone of secondary sulfide enrichment by reaction with certain sulfides or with constituents in the ground water (Emmons, Irving, and Loughlin, 1927; Emmons, 1912, pp. 25–28).

The writer found conclusive evidence of a secondary sulfide zone only in the South Ibex (Venir) mine, where chalcocite has stained otherwise fresh surfaces of pyrite.

The absence of copper in the ore and the complicated relation between ore zones and topography nullified every attempt to trace the relation between secondary sulfides and depth below the surface and makes impossible any regional generalizations about the depth of secondary enrichment in the marginal areas around Leadville; in short, secondary sulfide enrichment is not an important factor in these areas.

Suggestions for Prospecting in the Outlying Areas

Attention has already been directed to the most promising areas of the central part of the Leadville district (Loughlin, 1926; Emmons, Irving and Loughlin, 1927, pp. 323–326). In the following paragraphs, suggestions are offered for selection of the outlying areas that deserve more careful exploration. The recommendations are based on inferred geologic relations and upon explorations already carried out.

The principal centers of mineralization and the largest ore bodies are in the central Leadville district, but in the outlying areas there are minor centers that are likely to have somewhat smaller ore bodies. Such deposits are likely to be rich in lead, zinc, and silver, and to contain some gold; they are most likely to occur as fissure veins, but replacement bodies in limestone may also be present. Preliminary exploration indicates that the outlying ore bodies are most abundant near the major premineral faults and are (1) most likely to pass from fissure fillings into replacement bodies (2) at the contacts between the upper Leadville dolomite and the overlying sill or if the sill is absent or does not rest directly on the dolomite, between the

Leadville dolomite and the Weber (?) formation. The Hellena mine exemplifies the first of these and the Continental Chief and Hilltop mines the second. The deposits are characterized by silver in association with galena, sphalerite and pyrite, and by such gangue minerals as carbonates, quartz, and barite. Within this broad pattern, a few suggestions may serve as a general guide in prospecting.

First, the most favorable zone is the upper part of the Leadville dolomite. This zone is preferable to lower parts of the same unit and to the Dyer and Manitou dolomites, particularly because it is more massive and more brittle than the slightly more shaly lower limestones, and because it is directly overlain by thick impervious rocks. These impervious rocks include the thick sill of early White porphyry and the lowest, shaly beds of the Weber (?) formation.

Second, the Leadville dolomite seems to be at least moderately re-crystallized in the neighborhood of ore and this feature may, with care and due conservatism, be used as a guide to ore. The alteration product, known as “zebra rock” because of its alternating layers of fine-grained blue-gray and more coarsely crystalline white dolomite, is characteristic of regions where at least a little mineralization has taken place. Ore is not in all cases found near “zebra rock” but the presence of such markings suggests fracturing and the possible circulation of mineralizing solutions.

Third, the Johnson Gulch porphyry seems to be the facies of the Gray porphyry group most commonly associated with mineralization. This does not hold for many sill-like bodies but apparently it applies to dikes (such as those in Iowa Gulch near the Lillian mine) and to plugs, like those on Breece Hill and near the Rex and Mansfield mines.

Fourth, premineral fractures have been channels of mineralizing solutions. Most of them trend N 0º to 30º E, but detailed study shows that the pattern varies greatly with the part of the district studied. Many of these premineral fractures are reverse faults that may not be mineralized themselves but do commonly contain some ore, have related small ore-bearing fractures or replacement bodies. It is not everywhere possible to determine which faults are reverse and which are normal. Generally, at least in faults of larger displacement, the eastern side is raised. Most of the faults that dip eastward are reverse faults and, being premineral, have economic potentialities.

Fifth, many of the minor faults of the outlying districts—like parts of the Tucson, Colorado Prince, and Bowden faults of the central Leadville district—lie very nearly parallel with the bedding as essentially flat reverse faults, and are most probably of premineral origin. As expected, the related small fissures are highly productive in many places. They are structural features favorable to the occurrence of ore.

Sixth, in driving for ore, it is best to tunnel toward the uppermost beds of the Leadville dolomite. The geologic map of the region will aid in finding places where these uppermost beds are cut by fractures that may have served as ore feeders. In these places exploratory tunneling should be planned, insofar as the topography and dip of the rocks will permit, to cross the largest number of fissures at right angles in order to reduce the cost of drifting in ground that is barren. It is generally preferable to tunnel in the upper Leadville dolomite rather than in the overlying Weber (?) formation, which slabs off badly. Commonly, the early White porphyry is likewise a difficult country rock in which to drift, especially where it has been slightly mineralized. Moreover, effects of mineralization, even if slight, are most readily recognized along fissures in the dolomite. Raises may then be put up along any such promising fissure to the desired zone in the uppermost most productive part of the Leadville dolomite.

The question of drilling versus exploratory drifting furnishes a never-ending argument. Certainly at Leadville a narrow vein can best be followed by drifting, for it is very likely to pinch out locally with no clue as to its direction of continuation except a small unmineralized fissure, rarely visible in diamond drill cores and wholly unrecognizable in the cuttings of a churn or percussion drill. On the other hand, tabular deposits of the “contact” or blanket type, such as have been reported from the Kenosha and related openings near the crest and on the southern slope of Long and Derry Hill, are ideal among western lead-zing ores for exploration with the drill. This statement is made with a full realization of the economic factors involved in deep drilling, the limitations caused by an alpine climate, and the problems involved in the interpretation of the drill cores or cuttings.

NORTHERN AREA

North of the central Leadville district the principal rocks exposed are sandstone and shale beds of the Weber (?) formation and sills of the Gray porphyry. Surface exploration is not feasible, as exposures are poor and there are but few distinctive limestones to serve as horizon markers. Detailed geologic structure, therefore, cannot thus be deciphered and any productive beds, especially the Leadville dolomite and the Dyer dolomite member of the Chaffee formation.

Especially disappointing is the large area extending from the Board of Trade mine westward to Canterbury Hill. At the surface this area shows scant evidence of mineralization, but little could be expected as the surface cover consists almost wholly of unfavorable clastic beds of the Weber (?) formation. Search will necessarily have to be below the surface, and the writer considers exploration northward and eastward from the Yak tunnel toward the Great Eastern shaft and beyond and also near the Diamond and Resurrection mines as most likely to discover ore. Unfortunately, the northeastward dip of the beds carries the most promising zone progressively deeper beneath the Yak level, increasing the difficulties of hauling and dewatering if ore is found.

MOSQUITO PASS, EVANS AMPHITHEATER, AND SOUTH EVANS GULCH

The Mosquito fault and its subsidiaries in this area are at least locally mineralized. Careful search along them is merited, especially where Leadville dolomite lies close to the main Mosquito fault or between two minor faults of the Mosquito fault zone, as in the northern end of the South Evans Amphitheater and in the floor of Evans Gulch half a mile east of the upper Leadville reservoir.

In the two areas designated limestone “slivers” lie between two branches of the main Mosquito fault. The larger faults, such as the Mosquito fault, are commonly not mineralized because of their general tightness, but there are many open crevices and therefore favorable localities where (1) minor feather fractures lead off from the main fault and rejoin it farther on. On these two criteria, the two areas mentioned hold much promise for exploration, especially in view of the ore found in the openings 1,000-ft north of the Best Friend tunnel and the extensive mineralization along the main Mosquito fault at Prospect C-103 south of the Best Friend group.

The southerly head of Evans Amphitheater also seems to merit careful examination, although showings there in the past have not been highly encouraging. As in other areas, the most favorable locations are at the contact between the Leadville dolomite and the overlying thin band of Weber (?) formation or the sills of porphyry. Of special interest here are minor workings about 1,500-ft northeast of the peak of West Dyer Mountain (Prospect N-25). These workings have revealed considerable barite in the dolomitic country-rock, which suggest mineralization of the type found in the Continental Chief and Hilltop mines; but the workings developed are too low, lying only about 40-ft above the base of the Leadville dolomite. Important fissures were not noted here, but to the northwest there are several that strike northeast. Exploratory work should be directed into the northern slope of West Dyer Mountain. Drifts due west should gain depth, follow the top of the Leadville dolomite, and yet cross fissures nearly at right angles.

IOWA AMPHITHEATER

The Iowa Amphitheater area is more promising because the rocks are considerably shattered. The Dyer, Liddia, and South Dyer faults are major fractures and the last two have large displacements. The thrust faults on Mount Sherman, on the east wall of the northern head of Iowa Amphitheater, are noteworthy also; throughout most of its extent each is nearly parallel with the bedding planes and locally the walls have been mineralized. These thrust faults and the Liddia fault contain silver-lead-zinc ore with much barite. The high-grade ore produced in the Continental Chief mine indicates uncommonly intense mineralization for this area. Here, as elsewhere, exploratory mining consists of finding one or more northeast-trending mineralized fissures, and then raising or sinking along them to the top of the Leadville dolomite. Adits and crosscuts should be driven as nearly as practicable at right angles to the mineralized fissures, which trend N. 40º to 45º E. Similar suggestions apply to the vicinity of the Hilltop ore body, a mile and a quarter farther south. In that area the fissures are parallel in strike with those on the west slope of Mount Sherman.

On the northern slope of the northern West Sheridan Peak, on the southern slope of East Ball Mountain, and at a few other localities small bodies of gold ore have been mined. Commonly, they are characterized by narrow shear zones which are rusty and perhaps quartzose, but they do not contrast strikingly with the barren country rock. Mineral deposits of this type lie along fissures in pre-Cambrian and Cambrian rocks throughout the Mosquito Range. The ore bodies are commonly small, and locally very rich. Search for similar deposits by small-scale operations is suggested.

PEERLESS AND HORSESHOE MOUNTAINS

Along the crest of the range, from Mount Sheridan south to the north slope of Horseshoe Mountain, the ore has generally been found in small but productive deposits at the contact between the Leadville dolomite and either the early White porphyry or a highly silicified bed which marks the top of the dolomite. The most promising places for search are along the fractures that cut across the beds—fractures such as those near the Peerless Mountain and at the pits half a mile north of Horseshoe Mountain along the range crest. Especially interesting are the mineralized faults northeast of Prospect U-71 and near Prospect U-67. The ground there resembles that at the Continental Chief and Hilltop mines. Alt Prospect U-67, on Peerless Mountain, eastward-dipping Leadville dolomite is overlain by a White porphyry sill which may conceal promising ground. Fissures should be sought in the exposed part of the dolomite and in the overlying sill for productive bodies at the contact between the two rock units. Prospecting is made especially difficult by the altitude and ruggedness of this area; nevertheless, further exploration here is merited.

HEAD OF EMPIRE AMPHITHEATER

The territory at the head of Empire Amphitheater is less likely to contain ore than the others described, as the country rock is chiefly pre-Cambrian granite. Considerable prospecting has been done here, mainly and misguidedly along pegmatite dikes. Small gold veins have been discovered, mostly trending northeast, but evidently have not encouraged further prospecting.

EMPIRE GULCH BETWEEN MITCHELL RANCH AND EMPIRE HILL

There has been extensive prospecting in the area of Empire Gulch between Mitchell ranch and Empire Hill, especially along the Mike fault, north of its junction with the Union fault. This relatively inaccessible area is one of the most promising places in the marginal Leadville area. The area along the minor faults trending east on the western slope of Empire Hill should be prospected. The workings on the Eclipse claim (T-151) are of interest because rock in the dump is considerably iron-stained and ore reputedly of high grade was once mined here. However, ore in place is not available as the workings are caved.

The prospects about 1½ miles due west of the crest of Empire Hill are especially interesting. The Leadville dolomite, here beneath a sill of early White porphyry, is considerably shattered, not only by faults transverse to the strike but also along others, unquestionably of premineral age, that are parallel with the strike almost parallel with the bedding planes. The structural situation is thus analogous to that on the northeastern wall of Iowa Amphitheater. Unfortunately, erosion has destroyed all but one small area of the earlier White porphyry caprock. Several “showings” of high-grade ore with silver-bearing galena are exposed in shallow workings or at the outcrop, but lack continuity.

IOWA GULCH BETWEEN CRESTS OF PRINTER BOY HILL AND LOWER LONG AND DERRY HILL

The area of Iowa gulch between the crests of Printer Boy Hill and Lower Long and Derry Hill contains the Lillian, Rex, and Mansfield workings. Of special promise is the region east of the Mike fault, for this fault is known to be of premineral age, and shattered ground along it may have provided channels for ore-forming solutions. Moreover, the area between the Mike fault and the Doris shaft, three-quarters of a mile east, is heavily shattered and cut by dikes of the Johnson Gulch porphyry, the member of the Gray porphyry group generally most closely associated in time and place with ore. Apparently, a small plug of Johnson Gulch porphyry, similar to the Breece Hill stock to the north, cuts the sill of early White porphyry exposed west of the Mike fault. By analogy, fissures in or close to such a plug should be favorable for mineral deposits. The ore and gangue minerals at the Julia-Fisk and First National mines reflect the relatively high temperature and great intensity of mineralizing processes. A short distance to the north are the once highly profitable workings of the Lillian and Steel Spring mines, whose output included unusually large proportions of precious metals. The exposures are generally fair, and exploration at definite horizons is thus not difficult. The First National, Lillian, and Steel Spring mines are located in the upper part of the Leadville dolomite and the Julia-Fisk mine follows a vein that cuts the overlying White porphyry and Weber (?) formation. The intensity of mineralization, however, justifies prospecting where dikes and premineral faults cut the lower formations.

On the south side of Iowa Gulch, the Belcher tunnel near the valley bottom and the Kenosha, Diana, and Porphyry prospects on higher ground have all been productive, at least on a small scale. Their records show that pockets of good ore have been mined. The Belcher and Kenosha tunnels are in the Manitou dolomite and Cambrian beds, the Diana and Porphyry prospects are in the upper part of the Leadville dolomite, and several prospects to the west are in the lower part of the Leadville, Dyer, and Manitou dolomites. Perhaps all the rocks from the base of the Weber (?) formation to the top of the pre-Cambrian have been somewhat mineralized. Certainly the highly stained silicified outcrops and the few showings of ore on the dumps of the prospects in their vicinity along the crest of Lower Long and Derry Hill merit some investigation.

The widespread mineralization indicates that the margins of the numerous dikes and the traces of the many faults that cut the quartzite and limestones on both sides of Iowa Gulch deserve careful search for more ore.

IOWA GULCH NEAR THE WESTON FAULT

From the Mosquito fault west to the Weston fault, the area bounded on the south by Upper Long and Derry Hill and on the north by the southern slope of Ball Mountain is of great interest. Within or closely adjacent to it are the Ontario, Hellena, Clear Grit, and other properties that were once extensively worked. Several of them, notably the Hellena, have yielded rich ore. The area from the Hellena mine northward along the Hellena vein especially merits exploration. From the Hellena mine south this fault was productive, and it is known to have extended to the American Continental workings, 600-ft north of the Hellena. As the Hellena fault was at least moderately well mineralized there, and as its northward continuation may be represented by the productive Sunday vein, exploration between the Sunday and American Continental mines appears to be merited; cover at the surface, however, would make underground exploration by test-pitting or shallow prospecting necessary. A lateral from the Yak tunnel would afford drainage down to approximately the 600-ft level of the Hellena mine. Such a lateral would reach the Sunday vein in about 4,500-ft, and the vein zone could be explored by drifts for a distance of 3,000-ft as far as the Hellena shaft.

The entire region of Iowa Gulch between the Ball Mountain and Hellena faults and north of the Iowa fault holds considerable hope for production below the Leadville dolomite, but very much water is likely to be encountered on any faults below Iowa Gulch. This difficulty may perhaps be reduced by preliminary diamond drilling, following careful planning.

Another area meriting exploration is that in the Leadville dolomite west of the Weston fault, where search should be directed at possible ore bodies below the thick sill of early White porphyry, the bedrock that underlies the gravel-covered floor of Iowa Gulch.

MINES AND PROSPECTS

Plan of Description

The excellent studies by Emmons, Irving, and Loughlin (1927), contain adequate descriptions of the surface geology, the mines, and the prospects of the central part of the Leadville district. The current report pictures in similar detail the surface geology and mines of the outer part of the district, beyond the limits shown on plate 13 of their report.

In this outer area there are probably more than 1,800 openings. Most of them are but shallow pits, shallow caved shafts, or short caved tunnels, which yielded little ore and are useful mainly because they furnish clues to the bedrock geology, and so are not described here. However, the dumps of a few minor inaccessible pits and tunnels which reveal ore minerals or other features encouraging to prospectors are described as fully as is feasible on the basis of data collected from former operators and miners. Finally, several larger mines, and also the few smaller prospects that were in operation or at least accessible at the time of these studies, contain ore or exhibit the relations of ore bodies and are therefore described in considerable detail.

To facilitate finding the places, the large map (plate 1-not included) has been divided into sections on the basis of latitude and longitude. These sections are designated by letters. In each section the separate openings, or groups of openings where individual pits and tunnels lie close together, have been numbered. In general, the numbers begin in the upper left corner of each section, progressing toward the lower right. Any mine may thus be found by reference to its letter and number on this grid. The names of certain prominent mines appear on the map.

The descriptions of the mines of the marginal districts are arranged in geographic groups, as, for example, the Canterbury Hill group. Mines of the northwestern part of the mapped area are described first then those of the northeastern, southeastern and southwestern parts.

Only a few mines in the central part of the Leadville district (shown on plate 13 of Professional Paper 148) that have been opened or greatly extended since 1927, are re-described. For convenience the original numbers of plate 13 are retained for mines of the central Leadville district, but the sections are lettered differently to make them consistent with sections of the marginal part of the district.

Outlying Leadville Area

CANTERBURY HILL

Very few mines or prospects on Canterbury Hill are now accessible, and the geology must be largely inferred from early reports and from the surface exposures. It is clear that the Mikado fault reaches the southwestern slope of Canterbury Hill, but it appears to be broken and repeatedly offset by branches of the later Pendery fault. Such branches were not recognized with certainty by Emmons, Irving, and Loughlin (1927), but the irregularities in outcrop pattern of the Leadville dolomite between the Chicago Boy mine and the Old St. Louis shaft cannot be explained satisfactorily unless faulting is postulated. Because the actual structural relations are not clear, faults and formation boundaries are indicated by dashed rather than by solid lines on the map (**Plate 1**).

A thick sill of Johnson Gulch porphyry overlying the Leadville dolomite crops out over much of the southern slope of Canterbury Hill. Stratigraphically above this sill and northeast of it are alternate thick beds of grits, thin shales, moderately thick limestones of the Weber (?) formation, and sills of Gray porphyry of various types; these rocks form the southwestern slope of Prospect Mountain. Shallow prospects in this region are not likely to show ore, as the Weber (?) formation shows little, if any, mineralization in the marginal part of the Leadville district.

There are only two important groups of workings on Canterbury Hill-the Canterbury tunnel (No. A—1) and the several workings of the Old St. Louis-Princeton-Little Blonde group, situated within 2,000-ft to the south and southwest of the Old St. Louis Shaft.

CANTERBURY TUNNEL

The Canterbury tunnel (No. A-1), a community project intended to explore the land between Canterbury Hill and the Ibex mine and to drain the deeper workings of Breece Hill, was begun in 1921. It extends 4,170 ft in a S. 62º E. direction. Since 1926 no work has been done on it. A plan and section of the tunnel are given on plate 11 (not included). Starting in glacial and alluvial material, it enters altered porphyry 1,150-ft from the portal and for 300-ft exposes alternations of grits of the Weber (?) formation and porphyry. At 1,450-ft from the portal it crosses a major fault, beyond which it cuts successively the Peerless formation, the Parting quartzite and Dyer, dolomite members of the Chaffee formation, and the Leadville dolomite; the Manitou dolomite is faulted out and the relations among the other formations are complicated by repeated faulting. Still farther southeast, a small anticline has brought Parting quartzite to the tunnel level, then Dyer dolomite and Leadville dolomite as the beds dip southeast on the southern limb of the fold. Approximately 3,200-ft from the portal the Canterbury tunnel crosses a conspicuous fault, probably the main Pendery fault, to judge from its position in the new deep-drainage tunnel driven in 1945. This fault strikes N. 70º E. and dips 75º NW, in contrast to its strike of N. 35˚ E. and dip of 67º NW in the new tunnel. Beyond it the tunnel crosses Cambrian quartzite and small down-faulted blocks of the Peerless formation. Near the face of the tunnel the beds dip east to, northeast, and this dip, coupled with a small fault, brings limestone to the level of the tunnel. The identity of this limestone is in doubt, some observers regarding it as Dyer or Leadville dolomite, but both its lithologic character and its position next to the Peerless formation favor its identification as Manitou dolomite.

Economically, this tunnel has been disappointing. Some high-grade ore in small bodies is said to have been found long ago in the Roseville (No. A-3) and Minneapolis (No. A-6) shafts before the tunnel was begun. Ore was found in the tunnel only at about 2,720–2,780-ft from the portal. The ore is in the margins of small fissures striking N. 55º to 80º E. and N. 60º W., and dipping variously. The northwest-striking fissure, exposed in a crosscut northeast of the tunnel line, has been the site of a little stoping. Most of the mineral matter here is barite that has replaced limestone bordering the fissure. A very small amount of galena that contains some silver is associated with the barite. A raise of 146-ft was put up 50-ft northeast of the tunnel, but no ore was found. Samples of ore, selected because relatively rich in sulfides, assayed 13 to 14.5 percent lead, 2.5 to 4.5 percent zinc, and 14 to 16.5 ounces of silver to the ton (Dickerman, personal communication, 1936). The limestone in the face of the tunnel, however, contains disseminated sulfides said to carry as much as 100 ounces of silver to the ton (Cortellini, personal communication, 1934), though the average content is 10 ounces of silver together with a small amount of zinc carbonate.

It thus appears that the Canterbury tunnel has so far not proved to be an encouraging venture. There is no evidence that any of the major premineral faults hitherto recognized intersect the tunnel. Surface mapping on the southwestern slope of Prospect Mountain (where the rock exposures are poor) indicates that an additional 6,300-ft of tunneling will be necessary to reach the Weston fault. However, there are two favorable indications. One is the presence of extensively mineralized ground along a line of prospects extending N. 35º E. up the southwestern slope of Prospect Mountain from a point about 2,000-ft east of the face of the tunnel. If results of further investigation are encouraging, extension of the tunnel beneath the prospect holes should be considered, as the top of the Leadville dolomite may not be far from tunnel level. The other favorable indication is the presence of oxidized ore rich in silver in the Pawnolos (No. F-6), shaft, as reported by E.P. Chapman (Personal communication, 1938). It occurs near the projected course of the east branch of the Iron fault, presumably along premineral fissures. The east branch of the Iron fault should be intersected about 1,000-ft beyond the Weston fault.

OLD ST. LOUIS SHAFT AND NEARBY WORKINGS

The sequence of rocks on the southwestern slope of Canterbury Hill near the Old St. Louis shaft (No. A-54) was outlined by Emmons in 1886 (p. 223). A thick sill of Johnson Gulch porphyry (the Gray porphyry of Emmons) overlies about 30 ft of early White porphyry. Below it is Leadville dolomite; this and older formations are exposed only locally in the region northwest of the Chicago Boy mine. The Leadville dolomite in this vicinity underlies a thick porphyry sill, a condition generally favorable, but there, is little evidence of premineral faults, which might have admitted ore-forming solutions. Moreover, the rocks here are poorly exposed and the favorable Leadville dolomite lies mostly under so thick a cover that it cannot be explored from the surface.

A feature of interest is the extensive silicification of the Leadville dolomite where it crops out north of the Chicago Boy mine. Here, presumably near the intersection of the Mikado fault with the several branches of the Pendery fault, the dolomite is brecciated, deeply iron-stained and silicified. This alteration is exemplified near the Little Blonde (No. A-85) and Princeton (No. A-84) tunnels. These facts alone suggest that this part of the Mikado fault was premineral near the larger, postmineral faults. It is also possible that small premineral faults were localized here but have not been recognized in the relatively sparse outcrops. Perhaps in this part of its course the Mikado fault is parallel to an older premineral fissure, as in the similar case in Graham Park (Emmons, Irving, and Loughlin, 1927, p. 92).

Some mines near here are said to have supplied appreciable quantities of native silver, apparently from oxidized ore, but only small amounts of sulfides are found in place today. This type of altered and mineralized ground extends a thousand feet east, north, and west, from the two mines mentioned. The silicified limestone is clearly restricted to the faulted areas and not to the contact between limestone and porphyry. Similar ore from the silicified upper part of the Leadville dolomite in the Evelyn mine in Graham Park (No. J-122), contained 8 to 9 ounces of silver to the ton (Chapman, personal communication) but generally beds that contained sulfides and constituted a good grade of ore where unsilicified declined abruptly in value where silicified. In such cases silicification apparently antedated ore deposition and converted the hitherto soluble limestone, favorable for ore, into an insoluble, difficulty replaced, and densely crystalline rock.

PROSPECT MOUNTAIN

Almost all of the rock exposed on Prospect Mountain is of the Weber (?) formation, which consists of grits and sandstones with smaller quantities of shale and thin-bedded limestone. The limestones, which contrast sharply with the rest of the strata and can be traced for a mile or more along the outcrop, are especially valuable as guides to the structure.

In addition to the Weber (?) formation, and the Leadville dolomite (which is exposed by faulting in a small area along shallow workings near the Uncle Sam shaft) the surface formations consist of several sills of porphyry belonging to the Gray porphyry group and one thin sill of early White porphyry. An especially conspicuous sill of Johnson Gulch porphyry with characteristic large phenocrysts of potash feldspar separates the uppermost Leadville dolomite from the lowest grits of the Weber (?) formation. A porphyry sill of the Evans Gulch type, 50-ft thick, forms a large outcrop in the Lake Isabelle basin, southeast of Prospect Mountain; the extent of this outcrop results, not from the exceptional thickness of the sill, but rather from the chance parallelism of the sill and the surface of the ground. It is significant that no dikes whatever are known in the area. A pipe of rhyolitic agglomerate, first found by R.T. Walker in a west crosscut from the Resurrection mine and later recognized by him at the surface, underlies the basins of the two small lakes northwest of the Resurrection mine.

There are faults of small displacement on Prospect Mountain but complete details are not known because exposures are poor. A continuation of the Winnie-Luema fault (which is mineralized farther south) extends slightly west of north from Little Evans Gulch for about 2,500-ft up Prospect Mountain. The Weston and Iron faults should intersect near Little Evans Gulch, as mapped. The Weston fault is mineralized farther south but the Iron fault is generally believed to be postmineral. The smaller faults on the sides of the amphitheater in which Lake Isabelle is situated do not appear to have favored mineralization. Two apparently unmineralized faults that seem to be related to those of the Pendery system are exposed at the west end of the south slope of Prospect Mountain.

Very few shafts and pits on Prospect Mountain, south as far as Little Evans Gulch and west to Canterbury Hill, are more than 75-ft deep. Most of the tunnels are short and, as the dips of the rocks are generally slight, do not expose very thick stratigraphic sections. The Weber (?) formation and the 250-ft sill of Johnson Gulch porphyry beneath it are equally unfavorable to mineralization; shallow holes on Prospect Mountain where these are the dominant surface rocks clearly offer little promise. The limestone beds within the Weber (?) formation are not thick enough nor sufficiently fractured to have been the places of large-scale mineralization. The only indications of mineralization, even in lower zones, are: the fairly general bleaching of the porphyry sills; the local silicification of some shale of the Weber (?) formation; for example, along the northeast-trending line of prospects (Nos. B-27, B-29, B-30, B-53, and B-52) that lies about 2,000-ft southwest of the crest of Prospect Mountain; and the small deposits of alteration minerals, such as epidote, found in lenses of limestone of the Weber (?) formation, which are exposed in several small tunnels, notably No. B-75, about 1,500-ft, S. 65˚ E. from Lake Isabelle.

The striking. alignment of two groups of prospects on the southwestern slope of Prospect Mountain suggests the presence of mineralized fractures. One group was mentioned above and the other (Nos. A-14, A-15, A-17, A-18, A-24, A-25, and A-26) extends along the gulch that separates the crest of Canterbury Hill from the western spur of Prospect Mountain. However, evidence obtained on the dumps is insufficient to prove that either line is located on a mineralized fissure, despite the arrangement which so strongly invites that interpretation.

UNCLE SAM SHAFT

The Uncle Sam shaft is no longer accessible. Emmons (1886, p. 260) describes it as 420-ft deep, passing through a very thin body of early White porphyry and penetrating successively the Leadville dolomite, the Dyer dolomite and Parting quartzite members of the Chaffee formation, the Manitou dolomite, and probably the Peerless formation. The Uncle Sam tunnel nearby penetrates only the Johnson Gulch porphyry, which is the surface rock. Nothing is known of the history of operations.

GREAT EASTERN SHAFT

The Great Eastern shaft, 1,500-ft south-southeast of Lake Isabelle, must have been a large operation; several buildings are still in place, and there is evidence of a campaign of exploration involving extensive core drilling. It is said that the shaft is 116-ft deep and that a drill hole below it extended 500-ft more. Old maps show a small amount of drifting northeastward from the bottom of the shaft. Little else could be learned of its history, except that a well-defined "contact" deposit, 5-ft thick, was found at the bottom of the shaft; the contact is in the grits of the Weber (?) formation and dips in general southward parallel to the beds at an angle of 25 degrees. Assays showed small amounts of precious metals, especially silver, in oxidized ores rich in manganese and iron. The dump of this shaft reveals fine-grained porphyry of the Evans Gulch type, considerably bleached and silicified, and also a small amount of breccia of the same rock, greatly stained with iron and manganese oxides. As the drill cores found at the shaft collar are of Evans Gulch porphyry, it is inferred that this porphyry and Weber (?) strata extend to a depth of 616-ft below the surface.

BOARD OF TRADE AMPHITHEATER

The Board of Trade Amphitheater offers hope only for deep workings. No important faults are known to occur in it and the surface rocks are sills of the Evans Gulch and Lincoln porphyries and grit and shale beds of the Weber (?) formation with thin intercalations of limestone, locally a little silicified. Several shafts and shallow pits, none more than 100-ft deep, have been sunk in the bottom of the amphitheater, Some short tunnels have been driven into the steep slopes below the mouth of the amphitheater and also in the west wall,

It is not likely that ore can be developed under these openings merely by continuing the Yak tunnel in a N. 30° E direction. As the beds dip eastward, and as the level of the Yak tunnel (at an altitude of about 10,430-ft) is above the top of the Leadville dolomite at the Diamond mine farther south, extension of the tunnel northeastward to a place near the Board of Trade Amphitheater, would cut progressively higher strata and correspondingly less favorable rocks, stratigraphically well above the top of the Leadville dolomite (sec. A—A'. pl. 2). This conclusion was suggested by Emmons, Irving, and Loughlin, (1927, pl. 14) and is amply borne out by the studies here reported.

BIRDSEYE GULCH AND ADJACENT SLOPES

HEAD OF BIRDSEYE GULCH

The Mosquito fault extends northward from the north branch of Evans Amphitheatre into the head of Birdseye Gulch, along the western slope of the range. The escarpment along that slope is virtually a fault scarp with the lower part of the Paleozoic section exposed on the upthrown side of the fault. East of this escarpment there are several distributive faults, approximately parallel to the Mosquito fault and somewhat similarly mineralized. No faults that might offer encouragement to vein mining are known west of the Mosquito fault near the head of Birdseye Gulch and mining would have to be carried to depths corresponding to an altitude of about 10,200 ft, where the top of the Leadville dolomite would be reached. Mining at such depth would involve a long extension of the Yak tunnel and the sinking of winzes for 230 ft or more below the tunnel level; or the sinking of shafts to depths of 1,600 ft or more, depending upon their location.

It is reported that at some prospects at the very head of Birdseye Gulch, small fissure veins in the grits of the Weber (?) formation contain some gold (Youe, personal communication, 1929).

LITTLE CORINNE AND NEARBY PROSPECTS

In an area east of Birdseye Gulch on the western slope of the Mosquito Range, and northeast of the area shown on the main geologic map (plate 1) there are the Little Corinne and several other small mines and prospects; all except one of them have been abandoned (**Figure 74**). They are of interest because they lie between the Mosquito and London faults, and near their junction. Both of the faults, especially the London, are mineralized to the south. The writer spent two days studying the western slope of the range just west of Mosquito Mountain and prepared a geologic map of the area. Much of the crest of the range west of the London fault is covered with rubble and therefore the geology must be inferred. No topographic map was available and locations are approximate. A claim map was kindly furnished by Mr. F. J. McNair of Leadville.

The Little Corinne mine, on the northern slope of Mosquito Mountain, was developed by two tunnels on the Little Corinne claim; the upper was near the top of the Leadville dolomite, the lower in Manitou dolomite. Both are now abandoned. The country rock is intensely shattered and the Leadville dolomite is considerably stained by iron oxides and copper carbonate. The mining properties lie in a triangle formed by the main London fault, an intersection fault to the west, and a fault trending east, which forms the southern border of the triangle. The Little Corinne mine is said to have been highly productive, but records of shipments are not available.

Several adits have been driven eastward from the western slope of Corinne and Mosquito Mountains, but generally they do not follow fissures. The adits trend northeast to east, whereas the three faults recognized on the surface west of the London fault trend southeast, as show on Figure 74. A caved adit on the Governor claim evidently started with an east-northeast trend, then followed the accessory thrust fault that lies west of the London fault; material from this accessory fault is represented on the dump by breccia cemented with pyrite and siderite.

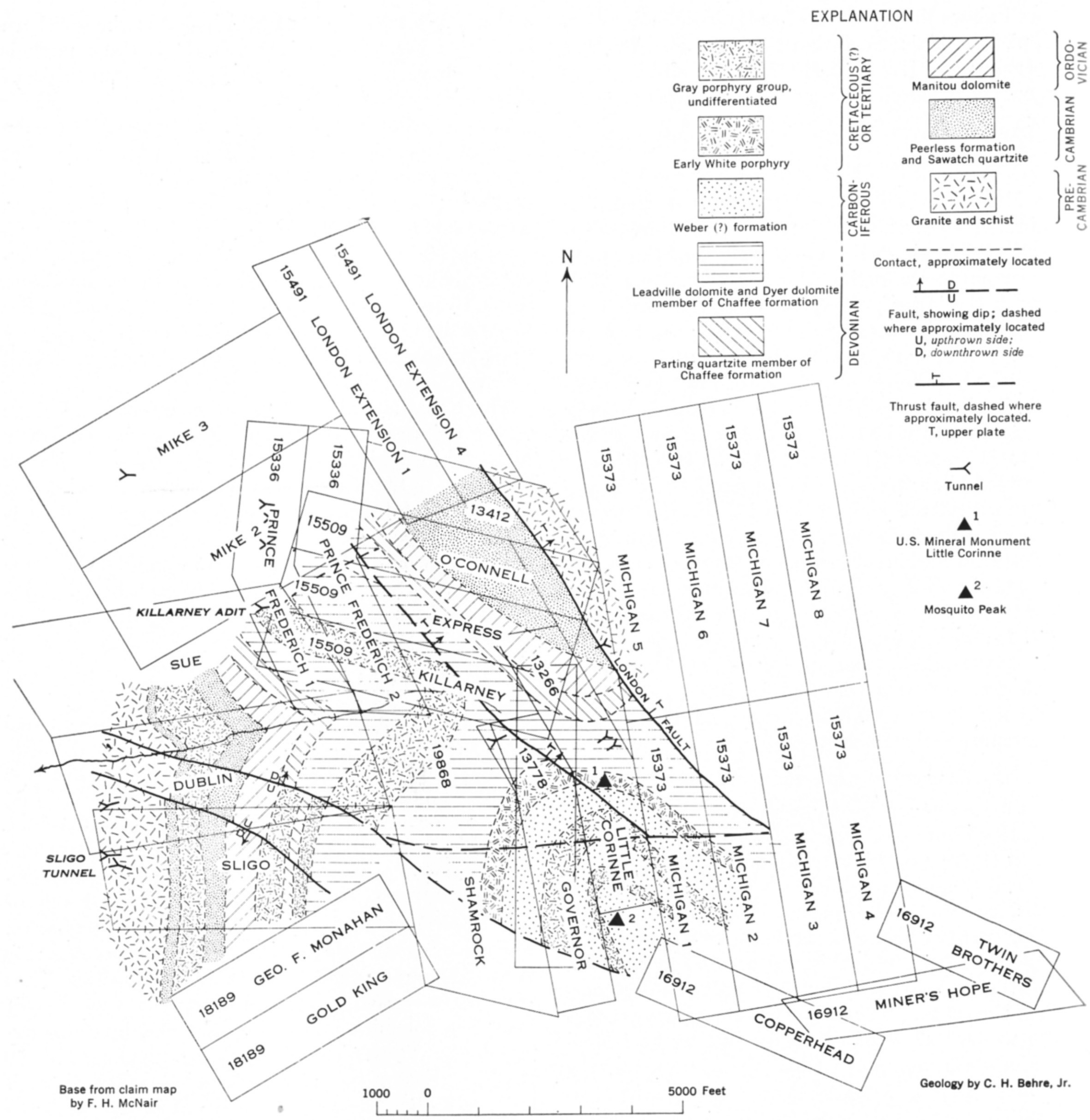


Figure 74. Map showing geology near Killarney and Little Corinne workings. In part after F. H. McNair.

The Killarney adit, southernmost of four openings on the Prince Frederick claim, has a course generally eastward through Leadville dolomite and a sill of rock belonging to the Gray porphyry group. About 640 ft from the portal the adit passes through upturned westward-dipping beds that may be indicative of drag along the same thrust fault as that followed by the Governor tunnel, or perhaps along the London fault itself. This adit had been extended intermittently for about 10 years previous to 1930 but cut neither the faults nor any ore bodies.

EVANS AMPHITHEATER

North of the point where the Mosquito fault crosses the saddle between West Dyer Mountain and Little Ellen Hill it follows a north-northeasterly course across Evans Amphitheater. There is little faulting on the west or downthrown side, though one accessory fault lies subparallel to the major fault plane. The rocks exposed are the clastic beds of the Weber (?) formation with a few thin limestone strata and sills of Lincoln, Evans Gulch, and Johnson Gulch porphyries. Thrusting from the east has sharply upturned the Weber (?) strata against the Mosquito fault and has apparently broken away and dragged up a mass of Leadville dolomite, bounded on the west by the accessory fault. This fragment is nearly 1 mile long and 500 ft wide. East of the fragment, and also farther north and south along the outcrop of the Mosquito fault, the rock succession on the upthrown side is fairly regular, with the beds dipping generally east or southeast, as shown in the head and in the eastern wall of the Evans Amphitheater (**Figure 75**). Pre-Cambrian rocks form the eastern wall of the fault and farther east the strata exposed include all formations up to the grits and shales of the Weber (?) formation, which cap the crest of Mount Evans. This upthrown side is broken by several faults having strikes similar to that of the Mosquito fault. Only one fault of this group has a throw of as much as 100 ft. The dips of only a few of the fault planes are determinable. Generally the western side is downthrown, as also along the Mosquito fault.

Four groups of prospects in Evans Amphitheater merit description. They are the Daisy-Kemble group, the Miller group, the Best Friend group, and the group of prospects and mines at the southern head of the Evans Amphitheater.

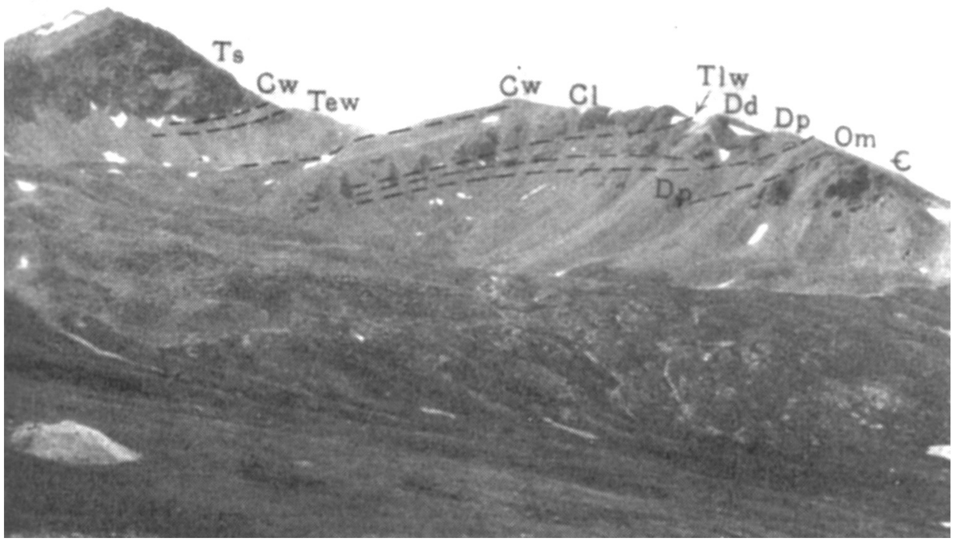


Figure 75. Floor and walls of southern head, Evans Amphitheater; rock glacier in left middle distance; laccolithic sill of Dyer Mountain in background; note later white porphyry dike (*Tlw*) in saddle and, *Ts*, Sacramento porphyry in Dyer Mountain; *Tew*, early White poryphyry; *C*, Cambrian; *Om*, Manitou dolomite; *Dp*, Peerless shale; *Dd*, Dyer dolomite; *Cl*, Leadville dolomite; *Cw*, Weber (?) formation.

DAISY-KEMBLE GROUP

At the extreme northern end of the Evans Amphitheater the several faults with strikes of N. 15º to 50º E. are subordinate, locally show much drag of the adjacent beds, and are apparently related to the great Mosquito fault. They are clearly exposed near a group of prospect tunnels and shafts (Nos. C-59, C-60, C-61, and C-62) situated between the 12,250-ft and 12,500-ft contours. The short tunnels, now largely caved, were driven into the hillside along the zones of shattered, iron-stained rock bordering the faults.

The easternmost tunnel of the group (No. C-60), situated on the Kemble claim, is 150 ft long and has a shallow shaft near its end. The rock penetrated is bleached Dyer dolomite a short distance above the Parting quartzite. The tunnel apparently follows a fissure striking N. 25º E.; along it there has been a small amount of stopping. About 50 ft higher is a short adit just east of the fissure; at its portal the beds of Dyer dolomite are dragged sharply up along a fault whose west wall is upthrown.

The workings of the Daisy mine (Mo. C-62), 800 ft northwest of the Kemble tunnel, are caved, but apparently are along a small fault trending northeast in the upper part of the Dyer dolomite.

Three shafts (No. C-59), situated at an altitude of 12,050 ft and 110 ft S 35º W. from the Daisy tunnel, have been sunk to depths of 100 ft or less in brecciated granite, pegmatite, and schist. On one of the dumps there are much coarsely crystalline dolomite and small quantities of pyrite and sphalerite. Apparently the shafts were sunk along a fault fissure, here trending N. 40º E., that is continuous with that of the Daisy mine.

MILLER GROUP

Along the western flank of Evans Mountain and on the cliffs rising to that peak there are numerous small tunnels and shafts of pits, none of which has yielded appreciable quantities of ore. Several tunnels that have been driven in the Dyer dolomite and the Leadville dolomite are the most promising.

The northernmost opening of the group (No. C-74, north adit) is situated about 1,500 ft south of the Daisy mine. It represents some 300 ft of workings in the Gray porphyry group and early White porphyry and Dyer dolomite (**Figure 76**). The structural relations are complicated by several minor faults that do not reach the surface, but are seen to strike north or northeast in the adit. The faults generally have the west side dropped and are only weakly mineralized, containing mainly coarsely crystalline dolomite.

About 1,500 ft south of opening C-74 are two other openings (No. C-91); only Miller's adit, the lower of them, is accessible (see figure 77). It is driven chiefly just below the contact between the Peerless formation and the Sawatch quartzite (and at a lower altitude than No. C-74) (**Figure 77**). Like C-74, Miller's adit has revealed numerous small northeastward-trending faults that are vertical or dip steeply west and generally have the west side down-thrown. They are not mineralized and, except for a small amount of fluorite found on the dump, there is little here to encourage prospecting. Work here was carried on in 1927-30.

South of the above prospect several tunnels on the western slope of Mount Evans seem to have coursed about due east along a series of joins or small faults. No evidence of mineralization remains, but it is said that several of these fissures contained very small but rich pockets of native gold.

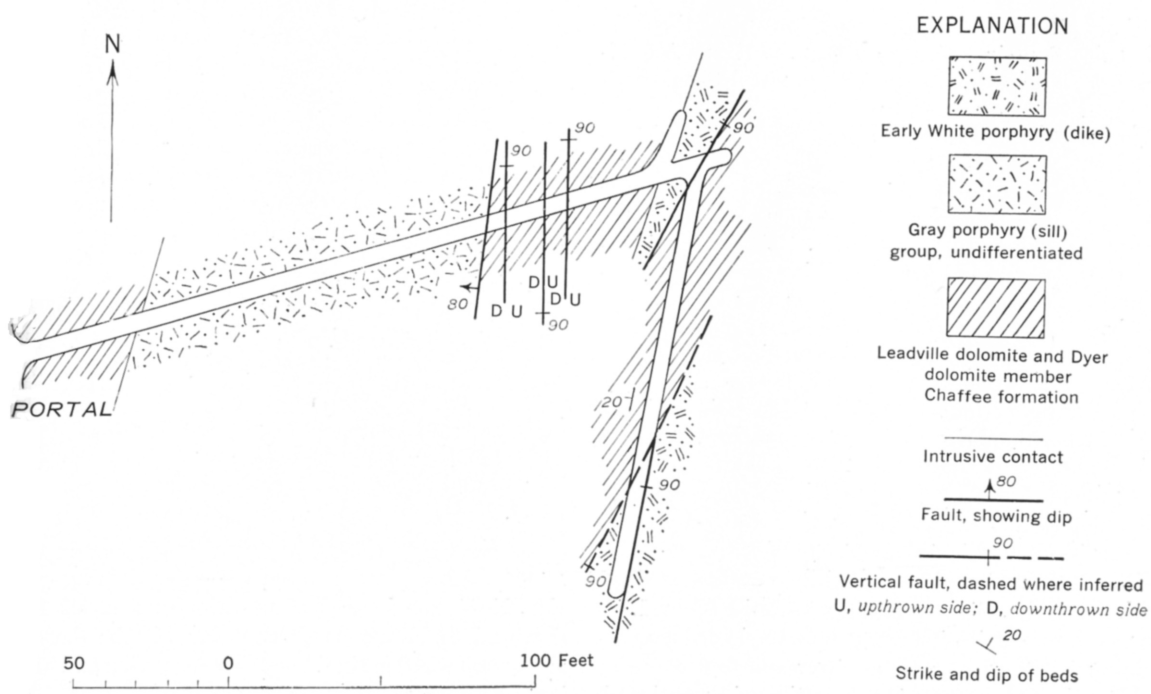


Figure 76. Geologic map of prospect C-74, Evans Amphitheater.

BEST FRIEND GROUP

Many attempts have been made to explore the main Mosquito fault in its course across the Evans Amphitheater. The prospects are here grouped together although they lie on several properties.

The northernmost of the openings, an isolated tunnel (No. C-77), is in the pre-Cambrian rocks just east of the Mosquito fault. Here brecciated schist forms the walls of a subsidiary fissure about 200 ft east of the probable location of the fault. The breccia is cemented by pyrite and galena, and is somewhat copper-stained. A shaft is located close to this tunnel.

About 1,500 ft southwest of this tunnel is a group of workings (No. C-80) which comprises three shafts and an adit. The adit (**Figure 78**) follows a northeasterly vein and fault contact that dips 75º SE, and has brought pre-Cambrian schist on the northwest against granite on the southeast; the walls of the fault are locally silicified, and bear strong vertical striae. Rocks on the dump of this and the neighboring shafts are somewhat epidotized, silicified, and iron-stained, and contain a little pyrite; a few pieces of granite contain vugs lined with sphalerite. These workings are said (John Harvey, oral communication, 1939) to have yielded ore containing 100 to 200 ounces of silver and 0.40 ounce of gold to the ton, presumably from the vein mentioned.

The Best Friend tunnel (No. C-88), now caved, is said to be 300 ft long and to trend south-southwest, evidently along the Mosquito fault. Its dump contains fragments of Leadville dolomite and grit of the Weber (?) formation from the downthrown wall of the fault and of pre-Cambrian granite from the opposite wall. There is little mineralized material containing pyrite and chalcopyrite, but no massive ore could be found on the dump. This tunnel is said to have disclosed pockets of high-grade ore in the fault. Previous to 1893, the operators are reported to have mined ore valued at $100,000, chiefly gold but also considerable silver. (Harvey, oral communication, 1938).

A short distance east are two shallow shafts and a tunnel (No. C-89). The tunnel is in pre-Cambrian granite east of the fault. It shows no fissure, but both shafts, now inaccessible, have on their dumps fragments containing veinlets of galena, sphalerite, pyrite, and chalcopyrite crustified upon earlier quartz. In general, the mineralized rock occurs along a small fissure approximately parallel to the main Mosquito fault; there is, however, no good evidence of such a fissure in the scattered surface outcrops of granite.

About 1,200 ft southwest along the trace of the Mosquito fault are a shaft and two small pits (No. C-103). The depth of the shaft is estimated to be 85 to 100 ft. The dumps here containing siderite, quartz, and pyrite, with a little sphalerite and some galena. Crustified veinlets prove that the pyrite was earlier that the siderite. This operation is said to have yielded $100,00, chiefly in gold and silver (Harvey, personal communication, 1938).

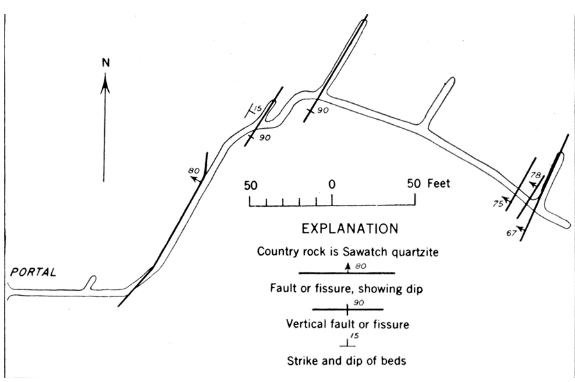


Figure 77. Geologic map of Miller's adit. Note dominance of faults with northeast trend.

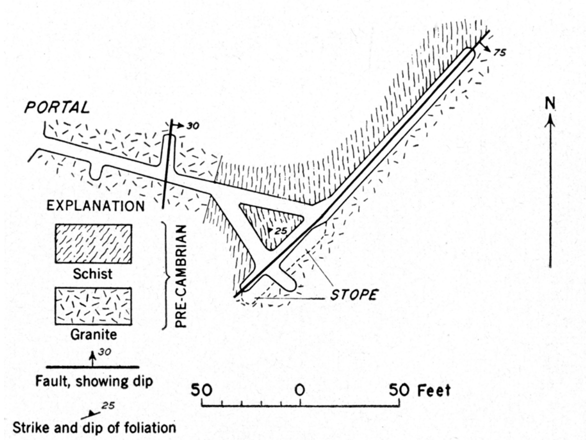


Figure 78. Geologic map of Prospect C-80.

PROSPECTS AT HEAD OF EVANS AMPHITHEATER

One shaft and two tunnels with an adjoining cabin (No. N-24) are located at an altitude of 12,200 ft at the head of Evans Amphitheater. All the development work was done in the Peerless formation and hence is not well located for discovery of ore.

About 800 ft south of the cabin of Prospect N-24, on the northern slope from the saddle connecting West Dyer and Dyer Mountains, are three tunnels (No. N-25) driven in the upper part of the Dyer dolomite or just above it. Barite is disseminated in the limestone country rock and fills small fissures. The mineralization resembles that in the Continental Chief mine (pp. 62–67) and seems to justify more careful prospecting, especially at higher horizon.

LITTLE ELLEN HILL AND ADJACENT PARTS OF EVANS GULCH

Sills of various porphyries of the Gray porphyry group alternation with beds of the Weber (?) formation are exposed on Little Ellen Hill. The Mosquito fault passes between Little Ellen Hill and West Dyer Mountain (**Figure 79**). On the southern slope of Little Ellen Hill and the northwestern slope of West Dyer Mountain the beds of the downthrown block are dragged up so sharply that their dips are generally as high as 55º and locally 70º. Elsewhere, however, the structure is gentle and the beds dip gently eastward or northeastward. This gentle dip of the rocks is also seen in Evans Gulch, between the Board of Trade Amphitheater and Little Ellen Hill, and here, too, the surface rocks and sills of rocks of the Gray porphyry group, continuous with those of Little Ellen Hill.

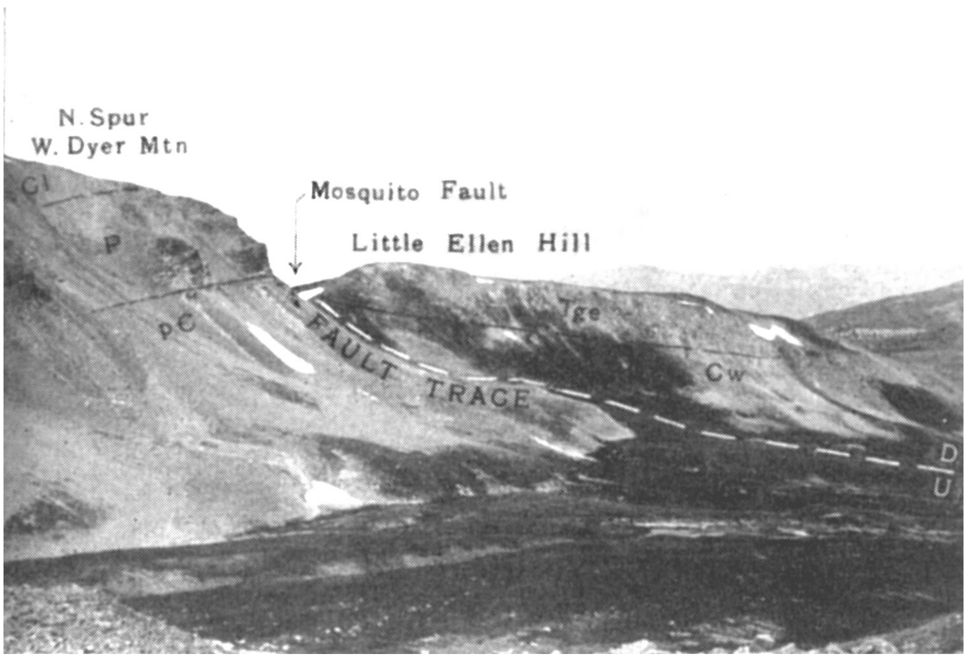


Figure 79. Trace of mineralized Mosquito fault near the south head of Evans Amphitheater, looking southwest. Barren Weber (?) formation (*Cw*) and Tertiary porphyry (*Tge*) exposed on Little Ellen Hill over the potentially productive Leadville dolomite, which passes beneath the valley to the right. Rocks exposed on slopes of West Dyer Mountain include the Leadville dolomite (*Cl*), early Paleozoic formations (*P*), and pre-Cambrian rocks (*pЄ*).

PUZZLER GROUP

The Puzzler group of prospects (Nos. C-117, C-118, and related openings) and the Diamond mine are the principal workings of an economic interest on Little Ellen Hill and the adjacent parts of Evans Gulch. These workings disclosed lenses of slightly silicified limestone in the Weber (?) formation. The Leadville dolomite, however, lies too deeply buried to be readily accessible from the surface, and the limestones of the Weber (?) formation are not sufficiently mineralized to justify exploration.

The Izzard (No. M-14) and other mines just southwest of the Puzzler group, are outside the area here described and also inaccessible, but they may indicate the nature of mineralization at depth in the Puzzler and related claims. Lessees working in these mines discovered many small fractures, along which ore has replaced Leadville dolomite below the basal shale of the Weber (?) formation (John Harvey, oral communication, 1939). As suggested to the writer by E. P. Chapman, the Puzzler area thus gains in interest, and the geologic conditions appear to justify further exploration at depth.

DIAMOND MINE

According to data assembled by E. P. Chapman (Personal communication, 1936), the Diamond mine (No. D-2) was opened in mineralized ground that may be regarded as a single, almost continuous shoot extending northward from the Little Ellen incline (No. M-9) to the Diamond mine. This shoot was a "contact" body at the top of the Leadville dolomite, here covered by a sill of early White porphyry about 100 ft thick (Emmons, Irving, and Loughlin, 1927, pl. 15). As mining was carried progressively farther north, past the Resurrection No. 2 shaft and into the Diamond claim, the northeasterly dip of the beds compelled progressively deeper mining, largely below the level of the Yak tunnel. This in turn necessitated hoisting through several winzes; moreover, it is said that pumping, handicapped as it was by the indirect course of the openings, became expensive, although it amounted to only 350 gallons per minute. These factors, together with a decrease in the size of the ore body, finally brought an end to the operations about 1917. The ore mined was apparently ferruginous, largely oxidized, and rich in lead. Some ore was found in the Manitou dolomite, but it was more siliceous, contained considerable zinc and less lead, and was but little oxidized.

The area northeast of the Diamond shaft may justify further exploration, but this exploration would have to be carried on below the level of the Yak tunnel and, almost certainly, large volumes of water would be encountered. Exploratory deep drilling might be successful but it would have to be carried to depth of 1,000 ft at the Diamond shaft, with an increase in depth of about 120 ft for every 500 ft of horizontal advance northeast of that shaft.

BALL MOUNTAIN AND SOUTH EVANS GULCH

North of the spur connection East Ball Mountain with Ball Mountain, the geology is relatively simple. The conspicuous features here are the Mosquito fault and several somewhat similar and subparallel faults in the head of South Evans Gulch. A block exposing parts of the Leadville and Dyer dolomites and part of a sill of early White porphyry lies between the Mosquito fault to the east and a subsidiary fault to the west; this block is noteworthy for its similarity to the one west of the Best Friend mine (p. 53).

South and southwest of the saddle at the head of the Alps Gulch the structure is more complicated. The main Ball Mountain fault extends north–northwestward from Iowa Gulch crossing Ball Mountain just a little west of its crest. Its course is marked by a highly silicified and altered breccia zone, in places attaining a width of as much as 300-ft. East of it are several minor subparallel faults. On the eastern slope of Ball Mountain, east of the minor faults, an eastward pitching anticline with axis trending about N. 80º E. is cut along its crest and on its north limb by numerous dikes of Johnson Gulch porphyry. In vertical sections at right angles to the axis of the fold, these dike fractures radiate outward from the central part of the fold and are chiefly on the crest of its northerly, more gently dipping limb. Two faults north of the fold trend northeastward in the direction of Alps Gulch, but surface evidences of their northward extension are lost in the Weber (?) formation near the middle of the gulch. Along its southern limb also the anticline is broken by a fault that dies out northeastward toward the Mosquito fault. Within the boundaries of the area here described, three blocks of ground are of possible economic interest. One is in the group of prospects near U.S. Land Monument Alpha (Prospects N-80 and N-82) another is about 1,500-ft farther north near Prospects N-62 and N-68, adjacent to subsidiary faulting on the Defiance and nearby claims; the third is near the Way Up No. I claim, in the region of Prospect N-17, in the block of "Blue" limestones between the Mosquito fault and the subsidiary fault that passes northeast of the notch between East Ball and Ball mountains.

PROSPECTS NEAR U.S. LAND MONUMENT ALPHA

The prospects and shafts (Nos. N-78, N-81, N-82 N-90, N-128, and 0-129) east of the Ball Mountain fault near Land Monument Alpha are of interest because, of their stratigraphic and structural position. Several are near the contact between the Leadville dolomite and the overlying thick sill of early White porphyry. All are within 1,000-ft of the great Mosquito fault, along which mineralizing solutions rose and formed the ore deposits of the Best Friend and other mines in the more northerly part of the Leadville district. Although conditions are similar in this area, no surface evidence of mineralization was found, perhaps because of the absence of fractures other than the Mosquito fault itself along which mineralizing solutions could rise, and possibly because the quantity or concentration of the solutions rising along the fault was less here than farther north.

The Mosquito fault is premineral in this area. A caved tunnel (No. N-128) situated about 700-ft east-southeast from U.S. Land Monument Alpha and driven directly on the Mosquito fault is inaccessible, but the Leadville dolomite on the dump is largely replaced by pyrite. As at several other localities in Evans Amphitheater, similar evidence indicates that the Mosquito is a premineral fault. The writer suggests that it be explored where it passes through the Leadville dolomite.

DEFIANCE AND ADJACENT CLAIMS

There is some mineralized ground in and near the small fault trending northeast along the south limb of the anticline situated east of Ball Mountain. Mineralized material found on the dump of the prospect pit of group No. N-70 consists chiefly of iron-stained, baritized limestone. A tunnel located 1,500-ft from the summit of Ball Mountain in a direction S. 43º E. and west of the Ball Mountain fault cuts pyritized Johnson Gulch porphyry.

The dumped material from several minor openings in this area is heavily iron-stained, which indicates the oxidation of disseminated pyrite and, possibly, the presence of other sulfides. Nothing could be learned of the history of operations in these localities, however, and none of the openings is large enough to indicate that large ore bodies had, been present. The Ball Mountain fault is definitely premineral, but the surface rocks on both sides of it in this immediate locality are not especially susceptible to mineralization as they consist of the Weber (?) formation, Sawatch quartzite, Peerless formation, and porphyry.

WAY UP NO. 1 CLAIM

Several small openings (Nos. N-14, N-16, and adjacent claims) in the block of Leadville and Dyer dolomites lying west of the Mosquito fault expose Leadville dolomite, which is deeply stained by oxidized iron pyrite. The Mosquito fault, which forms the eastern boundary of the block, is mineralized at points 2,000-ft to the north and 3,500-ft to the south; moreover, the branch of the Mosquito fault that forms the western boundary of this block is probably mineralized. The block of limestone between the faults therefore merits prospecting and some evidence of mineralization is exposed in Prospects C-113 and N-16. The top of the Leadville dolomite, however, has been removed by erosion. The normal depth the to the top of the Leadville dolomite along the western wall of the fault should be 1,800 to 2,800-ft.

These depths are respectively about 400 and 950-ft below the nearest point on the Yak tunnel from which a lateral could be driven to this block of ground. Ore and water would therefore have to be raised to the Yak tunnel level. Moreover, the length of such a lateral would approximate a mile. Exploratory mining in the downthrown block west of the fault should be undertaken only if preliminary exploratory drilling from the surface clearly indicates that such mining would be worthwhile.

EAST BALL MOUNTAIN

PROSPECTS ON SOUTHERN SLOPE

In the pre-Cambrian and Cambrian rocks west of the mouth of Dyer Amphitheater and east of the Mosquito fault, there are several small openings (Nos. N-83 to N-89) at altitudes between 11,600 and 12,000-ft. The rocks exposed here are just beneath the South Dyer thrust, and most of the prospects are located on small fissures, in part true faults, which strike N. 0º-45º E. and dip westward or vertically. Evidence of mineralization consists of iron and manganese staining along these fractures. Some of the openings are in sills of early White porphyry, some are in pre-Cambrian granite, but most are in dense, massive, white Cambrian quartzite. The two largest adits lie at altitudes slightly above and below 11,900-ft respectively. They are nearly parallel, trending approximately due north along a well-marked fault that dips 50º-70º W., and displaces the South Dyer thrust fault It is characterized by a quartz filling accompanied by limonite, pseudomorphic after pyrite; accessory fissures seen in the openings meet the fault at a small angle, striking similarly but dipping only 40º W. The lowest pits on the southern slope of East Ball Mountain are openings in the lateral moraine of the Dyer-Iowa valley glacier; they do not enter bedrock. There is some development work also along a dike of quartz-diorite porphyry that crops out along the western slope near the crest of East Ball Mountain.

Prospects of this group are said to have been operated largely for gold. No evidence remains that gold was ever found here but fissure walls are commonly stained with manganese oxide, and possibly, as inferred by mining men familiar with the area, there was enough gold to support small-scale operations.

PROSPECTS ON CREST AND EASTERN SLOPE

Several small openings on the crest of East Ball Mountain were driven along faults that trend N. 15º E. The faults displace the contact between Cambrian and pre-Cambrian rocks or intervening sills at many places and are occupied by dikes of later white porphyry. Farther northeast an adit (No. N-43) about 10-ft long is driven along a, fracture trending N. 30º W. These openings and others of the same kind nearby were located on iron-stained fractures in Cambrian quartzite; apparently they were driven in search of gold ore but there are no evident results.

DYER AMPHITHEATER AND DYER MOUNTAIN

The area near the mouth of Dyer Amphitheater and the southern slope of Dyer Mountain forms a structural unit. The South Dyer reverse fault dipping northeast breaks across the local rock sequence, lifting the block composing Dyer Mountain and Dyer Amphitheater and advancing this block southward with respect to the block beneath Iowa Gulch. The sequence of rocks exposed above the fault in Dyer Amphitheater and on Dyer Mountain is normal. It consists of pre-Cambrian rocks forming the floor of the amphitheater and overlain by the usual succession. A thick sill of Sacramento porphyry some distance above the base of the Weber (?) formation caps the crest of Dyer Mountain. In addition to the South Dyer thrust, this region shows two noteworthy faults, the Liddia and Dyer. The former is not mineralized, but premineral fissures near it control the positions of ore bodies in the Liddia mine. No ore has so far been discovered along the Dyer fault.

There are three groups of prospects and mines of interest in this area: the tunnels on the west slope of Dyer Mountain near the Kitty and Dyer group of claims, the prospects on the southwestern spur of Dyer Mountain near the Revenue and Eagle-Tangle claims and the Liddia mine and nearby openings.

KITTY AND DYER GROUPS

The Kitty prospects (N-43a) include three small openings in vuggy upper part of the Leadville dolomite, stratigraphically about 50-ft below the base of the early White porphyry sill. These prospects are favorably located near the projected trace of a small fault that crosses Dyer Mountain about 1,000-ft north of its summit. This fault is presumably premineral, to judge by its course and its stained walls, but no mineral deposits have been discovered along it. A tunnel about 2,000-ft due south of the Kitty claim is in much the same geologic position.

Six openings on the Dyer or Dyer Extension claim (No. N-42) lie about 1,500-ft south of the Kitty claim. The three larger ones are adits; two of the smaller openings are short tunnels or shallow pits; the sixth is a shallow shaft. One of the adits begins along a fault striking N. 80º E. and dipping 40º S., on it the vertical displacement is 6 in. down on the southeast. All of these openings are either in the lower part of the Leadville dolomite or near the top of the Dyer dolomite. No ore is exposed in the accessible workings, but ore appears on all of the dumps; it consists chiefly of limestone replaced by scattered large crystals of barite, between which are small vugs or unreplaced remnants of limestone in the vugs crystals of light brown to yellow sphalerite and less commonly of galena rest on the barite. Some copper stain is seen. This ore and its geologic environment strongly suggest conditions in the Continental Chief mine.

The main and lowest Dyer adit (No. N-42) is still accessible (**Figure 80**). The workings are not extensive, but include at least two stopes. The ore bodies lay on or near a northeastward-trending fissure, not seen at the surface. They consisted of two small "contact" bodies, that, is replacements parallel to the bedding, one on the lower level under a shaly layer near the top of the Dyer dolomite, and the other and larger one on the upper level under a shaly layer a few feet above the base of the Leadville dolomite.

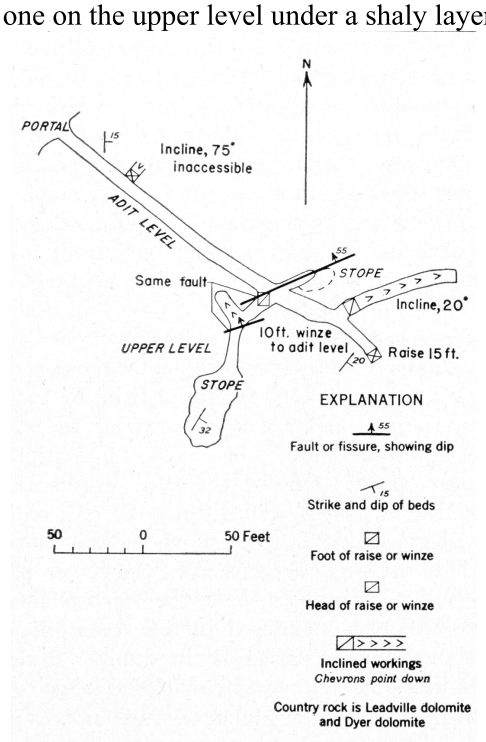


Figure 80. Geologic map of main lowest Dyer adit. Upper level and stope in Leadville dolomite; lower level and incline in Dyer dolomite member of the Chaffee formation.

Little is known of the history of the Dyer and Dyer Extension mine. Emmons (1886, p. 213) says it is one of the first mines of the district but that it was worked only intermittently because of its inaccessibility. He states also (p. 616) that some of the ore consisted of "flint, impregnated with galena"; this ore is in striking contrast with that now seen on the dump.

REVENUE AND TINGLE-TANGLE CLAIMS

The small openings near the Revenue and Tingle-Tangle claims (Nos. N-90 and. N-91) are along the contact between the Leadville dolomite and the overlying sill of early White porphyry The Leadville dolomite in them is appreciably iron-stained along discontinuous fissures trending generally north. They are of interest chiefly because they indicate that the top of the Leadville dolomite along Dyer Mountain should be explored.

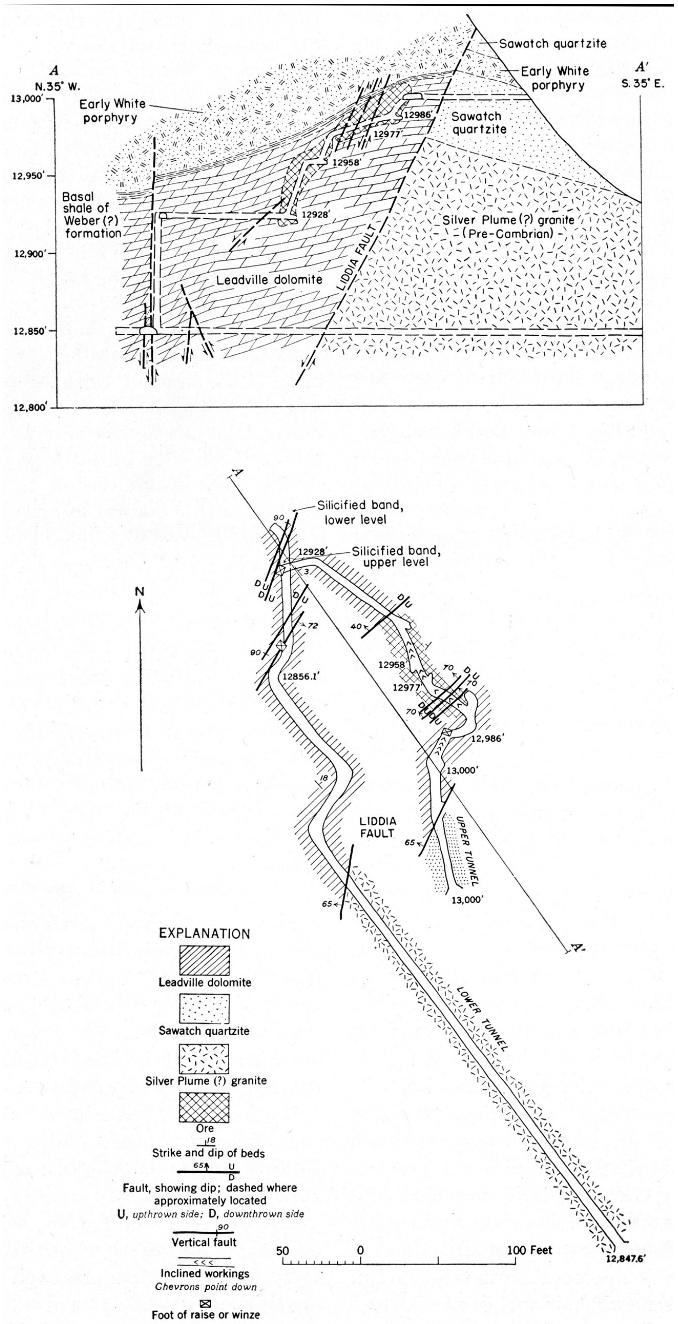


Figure 81. Geologic map and section of the Liddia mine.

LIDDIA MINE AND NEARBY OPENINGS

The course of the Liddia fault is generally N. 25º E., uphill a little west of the portals of the two Liddia tunnels. Pre-Cambrian crystalline rocks are faulted against Leadville dolomite (plate 1) with a vertical displacement of 530 ft near the Liddia mine. The Liddia fault can be traced by a breccia across the southern slope of Dyer Mountain, but openings directly in the fault zone (such as the several small prospects about 100-ft higher than the upper Liddia tunnel) show no mineralized ground.

The Liddia mine (No. N-94) (**Figure 81**) consists of two adits connected by a raise. The lower adit enters pre-Cambrian Silver Plume (?) granite and is driven N. 36º W. in this rock. About 240-ft from the portal a gouge zone, 10-ft wide, appears, striking N. 10º E., and dipping 65º NW. This is the Liddia fault. Both of its walls are sharply bounded against the gouge but are not striated. Beyond this fault zone Leadville dolomite with typical "zebra" markings appears, strongly recrystallized. The dip of the dolomite is uniformly and gently northeast. At three places within 100-ft of the breast of the tunnel the bedrock is broken by faults trending N. 20º-30º E. and dipping vertically or steeply eastward. Their west sides are down thrown, but the displacement can be measured only at the northernmost point, where it amounts to 17-ft of stratigraphic throw. The lower tunnel shows no trace of ore, even along the faults, but the dolomite, is somewhat silicified, a distinct band of silica being noticeable on the northwestern side of the northern fault mentioned above. The recurrence of this silicified zone in the raise to the upper level shows the amount of displacement on that fault.

The upper adit extends for 50-ft through Sawatch quartzite, crosses the Liddia fault, and enters the upper beds of the Leadville dolomite. There it connects with a series of alternate crosscuts and gently sloping inclines. The highest point on this level is the portal at 13,000-ft above sea level; its lowest point, 12,928-ft, is at the head of the winze connecting it with the lower level. Some 70-ft southeast of the winze the upper level crosses a fault having 8-ft of upthrow to the southeast. South of the fault this level enters a discontinuous replacement ore body lying above the silicified zone that is exposed in the winze. Directly above the silicified zone is a rather dense blue-gray limestone whose upper beds contain the ore which has supplied most of the output of the mine. As seen in a winze situated about a third of the distance from the portal to the main connecting winze at the breast, the gray, productive limestone is overlain by 7-ft of dense silicified rock, and by a thin bed of black shale of the Weber (?) formation, which evidently had a ponding effect not unlike that observed in the Continental Chief mine (p. 62). A few raises through this shale strike the overlying sill of early White porphyry.

The ore zone has been stoped discontinuously (figure 81) southward from a point about 180-ft. north of the portal nearly to the crossing of the Liddia fault, 135-ft farther south along the upper level. The shoot is thus at least 100-ft long. Apparently, much of the ore was oxidized, and was called "ocher ore". The ore mineral is chiefly cerussite stained slightly by films of malachite, azurite, and aurichalcite. The primary ore is not conspicuous; its most important mineral is galena; barite and some very fine-grained silica are especially conspicuous in the gangue. The oxidized ore seen is deeply iron-stained and almost every trace of its original pyrite content has disappeared, except casts: surrounded by poorly terminated crystalline quartz. Despite the copper staining mentioned, no chalcopyrite has been found. Typical assays are cited below (Karl Norber, personal communication, 1929):

Assays of ore from Liddia mine

Descriptions	**Lead (percent)**	**Silver (ounces)**	**Gold (dollars)**
1. "Ocher ore" from upper level	15.0	5.0	2.00
2. Primary(?) ore from stope	40.0	12.0	2.50
3. Oxidized seams without visible lead sulfide	4.5	4.2	
4. Ore from face of stope, upper level	13.5	4.0	
5. High-grade ore, locality uncertain	40.0	15.0	

In general, the ore increases in richness upward, in eluding the primary ore, and is especially rich at the black shale that forms its "cap." The history of the mine is not known.

The Liddia fault can be traced about 300-ft north of the portal of the Liddia upper tunnel. There it branches (plate 1), and although the western or main branch is undeveloped, a caved shaft (No. N-38, sometimes designated the Mammoth) and several smaller pits on the Hoosier Girl claim were dug, near or along it. The Leadville dolomite on the dump of the shaft is considerably brecciated and largely replaced by calcium carbonate. The distribution of these openings east of the Liddia fault and the general resemblance of their ores to those in the Liddia mine suggest that the Liddia and Hoosier Girl ore shoots were once continuous but that the Hoosier Girl shoot was lifted about 525-ft vertically by faulting after mineralization. About 500-ft to the southeast a short tunnel (No. N-96) has revealed somewhat iron-stained, fissured Dyer dolomite which gives no indication of ore although small bodies of oxidized lead ore rich in silver are said to have been mined here prior to 1921.

IOWA AMPHITHEATER, NORTHERN PART

The valley of Iowa Amphitheater and the head of Iowa Gulch form a **T**, the amphitheater representing the crosspiece and the valley representing the axis. At the junction, the South Dyer reverse fault is offset by the Liddia fault. To the northeast the sequence of formations is normal. There are sills of early White porphyry in the Cambrian quartzite and a thick sill of the same rock above the Leadville dolomite. The crest of the range east and northeast of this area is made, up of Sacramento porphyry, the Weber (?) formation, and early White porphyry, named in stratigraphically descending order.

Several faults serve to complicate the structure of this area. The Dyer fault trends west-northwestward and, close to the buildings of the Continental Chief mine at the head of Iowa Amphitheater, it is normal and drops the southwestern side about 50-ft. Several minor faults strike northeastward. They extend from the northern edge of outcrops of pre-Cambrian rocks in the Iowa Amphitheater to the Dyer fault; these minor faults break the formations into slivers or elongated blocks, some of which were lifted by the faulting, some depressed. On the eastern wall of the amphitheater two distinct types of faults occur: (1) steeply dipping faults with trace roughly east up the slope of Mount Sherman, and having only small displacement and (2) low-angle thrust faults with larger displacements, whose traces extend northward.

Mines and prospects of economic interest are the openings on the Umatilla and adjacent claims, the Continental Chief mine, the McGuire workings, and several small tunnels on the eastern wall of the amphitheater approximately a mile south of the Continental Chief mine.

UMATILLA GROUP AND NEARBY WORKINGS

Three tunnels are located on the Umatilla group of claims. The western one (No. N-98) is a short adit that trends N. 50º W. and crosses a fracture zone that trends N. 40º E. in Leadville dolomite. The northern tunnel (No. N-36) is 350-ft long and trends generally north-northwest in Leadville dolomite along a fault that dips steeply east and raises the eastern side about 4-ft. This fault has a branch trending northeastward near the northern end of the workings. Both faults slightly displace a dike of early (?) White porphyry. No ore is exposed.

The southern tunnel (No. N-37) includes 500-ft, of drifting in an easterly direction in coarsely crystalline Dyer dolomite, cutting through the basal conglomerate of the Leadville dolomite about 170-ft from its portal. Some "dolomite sand," probably formed by the solution of the calcareous cement between the dolomite grains by acid surface waters (Emmons, Irving, and Loughlin, 1927, p. 36), appears close to the portal. The breast of the tunnel is in Leadville dolomite which contains some "zebra" rock, but there is little evidence of mineralization.

In all of the Umatilla workings numerous small faults striking N. 0º-40º E. show no trace of ore and are evidently of postmineral age. They are comparable in strike, in lack of mineralization, and in age, with the Liddia fault (pp. 60–61).

CONTINENTAL CHIEF MINE

In the northeastern head of Iowa Amphitheater, just above the Leadville dolomite, a 5-ft zone of black shaly beds contains pyrite concretions. It forms the base of the Weber (?) formation, but because the shale is so thin, it is not practicable to differentiate it from the Leadville dolomite on the geologic map. The shale is separated from the rest of the Weber (?) formation by the thick sill of early White porphyry that forms the upper slopes on both walls of the northern head of Iowa Amphitheater This shale, like that in the Liddia mine (p. 60), forms a cap over the ore-bearing limestone beds. A similar but lighter-colored shaly bed, 2 to 5-ft thick, lies 12 to 15-ft below the top of the Leadville dolomite and likewise seems to have induced ore deposition beneath it.

The gentle folding seems to have caused some movement along the contacts of both shales and the more brittle Leadville dolomite. These movements produced small openings along the bedding planes above and below the shaly layers. Hence, along the western slope of the range, from the northern head of Iowa Gulch south to Mount Sheridan, a 25-ft zone directly below the thick sill of early White porphyry is locally mineralized. Many tunnels have been driven into this zone, most of them within 2,500-ft of the Continental Chief mine. These tunnels are largely inaccessible. Some are filled with ice, but most of them are full of caved black shale and White porphyry. However, the dumps contain blocks of porphyry and shale, pieces of ore, and many fragments of typical blue-gray limestone. The limestone is seamed with white dolomite and quartz veinlets, and partly replaced by bladed crystals of barite. Metallic minerals present include galena, light-colored sphalerite, and small amounts of pyrite, stained somewhat by iron and copper films. As is usual in this type of ore, the sulfides appear to have been deposited later than the nonmetallic minerals.

The Continental Chief mine (No. N-99) is the only large operation in such deposits in the Iowa Amphitheater. It consists (**Plate 12**) of an adit driven approximately due east for 125-ft and thence branching so that one arm (the "north drift") leads northeastward and forms with the adjacent stopes the "west working", whereas the other (the "south drift") follows an east-northeasterly course, leading toward the "east" or "main workings." Some older mining was carried out from the northeast-leading branch, which is driven in the upper part of the Leadville dolomite just below the gray shale horizon. The limestone along this branch is broken by fissures and faults of small throw, of trends N. 5º-50° E., and, generally, of steep dips. Quartz has been deposited along the fractures and has also replaced some of the limestone. The ore is quartz-rich and contains pyrite, smaller amounts of galena, and still less sphalerite, of local occurrence. Locally, the oxidized ore contains large quantities of cerussite and a little limonite. Stoping has proceeded along the fractures, especially where the ore is oxidized, and in some places the back or roof, partly made up of black shale of the Weber (?) formation, has caved, filling the passage. The oxidized quartzose ore is said to have had a high content of gold and silver. Samples collected in the stope walls –at two points within 75-ft of the northeast breast–contained respectively 4.4 and 1.4 ounces of silver to the ton, and traces of gold, according to J. R. Fyfe & Co., Leadville Assayers (courtesy of C.N. Larson, 1929).

The east workings consist of two generally separate parts. One of them lies at about the level of the main or south drift. This includes the Ice Palace stope and adjacent workings.

Approximately 300-ft from the point where the north and south drifts separate is the head of an incline. Most of the stoping was done along the incline or along subordinate drifts spaced at irregular intervals. This mining opened a series of stopes trending N. 30º-40º E., generally following fissures that dip steeply northwest or southeast (**Figures 82 and 83**). The small displacements along these fissures are mainly horizontal. In the lowest workings near the incline, and at a few other places, the mineralized ground is coextensive with a large number of such fissures, so closely spaced as to shatter the ground thoroughly. In places the mineralized fractures are offset by others of post-mineral age.

Approximately 1,000-ft east-northeast from the portal a large body of ore was found in the deeper part of the mine **(Figure 84**). This elongate shoot trend due east and thus differs conspicuously from the other large shoots of the mine. To develop this body further a crosscut was driven southeastward from the bottom of the incline, but the mineralized ground at this depth was disappointing. It apparently ended eastward against a fault striking N. 2º W., and little ore was found beyond.

The detailed stratigraphic sequence downward from the sill of early White porphyry, exposed in the cliffs a few feet higher than the portal of the main adit, is as follows:

	Feet
7. Early White porphyry.	
6. Shale, black, carbonaceous with a few pyritic concretions; very slabby and plastic	2-8
5. Limestone, coarsely crystalline blue-gray dolomitic, with few traces of fossils; locally characterized by secondary veinlets of white dolomite (“zebra” rock)	10
4. Shale, gray to blue-gray, slabby; not highly plastic; fossiliferous	2-5
3. Limestone, dense, light blue-gray dolomitic	2
2. Limestone, coarsely crystalline blue-gray dolomitic; “zebra” markings common; fracturing irregular	20+/-
1. Limestone, finely crystalline, light blue-gray, dolomitic.	

The black shale (bed 6) with overlying porphyry is found wherever stoping or exploration have been extended high enough. Faulting has raised or lowered these key horizons irregularly; a few faults pass upward into the shaly beds and are lost, apparently by dissipation of movements along bedding planes.

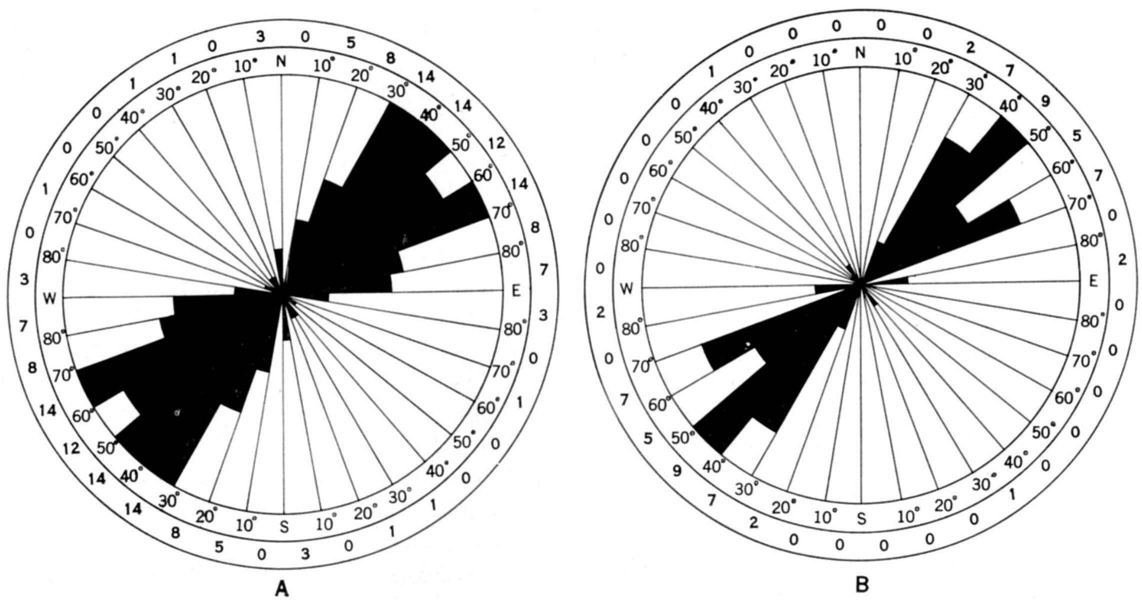


Figure 82. Strikes of fissures and faults in Continental Chief mine. Lengths of radii are proportional to total number of obsevations. All data plotted to within 10º of the true azimuth reading. Numbers on inner dials give degrees azimuth east or west of true north and south; those on outer dials give the number of observed fissures having the indicated azimuth reading. *A*, All fissures observed (91 observations). *B*, Definitely mineralized fissures (33 observations).

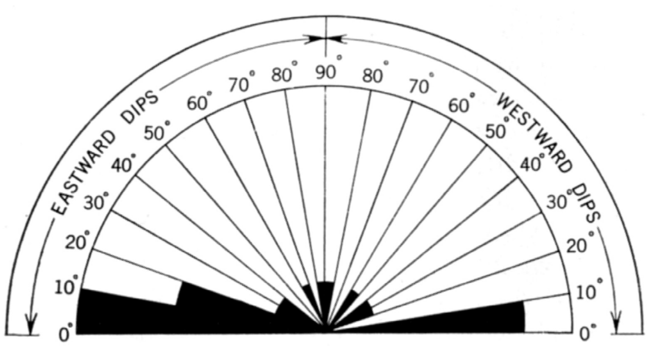


Figure 83. Inclinations of striae along faults observed in Continental Chief mine. Length of shaded segments proportional to number of observations. Note dominance of nearly Horizontal as opposed to nearly vertical readings.

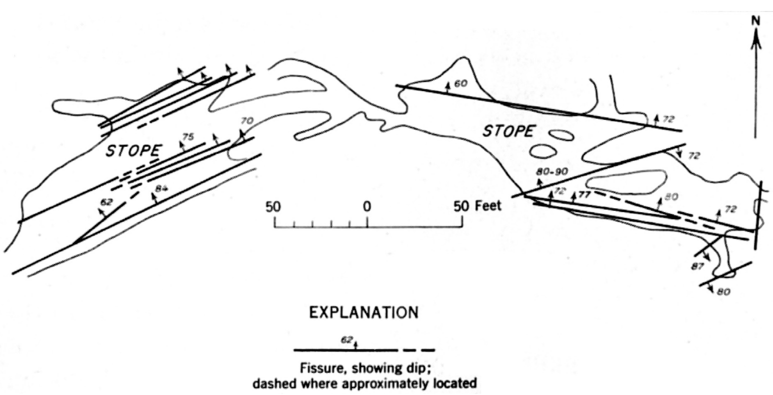


Figure 84. Lowest large stopes at foot of new incline, Continental Chief mine, showing prominence of fissures and their apparent relation to mineralization.

Although the premineral fissures were an important source of ore, by far the greater part of the output was from replacement bodies. Most of the fissures are fair fairly tight and few are wide enough to have been worth mining for their own ore content alone (**Figure 85**). The large stopes along the incline, the Ice Palace stope at the head of the incline in the south workings, and the "northeast" stope in the northeastern end of the mine represent ore, bodies of impressive size, formed chiefly by replacement. The Ice Palace shoot (even with the lower boundary arbitrarily placed at the level of the main southwest adit) is 250-ft long, its width ranges from 30 to 60-ft, and its height is as much as 45-ft. In general such bodies are elliptical in vertical cross-section, with the longer axis of the ellipse parallel to the mineralized fissures. These bodies (**see Figures 86 and 87**) are mass replacements of limestone that began along fissures, either closely spaced or isolated.

A significant feature of such replacement is that it is clearly preferential. The coarsely crystalline limestone, such as beds 2 and 5 in the stratigraphic column above, is distinctly more susceptible to replacement than the finely crystalline rock of beds 1 and 3. The two limestones do not differ in solubility, as chemical analyses indicate that both are dolomitic limestones of about the same composition. The difference is attributable to three other factors: (1) the occurrence of ponding beds, notably the black shale, No. 6, above the upper limestone, as in so many of the Leadville "contact" deposits; (2) the greater porosity of the recrystallized, cellular limestones; and (3) the mode of fracture.

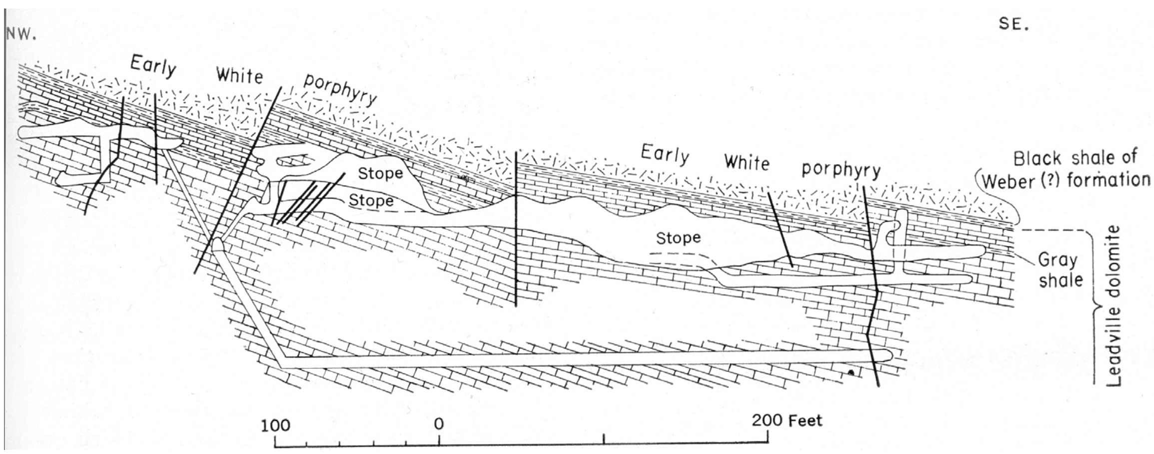


Figure 85. Vertical section through larger stopes near foot of incline, Continental Chief mine.

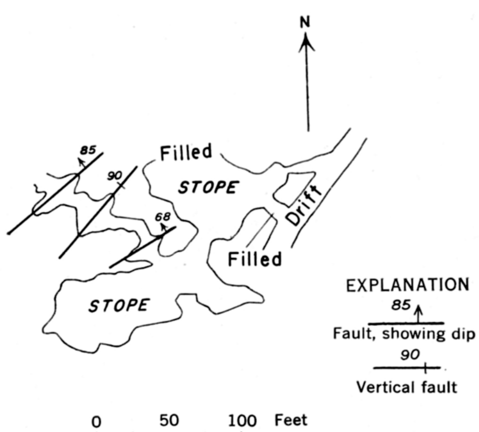


Figure 86. Stopes in sacking-ore developed in limestone along fissures. Plan of part of southwest stope in East Working. Continental Chief mine.

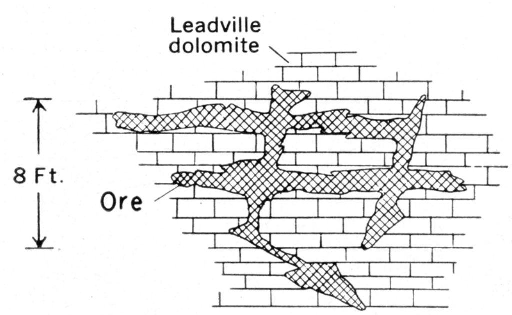


Figure 87. Preferential or selective replacement of certain beds adjacent to fissures. Wall of stope under head of incline. Continental Chief mine.

The dense limestone generally develops clean-cut fractures, which tend to be conchoidal and discontinuous; for this reason, it is frequently given the very graphic designations of "short-fracturing dolomite" or "short lime." In contrast, the coarsely crystalline limestone breaks along wider shattered zones, and the resulting angular fragments are more readily attacked from all sides. Moreover, the thinner beds of the dense limestone act as limits to the continuity of fractures across the bedding, whereas the more massive beds of the coarsely crystalline rock are cut by continuous fractures along which solutions should be able to move with greater freedom. These factors and the greater porosity of the coarsely crystalline limestone and hence its greater susceptibility to penetration and to replacement readily explain the preferential mineralization of this kind of rock.

Most of the ore occurred as replacement bodies of considerable vertical thickness about fissures that served as channelways, but some was found in small, flat bodies, essentially true "contacts." Thus along the old incline a blanket of this type formed a small shoot lying west of the main ore body and 25-ft below the shales; the present stope is about 20-ft square and from 5 to 6-ft high. Like most similar bodies it resulted from selective replacement of a bed, but a few bodies actually lie along bedding-plane faults. (See Behre, 1937, pp. 512–529.)

One of the mistakes made in development work in the Continental Chief mine resulted from a failure to grasp the importance of the stratigraphy in determining the location of the ore. The incline has an average dip of 19º-21º to the northeast. The average dip of the beds is 12º-21º , but varies greatly from place to place, and in the lower parts of the incline the strike is generally almost parallel to the direction of the incline; the component of the bedding dip along the incline is thus very low, averaging much less than 10º. Hence, as the incline loses altitude, it passes gradually from the productive beds into the underlying, denser dolomite, which is generally less favorable to ore deposition.

The mineral composition of the ores is fairly simple. Apparently, the chief primary ore minerals were galena, sphalerite, and pyrite, in a gangue consisting of dolomite, barite, and quartz. The most conspicuous ore mineral is galena, and the ore is largely rich in silver, especially where the sulfide has been slightly oxidized to cerussite. Galena is more conspicuous in the upper workings, and sphalerite and its alteration products in the lower, but there is no marked contrast in the quantity of the primary and secondary minerals containing the lead and zinc. Pyrite and quartz seem to have been associated with the ore that was richest in precious metals; much of the "sacking" or high-grade, precious metal ore, mined locally in the west workings and in the stopes on the level immediately below the head of the incline, was partly oxidized pyritic material. Most of the zinc recovered from the base-metal ore came from oxidation products, especially smithsonite of the "dry bone" type; some hetaerolite was found, and hydrozincite was common. Completely unoxidized sphalerite is rare and generally of a distinctive olive-gray color; large masses have been found only in the deeper parts of the mine, most of it in the lowest stopes east of the foot of the incline. Small amounts of aurichalcite and a few stains of malachite indicate that chalcopyrite or some other copper mineral was present. These products of oxidation are found even in the deepest workings, which are well above the ground-water table.

The metal contents of three samples collected by the writer are shown in the following table:

Assays of Samples from the Continental Chief Mine.
[J. R. Fyfe & Co., Leadville, Assayers. Courtesy of C. N. Larson, 1929]

No.	Gold (ounces)	Silver (ounces)	Lead (percent)	Zinc (percent)
1.	---	5.6	19.8	13.6
2.	Trace	2.4	11.4	1.4
3.	---			17.3

Sample 1 is from one of the deeper stopes about 125-ft up the incline from its lower end. Sample 2 is from sacked ore in the stopes immediately under the head of the incline. Sample 3 represents smithsonite ore found in a short drift branching southeastward from the north workings.

It is said that the Continental Chief mine was first opened in 1884, after a landslide had uncovered some of the western lode in the cliffs. This body of ore led to other shoots farther in the side of the mountain, and in order to remain below the early White porphyry sill an incline was started –the so-called "old incline"; later the new incline was driven to simplify haulage. Work was continued from this new incline and the total output up to about 1920 is said to have had a gross value of $3,000,000. The mine was shut down for a period, but operations were resumed in 1926 by the East Butte Exploration Co. Production methods (according to E.P. Chapman, who supplied most of the data) were modernized, and diamond drilling was used for exploration. These changes resulted in some production, chiefly from the lower part of the new incline and the stope at the far northeastern end of the mine. Most of the mineralized ground, however, ended against the fault striking N. 02º W. and bounding the northeastern stope along its eastern end. The maximum vertical displacement along this fault is estimated to be 12 to 25 ft. A so-called "dike" along this fault is merely the calcareous gouge and breccia derived from the dolomitic limestone. Evidently, efforts to find the offset extension of the ore body (or the productive zone) failed, and it appears that the ore body originally ended about where the fault crossed it. Work was abandoned by this company in 1928.

In 1930-31 exploration was resumed by a Denver company. Efforts were directed not at development work at depth, with its difficulties in haulage and ventilation, but at discovering new bodies near the surface to the south. As most of the mineralized fractures strike northeast and the beds generally also dip north east, drifting was begun in a southeasterly direction, with the object of maintaining an approximately constant stratigraphic horizon and, at the same time, transecting as many fissures as possible. The management planned a raise on each vein as found, up to the sill of early White porphyry, at the base of which ore was reasonably expected. The work was begun southeast of the Ice Palace stope. A small northeast-trending vein was found 250-ft south of the incline, and a raise put up on it, but little ore was discovered. The same procedure was followed with a second vein 100-ft farther south, with no better results. A third vein was found 75-ft farther south, but again a raise yielded no promising ore, and work was stopped. This very well planned prospecting campaign could be resumed and supplemented by other prospecting northward from the incline, at a point where the productive beds are stratigraphically about 20-ft higher than those at the bottom of the incline.

McGUIRE TUNNELS

The two small prospect adits (No. N-106) of the McGuire property lie close together, some 1,600-ft due south of the entrance to the Continental Chief mine. The portal of the upper tunnel is about 75-ft above that of the lower tunnel and 300-ft southeast of it. The upper tunnel is caved and inaccessible. The lower tunnel trends generally S. 70º E. for a total length of about 550-ft; at its end an inclined raise, 48-ft long as measured on a slope of 55º, gives access to about 20-ft of exploratory work in "Blue" dolomite. The main level is in the Manitou dolomite and the Parting quartzite and Dyer dolomite members of the Chaffee formation. The general strike of these rocks ranges from N. 10º E. to N. 20º W., and the dip is predominantly eastward, but 13 faults could be mapped in this short tunnel, and relations in the section exposed in the tunnel are not simple. The section is of interest chiefly because of the light it sheds on the structure typical of the western slope of Mount Sherman. Many of the faults are normal, but there are at least three thrust faults whose presence is indicated by drag of the beds in addition to the common gouge or breccia. Despite this extreme shattering, the only indications of ore are several pieces found on the dump, containing a small amount of pyrite, galena, and barite, and the presence of conspicuous dolomite veins along some of the faults.

To the north and south along the western slope of Mount Sherman, within a distance of 1,200-ft of the McGuire tunnels, there are several other prospects. They are shallow pits and tunnels, driven either along joints or small fractures that trend roughly due east or northeast or along irregular thrust faults. Most of them are not accessible, but the material on the dumps is characterized by small amounts of galena, rare, gray-green sphalerite, smithsonite of the cavernous type, and barite, all of which were formed by replacement of the Leadville and Dyer dolomites; vein material composed of quartz and pyrite is also found.

It is clear that the structural relations and mineral composition of these small deposits are essentially like those of the Continental Chief mine. Their mineralized fissures have northeasterly or easterly trends; ore occurs where these fissures cut the contact between the Leadville limestone and the overlying sill of early White porphyry. None of these prospects, however, seems to have shown enough ore to have encouraged extensive work nor to have left a record of production.

PROSPECTS ON EASTERN WALL OF IOWA AMPHITHEATER ON AND NEAR EQUATOR CLAIM

Approximately a mile S. 10º W. of the portal of the Continental Chief mine, on the western slope of the spur extending from Mount Sherman toward Hilltop Pass and Mount Sheridan, there are openings (No. N-171) comprising several tunnels, shallow pits, and one shaft. They are on or near the Equator, Klondike, and adjacent claims. Like the McGuire tunnels and, the Continental Chief mine, these openings lie along the contact between the Leadville dolomite and the overlying sill of early White porphyry They are largely caved and inaccessible, but a study of their dumps suggests that the carbonaceous shale seen in the Continental Chief mine separates the porphyry from the Leadville dolomite here also. There are no indications of definite fissures that governed the localization of ore. The scattered fragments of ore found on the dumps consist of limestone, which is partly silicified, or iron-stained, or replaced by barite. The barite contains small quantities of sulfides, mostly galena, and some zinc carbonate of the "dry-bone" type. Despite these indications of ore, the area lacks the fissures which might have guided mineralization and so is not as promising as that farther north near the Continental Chief mine.

IOWA AMPHITHEATER, SOUTHERN PART

South of the region where the northern and southern branches of Iowa Amphitheater join to drain westward through Iowa Gulch, the rocks exposed are mainly Cambrian and younger. The Liddia fault, its east side upthrown, is the cause of a marked difference on the eastern side of the southern head of Iowa Amphitheater. This part of the amphitheater is floored with pre-Cambrian rocks and its walls and higher slopes are made up largely of Cambrian and Ordovician strata and intruded sills, which west of the fault appear only in the floor of the amphitheater. The numerous southerly branches of the Liddia fault produced several offsets, which are visible in the southern walls of the amphitheater; along most of these faults the eastern side is upthrown, as, along the main fault. The South Dyer reverse fault, readily recognizable on the southern spur of Dyer Mountain, is less conspicuous in the pre-Cambrian rocks immediately east of the Liddia fault, reduced in throw in the lower Paleozoic rocks farther southeast, and split up into a series of faults that pass into sharp folds stratigraphically higher on the southeastern wall of the Iowa Amphitheater just west of Hilltop Pass. The South Dyer fault is not recognizable along the crest of the range to the east. Perhaps its discontinuity is linked to a change in the thickness of a sill of early White porphyry just below the Manitou dolomite, the intrusion of the sill having accompanied the faulting. Considerable ore might have been deposited along these branches had the faults reached the contact between the Leadville dolomite and the overlying sill of early White porphyry. Nevertheless, there are some fairly attractive prospects along the traces or the southeastward projections of the branches of the South Dyer fault.

Two groups of prospects in the southern part of Iowa Amphitheater deserve mention: the prospects on or near the Liddia fault and those on the northern slope of Sheridan Mountain.

PROSPECTS NEAR LIDDIA FAULT

Some pits omitted from the map, on the floor of the amphitheater near the Liddia fault, have revealed no mineralized rock and it seems that the fault itself is not mineralized. It is only coincidence that the Mammoth (Nos. N-38 and N-96) and Liddia (No. N-94) mines are near the Liddia fault. It is rumored that a little gold was found in these prospects, but there is neither evidence nor likelihood of this.

PROSPECTS ON NORTHERN SLOPE OF MOUNT SHERIDAN

Along the northern slope of Mount Sheridan, the general sequence of rocks, in descending stratigraphic order, is as follows:

	Feet
5. Thick sill of early White Porphyry	200
4. Black shales of Weber (?) formation	25
3. Thin sill of early White Porphyry (locally pinches out completely)	0-15
2. Blue-gray quartzite basal Weber (?) formation	10
1. Uppermost part of Leadville dolomite--	

Ore occurs in fractures or breccia zones of the quartzite (bed 2), or as replacement bodies or fissure fillings in the uppermost beds of limestone (bed 1). Mineralized ground is thus confined mainly to a zone stratigraphically about 30-ft thick, near the top of the Leadville dolomite. The dump of virtually every tunnel driven along this zone shows small quantities of ore minerals, chiefly smithsonite, cerussite, and galena, with some copper staining, and with barite and quartz as gangue minerals.

Two important groups of prospects (Nos. U-22 and U-23) are situated about 1,000-ft southwest of the 13,184-ft knob at Hilltop Pass. This was once apparently fairly active property, as shown by a cabin, traces of a shaft and seven tunnels. The quartzite in this vicinity has locally been replaced by barite, and the associated ore resembles the baritic ore of the Continental Chief mine. However, the ore seems to have been leaner because the quartzitic host rock is less favorable to ore deposition than dolomite.

The more western of the two prospects designated U-33 on the map is a tunnel driven along a fault zone. The basal quartzite of the Weber (?) formation exposed in this opening has been shattered to a breccia and then recemented by barite; there has also been replacement of the country rock by barite. Between barite blades are small amounts of galena.

UPPER IOWA GULCH, EAST OF HELLENA MINE

In the marginal part of the Leadville district, the only area rivaling the one between the Hellena mine and the Mansfield and Rex shafts in the complexity of its geology is in upper Iowa Gulch, between the Iowa Amphitheater and the Hellena mine. The traces of the Mosquito and Ball Mountain faults are well exposed on Upper Long and Derry Hill, cross upper Iowa Gulch, and rise toward Ball Mountain and East Ball Mountain. The Mosquito fault has its downthrow on the west, bringing pre-Cambrian rocks on the east against Dyer dolomite on the west. The Ball Mountain fault, north of its junction with the Iowa fault also has the western side downthrown, an almost equal amount. Between the two, there are minor faults, along most of which the western side is downthrown; in part they are occupied by dikes of Johnson Gulch porphyry. The Iowa fault apparently ends eastward against the Ball Mountain fault.

Many prospects lie between the two major faults. Some, such as N-146 and N-148, are relatively near the Mosquito fault; others, such as N-140 and N-141, are on the inferred trace of the Ball Mountain fault. Yet, only on the dump of the eastern tunnel of the western part of group N-134 has mineralized material been found. Even on the dumps only a small amount of pyritic ore was seen. Some of the workings–for example, the three shafts at N-142-give evidence of fairly extensive exploratory work but with no indications of mineralized ground.

East of the Mosquito fault several short tunnels were driven along fissures in the pre-Cambrian granite –for example, about half a mile northwest, or an equal distance northeast of the crest of the northern peak of West Sheridan Mountain (Nos. N-117, N-118, N-119, and N-163). The fissures trend northwest, contrary to the general structural pattern of this region. The mineral matter consists of quartz veinlets with iron and manganese oxides from which, it is rumored small pockets of high-grade ore were mined.

LOWER IOWA GULCH AND SOUTHERN SLOPE OF PRINTER BOY HILL

Rock exposures are few in the valley of Iowa Gulch west of Hellena mine. The overburden of glacial and alluvial material and the heavy influx of water made mining in the valley bottom very difficult. Despite reasonable expectation of mineralized ground, therefore, exploration has not been extensive though the prospects are numerous. Therefore, the bedrock geology in the valley bottom is not known in detail and must be inferred largely from rock exposures on the higher slopes.

Perhaps the most complicated surface geology of the marginal area is that along the Hellena-Weston-Union fault complex, near the Hellena mine. The fault relations here are of special interest because ground along the branches of the Weston fault is considerably mineralized. Several interpretations have been offered for the geological relations known for the area between the three great faults –the Union, Weston, and Iowa faults. The interpretation accepted and reviewed below takes into account the trend, the direction of displacement, the amount of throw of each fault, and also data obtained at surface and underground exposures by the writer and others who studied this region.

On the southern slope of Upper Long and Derry Hill the Union fault, trending north-northeast, breaks up into several smaller faults. These faults are clearly revealed by offsets of the contact between the Cambrian beds and the pre-Cambrian on the cliffs overlooking Iowa Gulch. They offset the Weston fault repeatedly along the southern slope and crest of Long and Derry Hill. North of the intersection of the Union and Weston faults, the Weston fault forks, the main fault trending about N. 20º W., and an easterly branch, the Hellena fault, striking approximately due north and dipping steeply eastward. The Hellena fault has been traced northward about 1,500-ft. from the stream in Iowa Gulch. Beyond this point the rocks in the hanging wall and footwall are too similar to reveal its position at the surface. The main Weston fault also forks near the southern end of the Clear Grit claim, and a western branch extends across Iowa Gulch almost parallel to the main fault, and reuniting with it a little farther north. At the surface the western wall of the main Weston fault consists of a thick sill of early White porphyry with lenses of the uppermost beds of Leadville dolomite.

Near the middle of Iowa Gulch the Hellena fault brings pre-Cambrian granite on the west against Weber (?) strata on the east. The Hellena is a reverse fault farther south, so this condition can be explained only by assuming the presence of the Iowa fault–an east-west fault along which shales and grits of the Weber (?) formation are thrown down to the north against the pre-Cambrian rocks at the south. This fault must be assumed to exist both in the block between the main Weston fault and the Hellena fault, and in the block between the Hellena fault and the Ball Mountain fault farther east.

From the vein complex of the Hellena mine westward to the neighborhood of the Rex shaft (where the Mike fault crosses Iowa Gulch) the succession is fairly regular, and the rocks crossed in a westward traverse are progressively older beds. The easternmost exposures are sills of early White porphyry with intercalations of quartzites and grits of the Weber (?) formation and of upper beds of Leadville dolomite. Westward are successively exposed the Leadville dolomite, the Dyer dolomite and Parting quartzite members of the Chaffee formation, the upper part of the Manitou dolomite, and farthest west, a sill of Iowa Gulch porphyry. All these rocks dip uniformly eastward. The structure is complicated by many faults, all trending approximately northward and nearly all having the western side downthrown. Along these faults are dikes of Johnson Gulch porphyry, near which the rocks are commonly mineralized. The crest of Printer Boy Hill is made up of early White porphyry, this being the sill above the Leadville dolomite, which appears also on the crest of Long and Derry Hill at and above the 11,500-ft contour.

In the ground between the Mansfield shaft, the First National shaft, the crest of Printer Boy Hill, and the bottom of Iowa Gulch, the effects of mineralization are such as to suggest higher temperatures than in adjacent regions. Probably a plug of Johnson Gulch porphyry (forming a minor center of mineralization) came close to the present surface here, and the exposed dikes of this rock are offshoots from it.

A similar plug is exposed about the Mansfield shaft, west of the Mike fault. Little is known about the bedrock geology owing to the cover of lateral moraines on the lower, western continuations of Printer Boy and Long and Derry Hills. Farther west, between the Dome and Iron faults, the bedrock in Iowa

Gulch seems to consist chiefly of Leadville dolomite and an overlying sill of early White porphyry, but these relationships are only inferred.

In lower Iowa Gulch and on the southern slope of Printer Boy Hill there are eight mines or groups of workings. In lower Iowa Gulch are (1) the Hellena mine, (2) the First National and Julia-Fisk group, (3) the Ontario-Lou Dillon group, (4) the Lillian mine, and (5) the Mansfield mine. On the southern slope of Printer Boy Hill are (1) the Doris group, (2) the Clear Grit-Ella Beeler group, and (3) the Rex shaft.

HELLENA MINE

The Hellena (**Plate 13**) was the only large mine in Iowa Gulch accessible at the time of these studies. Previous to 1909, operations at relatively shallow depths are said to have yielded $100,000 worth of ore. This work was stopped largely because of water trouble. The mine was again in operation in 1928 and 1929, but administrative difficulties between the operating company and land owners, together with increased costs of pumping forced the operating company to close down in 1930.

The Hellena shaft was sunk on the outcrop of the Hellena fault. Its depth in 1930 was 766-ft. Earlier work developed five levels (plate 13), at depths respectively of 99, 195 (first level), 272, 290 (second level), and 400-ft (third level) below the collar of the shaft. The operations in 1928-30 vere chiefly on still deeper levels: at 501 (fifth level), 605 (sixth level), and 700-ft (seventh level). Work was most extensive on the 501-ft level where long crosscuts were driven east and west from the shaft, whereas the higher levels were chiefly along the fault itself (the locus of most of the ore). This fault (**Figure 88**) is exposed on every accessible level, striking generally N. 15° E.-N. 05° W., and dipping east at angles ranging from 62°-85°. The steeper dips and the northeasterly ones are nearer the surface. The fault was opened into a widely gaping fissure on the 195 and 290-ft levels, but not at the deeper levels (**Figure 91**). The parts of the vein having a northeasterly trend and a relatively shallow depth are coextensive with the better grade and greater quantity of ore. This relationship may signify that the premineral shearing thrust that produced the Weston fault had a component on the east side of the fault that was directed southward as well as upward. This interpretation is consistent with the displacement of the Iowa fault south of the mine shaft (see plate 1) but, on the other hand, all the striae observed along the fault on the 290-ft level dip gently southeastward in the fault plane. They may be due to renewed but opposite movement on the same fault planes, as suggested earlier. The fault fissure itself contains much breccia; on the 290-ft level rhyolite, rhyolite agglomerate, and breccia are found along the edges of the fault, as though rhyolite had been forced out along the fault but had been somewhat shattered by subsequent movement. On the 400-ft level the Hellena fault contains a large block of pre-Cambrian granite between walls of early White porphyry and grit of the Weber (?) formation; here the rocks in the footwall of the fault dip westward as through dragged up by the elevation of the hanging wall. Fragments of country rock are cemented by ore (figure 73), indicating that part of the movement was of premineral age.

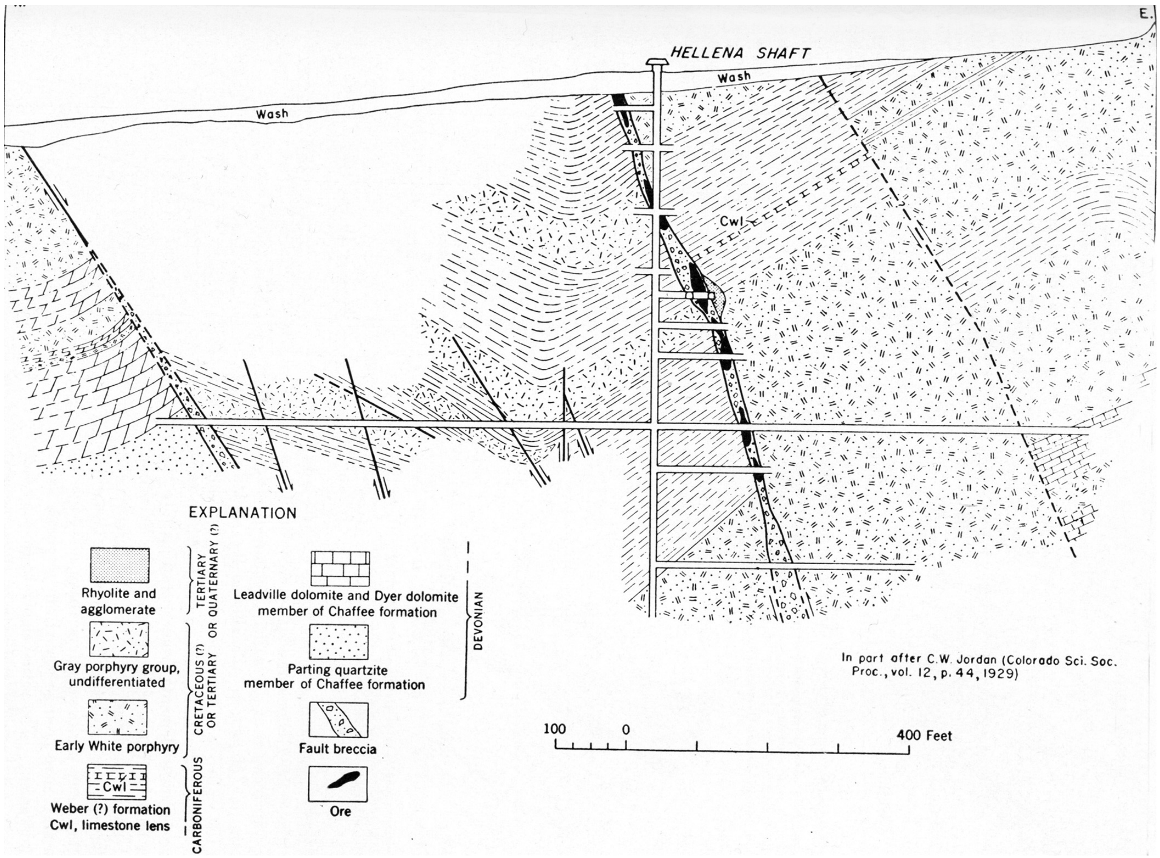


Figure 88. East-west section through the Hellena shaft; in part after C. W. Jordan.

The work extends far east of the Hellena fault only on the 501-ft level. The east wall of the fault below the 290-ft level is made up of early White porphyry that forms a thick sill lying under grit beds of the Weber (?) formation and presumably just above Leadville dolomite. This White porphyry mass has been generally identified as a dike, but the east wall of the Hellena fault consists of grit beds on the 195 and 290 ft levels. Peculiar structural features on the east drift east of the Hellena fault are the several clay dikes. At the extreme eastern end of this level Blue limestone was reported to have been found in drilling, but shortly thereafter this drift was no longer accessible and confirmation was thus prevented.

West of the shaft on the 501-ft level, the rocks are a series of sills of Johnson Gulch porphyry, intercalated with grits and sandstones of the Weber (?) formation. About 625-ft west of the shaft a zone of breccia and gouge, approximately 20-ft wide, and bordered by walls that show striae dipping 30° toward the southeast was cut; these walls strike N. 15°-45° W. and dip 55°-65° NE. Beyond this fault zone is Parting quartzite, dipping 55°-80° W, greatly shattered and yielding much water; its dip decreases westward and 75-ft beyond the fault the overlying Dyer dolomite appears. The latest working is said to have struck more quartzite, representing either the Parting again or the thin quartzite at the base of the Leadville dolomite, but the mine was abandoned before this new exposure could be studied.

All strongly mineralized ground seen in the Hellena mine is confined to the Hellena fault and the immediately adjacent rocks, and this fault is clearly the trunk channel (**Figure 89**). Where it is full of gouge or sheeted rock, the ore is absent or lean; where it is more open, gash veins in the sheeted rocks or in the gouge flanking the fault are common; where there is no gouge in it, the ore shoots are strong and are the chief source of ore. Locally, as on the 195-ft level north and the 501-ft level east, small replacement bodies adjacent to the fault have been stoped. Rhodochrosite is a conspicuous gangue mineral here, and also farther south along the Hellena fault (**Figure 90**). The chief ore minerals are galena and sphalerite; in the higher workings, according to reports, some of their oxidation products occur. There is also much pyrite, especially in tiny veinlets in the country rock. During the years 1928-30, about 25 tons of ore were obtained from the Hellena vein or from a small branch vein on the 290-ft level. This ore averaged 0.18 ounce gold and 8.0 ounces silver per ton, 23.1 percent lead, and 7.1 percent zinc; 500 tons of milling ore were recovered, assaying 0.14 ounce gold and 5.0 ounces silver per ton, and 7.0 percent lead and 6.0 percent zinc (H. H. Wallower, personal communication, 1930). Data furnished by U.S. Bureau of Mines and compiled by R.D. Longyear and G.M. Schwartz show that in 1906-12 and in 1924 the mine produced 1,113 short tons of ore, having a value of $45,104 and averaging as follows: 0.16 ounce gold and 10.42 ounces silver to the ton, 29.5 percent lead and 0.03 percent copper.

In 1930 five holes were sunk with a churn drill west of the Hellena workings. Some ore containing a moderate percentage of galena and sphalerite and considerable pyrite was found in two of the holes.

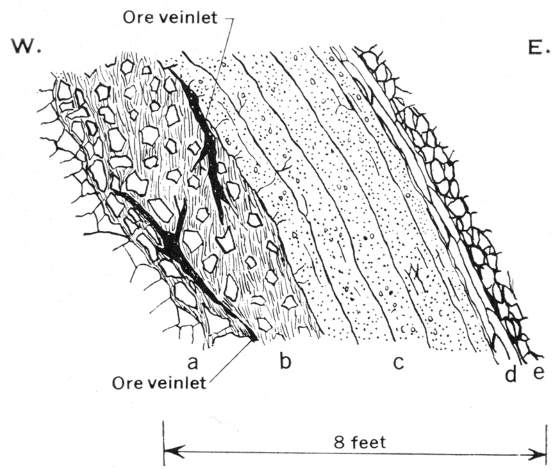


Figure 89. Section across hanging wall part of Hellena vein, 3d level, Hellena mine, showing sheeting, gouge, and ore. *a*, shattered rock in foot wall; *b*, fault breccia; *c*, sheeted or bedded grit of Weber(?) formation; *d*, rhyolite, sheeted parallel to hanging wall; *e*, rhyolite breccia.

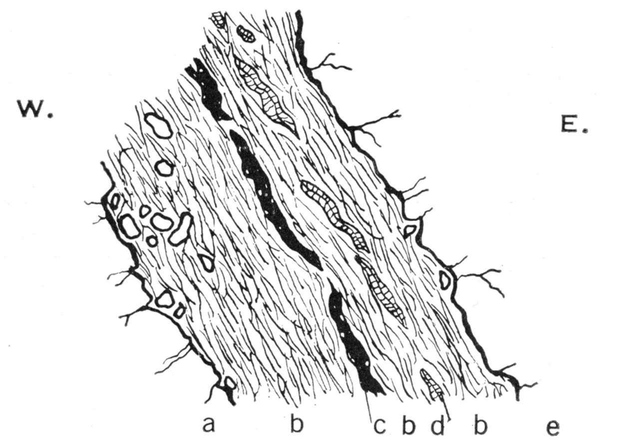


Figure 90. Diagrammatic cross-section of vein, showing rhodochrosite, Hellena mine, 3d level. *a*, shattered rock in foot wall; *b*, gouge; *c*, discontinuous vein of sulfide ore; *d*, discontinuous vein of rhodochrosite; *e*, shattered rock in hanging wall.

Two points are of special interest in connection with the Hellena workings. One of them is the type of ore that locally contains considerable quantities of gold and rhodochrosite; these minerals indicate a temperature slightly higher than that generally prevailing during ore deposition in the marginal part of the Leadville district. A second point of interest is that, despite the indicated higher temperatures, nearly all the ore is in openings along the Hellena fault and

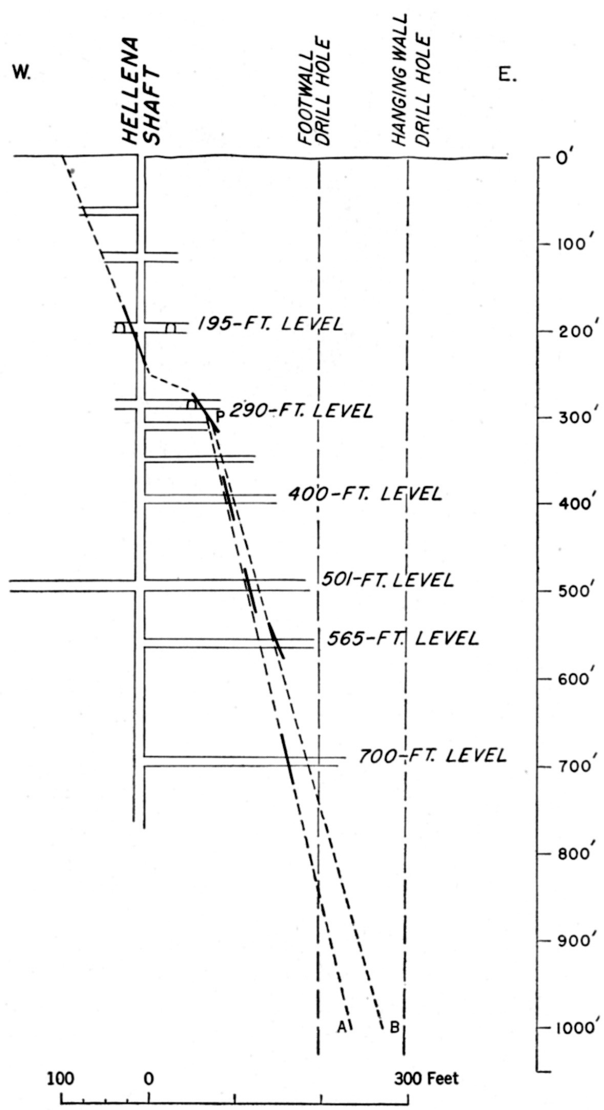


Figure 91. Projection of Hellena fault below shaft.

very little was formed by replacement of the walls. Perhaps this distribution is due largely to the chemically resistant nature of the wallrock so far exposed by the workings. It may also be attributed in part to gouge; which prevented ore-forming elements from spreading into the walls. It may be that at greater depths the limestone is extensively mineralized where the fault crosses the contact between the Leadville dolomite and the widespread sill of early White porphyry above, although the limestone may have been so sealed off by gouge as to escape replacement. The actual depth to that contact here is not known, however, and data on the structural conditions between the Hellena fault and the fault found at the west end of the 501-ft level are not adequate to justify an estimate. A preliminary step in exploring for such a deep ore body would be to drill holes from the 501-ft level or from the surface, on both sides of the Hellena fault. In selecting drilling sites, care should be taken that points east of the fault are started far enough east of the present shaft to avoid crossing the fault before reaching the limestone, and thus failing to explore its eastern or hanging wall.

ONTARIO-LOU DILLON GROUP

The old abandoned workings of the Ontario-Lou Dillon, group (O-20 to O-24, O-27 to O-30, O-42), are in the north wall of Iowa Gulch, north and northwest of the new Hellena shaft and within 1,200-ft of it.

The Lou Dillon (O-22) and New Orleans (O-29) tunnels and shafts are no longer accessible and no ore remains on their dumps. With the exception of the lowest Ontario tunnel, nothing could be learned of their past output or of details of their geology. The identity of the rocks penetrated can be inferred from material on the dumps. The northward extension of the Hellena fault was encountered in the east workings connected with an old shaft on the American Continental claim (O-29-a), about half way between the Lou Dillon shaft (O-22) and the portal of the American New Orleans main adit (O-29). A hole drilled in the American Continental workings at their eastern end and just east of the Hellena fault started 110-ft below the surface in early White porphyry, passed through 171-ft of porphyry, 8-ft of fault breccia (or rhyolite agglomerate), and then 103-ft more of porphyry. Here the drill entered grit of Weber (?) formation and penetrated it for a depth of 25-ft, to stop at a depth of 417-ft below the surface of the ground.

The Ontario claim lies about 650-ft northwest of the American New Orleans adits. In it are four adits and a shaft (O-27) They were driven along a fault that in places brings sills of Johnson

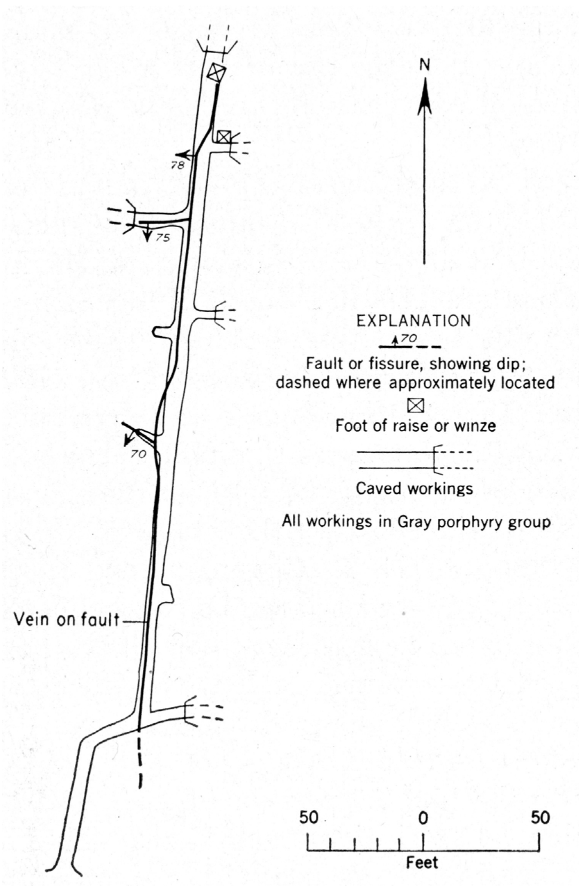


Figure 92 Geologic map of Lower Ontario or Midas mine. All workings show Johnson Gulch porphyry.

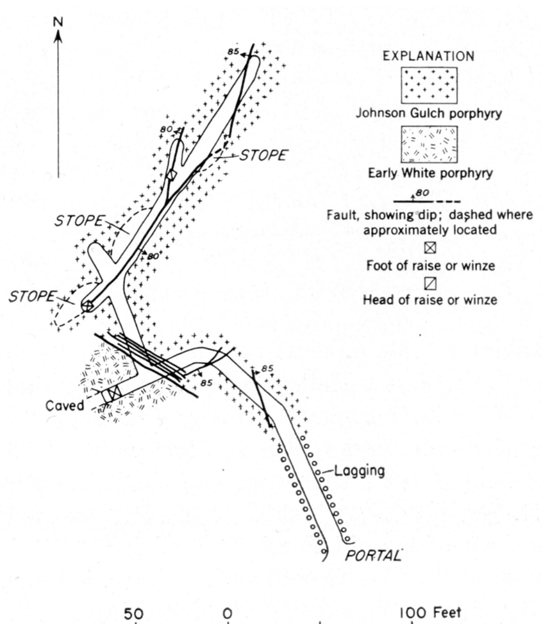
Gulch porphyry against grit beds of the Weber (?) formation. Only the lowest adit (also called the Midas mine) was accessible from 1929 to 1933 (**Figure 92**). In it a fissure vein filling a fault lies between walls of Johnson Gulch porphyry. The vein strikes N. 6°-11. ° E. and dips steeply west, but is joined in its hanging wall by several small fissures which strike about parallel but dip only 30° W., along them, as also along the main fissure, considerable stoping has been done and indeed the main adit is badly caved in many places under such stopes. In some places the ore-bearing material of the stopes still remains in the walls and consists of a silicified breccia suggesting, in the angular forms and mixed nature of its fragments, some of the rhyolite agglomerate found in various workings in this area. According to Emmons (1886, p. 507) this vein contained coarse-grained galena where the walls were porphyry, but was unproductive where it passed through sandstone. It strikes about parallel to the Hellena vein, but is 700-ft to the west and dips west instead of east. The output of this group of claims is not known but Emmons (p. 608) cites analyses of ore from the Ontario tunnels, rich in galena and pyrite, and containing 20 ounces of silver to the ton. Here also pyrite is a characteristic mineral, as in the Hellena mine and elsewhere in this area.

North of the Ontario tunnels, and apparently on the same vein, is the Green Mountain shaft. This property once supplied high-grade ore but is no longer accessible. Data regarding two exceptionally rich shipments made about 1884 are recalled by Mr. Ezra Dickerman of Leadville (Oral communication, 1930) as follows: 5 tons averaging 456 ounces of gold, 42 ounces of silver, and 30 percent of lead; and 8 tons averaging 266 ounces of gold, 40 to 42 ounces of silver, and a moderately high percentage of lead.

The two Yale adits (O-6 and O-7) are about 800-ft due west of the lowest and most southern of the Ontario adits. The east adit (O-6) (**Figure 93**) was driven along northeastward-trending fissures that are not exposed at the surface. The most conspicuous of these fissures strikes N. 32° E. This working is chiefly in Johnson Gulch porphyry. Near the portal, however, the tunnel and a northwest-trending crosscut expose a broad shear zone, irregular and filled with gouge, which is inferred to represent the main branch of the Weston fault. It brings the Johnson Gulch porphyry on the northeast down against early White porphyry on the southwest. Few signs of ore are seen.

The west tunnel (O-7) lies a hundred feet to the west and at slightly higher altitude (**Figure 94**) than the east adit. It is chiefly in Johnson Gulch porphyry but there is a small exposure of early White porphyry on the southwest side of a fault at the end of a west cross-cut (figure 94). Many fissures that trend N. 0°-45° E. and dip steeply northwest or southeast, resemble the fissures of the eastern adit and seem to be subsidiary fissures leading off from the main Weston fault, which is exposed in the east adit. The dump contains pyritic ore, partly oxidized, and small quantities of lead and zinc sulfides. The mineral composition of the ore is similar to that in the Hellena mine, suggesting that ore deposited in the immediate vicinity of the Hellena and Weston faults in Iowa Gulch was formed at somewhat higher temperatures than that deposited farther east or west.

The shaft of the old North Star mine (0-34) is no longer accessible, but is said to have supplied a small quantity of ore from about 300-ft of workings. Several shallow pits lie northwest of the shaft.



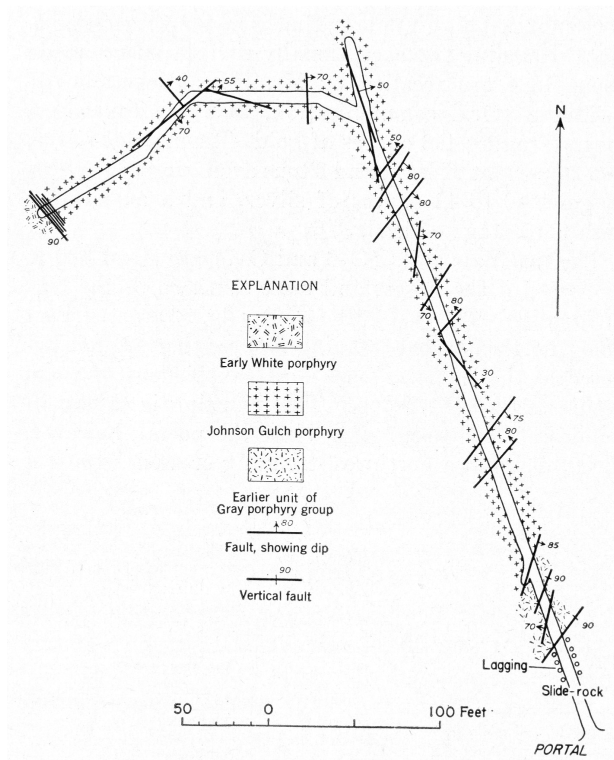


Figure 93. Geologic map of the East Yale tunnel. **Figure 94. Geologic map of the West Yale tunnel.**

FIRST NATIONAL AND JULIA-FISK GROUP

A group of prospect pits and shafts of the First National and Julia-Fisk mines lies on the northern side of Iowa Gulch, about 3,000-ft due west of the Hellena mine and about 1,400-ft due north of the Doris mine. With one exception, the surface workings are either in Leadville dolomite or in the overlying sill of early White porphyry. A single shaft was opened in limestone of the Weber (?) formation. None of the larger openings are now accessible, so the only sources of information are the material on the dump and data furnished by Mr. E.P. Chapman of Washington (oral communication, 1930), based upon his conversations with former miners.

The Julia-Fisk shaft (P-49) was sunk to a depth of 600-ft, penetrating a sill of early White porphyry, the Leadville dolomite, and the rest of the stratigraphic succession down to the Sawatch quartzite. At a depth of 410-ft the Parting quartzite was reached. On the contact between this quartzite and the Dyer dolomite a small bedding-plane deposit of silver-bearing galena was found; driving northeastward, the operators mined ore valued at $20 per ton. In the Sawatch quartzite near the bottom of the shaft, a gold-bearing fissure was discovered, assaying 1.0 ounce gold and 40 to 50 ounces silver to the ton, but organizational difficulties and heavy pumping costs compelled the company to stop operations. Mining was carried on chiefly between 1900 and 1910, and dewatering today would necessitate considerable initial cost. Ore on the dump contains galena, dark-brown sphalerite, and large quantities of maganosiderite. The presence of maganosiderite indicates that the ore of this mine, like that of other mines nearby, was formed at a relatively high temperature.

The First National shaft (P-52) is situated 400-ft southwest of the Julia-Fisk mine. The surface geology is like that at the Julia-Fisk shaft; the Leadville dolomite was reached at a depth of 198-ft by a shaft, which was dug to a depth of 256-ft. From this shaft four levels were driven-146, 160, 198, and 246-ft below the collar. In 1937 the longest drift extended 375-ft from the shaft. A map of the mine furnished by Mr. G. R. Elder of Leadville in 1934 indicates a small ore body south of the shaft on the 246 level. Later mining (according to E.P. Chapman) led to eastward drifting and developed a large body of zinc carbonate at a shallow depth near the east boundary of the property was resumed in 1937-38, when the 198-ft level was extended along three fractures. Selected samples of ore assayed 0.15 ounce of gold and 7.6 ounces of silver to the ton, 7.5 percent of lead, and 11.2 percent of zinc. Descriptions suggest that there has been some silicification of the Leadville dolomite under the base of the early White porphyry that appears at the shaft collar; the ore body is a discontinuous blanket just beneath this silicified stratum (R. D. Elder, personal communication, 1938). C. J. Moore (Unpub. rept. 1909) estimated the value of the output at $15,000. The large dump in 1932 yielded many specimens of primary minerals, including galena, dark-brown sphalerite, a little chalcopyrite, and much pyrite, and also some vein quartz and considerable manganosiderite. Most of the manganosiderite occurs as rhombohedrons with curved surfaces, and some as very thin rhombohedrons forming rosettes, under which arsenopyrite commonly appears in short prisms up to 0.05 in. (1.2 mm) in length. Both forms of manganosiderite are mentioned in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 151-152). Much of the ore is banded because it has replaced limestone along the beds. The presence of manganosiderite and arsenopyrite suggests that the temperature during mineralization was slightly higher here than in most of the outlying parts of the Leadville district and gives reason to hope for extensively mineralized ground in this vicinity.

The same general type of mineralized rock is seen in several small openings (P-45) and on their dumps, about 800-ft west of the Julia-Fisk shaft. The surface rock is Leadville dolomite and a sill of the overlying early White porphyry. It seems that most of the ore occurs at the contact of these two rocks. However, pieces of Parting quartzite found on one dump show incomplete replacement by small groups of galena and light-colored sphalerite crystals.

LILLIAN MINE AND ADJACENT OPENINGS

The term Lillian mine is now applied to large workings and a group of several small prospects. The eastern of the larger workings is known as the Altoona adit; its portal is at an altitude of 10,673-ft. The other large working is the Brian Boru mine, whose portal is about 400-ft, N. 60° W. from that of the Altoona adit.

The Altoona adit (lower tunnel, P-68) was worked as a prospect in 1929 and 1930. It connects with older workings of the Lillian mine, which are now caved and inaccessible. Work in the Altoona tunnel was on two levels. The upper level explored the Sangamon fault, which strikes N. 7°-8° W., dips 70° E., and is marked by down-dip striae. The Sangamon is one of several north-trending faults crossing the southern slope of Printer Boy Hill. Although the Leadville dolomite bordering the fault is considerably bleached and silicified in places, or ore is to be seen on the upper level.

The main level, 132-ft lower (**Plate 14**), penetrates Manitou dolomite and porphyry of the Johnson Gulch type, which contains the typical scattered pink phenocrysts of potash feldspar. Northward-trending faults are conspicuous in this adit. Several of them are reverse faults, but the Sangamon fault, which is well exposed at two points, is normal.

At the northeastern end of the workings that are now accessible a raise passed through 83-ft of the upper part of the Manitou dolomite, 18-ft of red and green shale of the lower part of the Parting quartzite, 29-ft of typical Parting quartzite, and it entered the Leadville dolomite above.

The contact between the Johnson Gulch porphyry and the Manitou dolomite on the main level is generally a fault along which the Manitou dolomite is dragged down so it would appear that bodies of the dolomite overlie the porphyry and were dropped down against it by faulting. At exposures in the northeastern workings of the main level, however, the porphyry (though overlying some of the dolomite) probably is a thin sill from one of the dikes in this region, intruded between beds of Manitou dolomite.

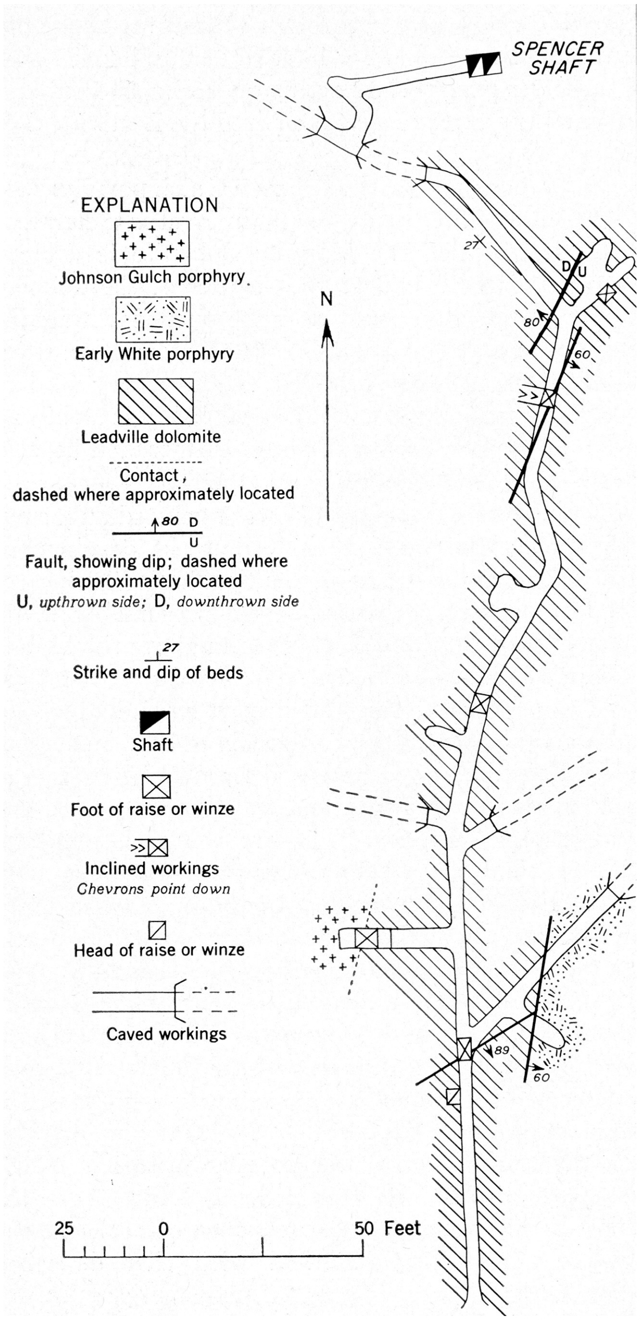


Figure 95. Geologic map of the accessible part of the Brian Boru tunnel.

The Altoona adit (plate 14) was operated on a small scale during the years 1920-30, but the development work was disappointing. From the Nellie S. mine several fair-sized stopes were opened, presumably in the upper part of the Leadville dolomite above the highest level of the Altoona mine. The ore bodies thus exposed were in part veins and in part small blanket deposits containing the lead minerals galena and cerussite and also zinc carbonate and pyrite. The minerals found included lanarkite and schapbachite, both bis-muth-bearing minerals. The ore was rich in silver, and some contained visible native gold (Emmons, 1886, p. 510; Emmons, Irving and Loughlin, 1927, p. 295). The blankets are distinctly elongate in a north or northeast direction (Emmons, Irving, and Loughlin, 1927, p. 295, pl. 45) and, according to the published maps, are parallel to the feeding fissures. The orientation of these blankets agrees with that of the Printer Boy vein, as described by Emmons (1886, p. 232)–in fact, the Sangamon fault or the Nellie S. fault may be identical with the vein found in the Lovejoy workings in the northern side of Printer Boy Hill. It is directly on the strike of that vein, and the sequence of rocks in the Lovejoy workings is identical with that described above.

The Brian Boru adit (P-62) is now largely caved, but some 300-ft of workings that can still be examined are in Leadville dolomite (**Figure 95**). An east drift about 70-ft north of the portal enters early White porphyry that has been brought down against the Leadville dolomite by a normal fault striking N. 10° E. Two small blanket deposits, within 250-ft of the portal, apparently related to other northeast-striking faults, have been mined out. Nothing could be learned as to the nature of these ores.

North and northeast of the Brian Boru and Altoona adits numerous small prospects have been driven in the beds at the top of the Leadville dolomite, just under the early White porphyry, and near faults trending northward or northeastward. At several of them, copper stained rock is found on the dump, together with silicified Leadville dolomite and extensively sericitized and partly epidotized early White porphyry; such altered rocks have been found associated with ore but are not infallible indicators. Some prospects reached the Dyer dolomite.

West of the Brian Boru and Sangamon adits, at altitudes ranging from 10,750 to 11,100-ft, several small prospects have been opened in beds below the base of the sill of early White porphyry that overlies the Leadville dolomite. Most of them seem to have been driven along dikes of Johnson Gulch porphyry, which locally contain a little, finely crystalline, disseminated pyrite. Strongly silicified Leadville dolomite is also found on many of their dumps. However, some of these prospects lie west of the Mike-Pilot fault complex, along which the west side is downthrown, and consequently they are in the upper part of the Leadville dolomite or in the overlying early White porphyry.

The widespread silicification of the limestones, and the magnetite found on some of the dumps, indicate that mineralization in this area, as in the vicinity of the Hellena mine, took place at higher temperatures than those of most of the marginal deposits. This magnetite is partly altered to hematite, and locally the Leadville dolomite contains small cloudy patches of finely disseminated hematite.

MANSFIELD MINE

The Mansfield mine and the prospects within 600-ft of it to the southeast and east were opened for the most part in the outcrop of the sill of early White porphyry overlying the Leadville dolomite. Some of the rock cut by the main shaft may be bleached Johnson Gulch porphyry, though the evidence is inconclusive because of the extreme degree of alteration. The Mansfield is a three-compartment shaft, said to have been sunk to a depth of 800-ft. It is said that some ore was found, but there is no record of production from this shaft. Operations were stopped because cost of pumping became excessive. Bleached, silicified, and conspicuously iron-stained Leadville dolomite was found on the dumps near the main shaft.

REX MINE

The Rex mine is the most extensive in Iowa Gulch, west of the Lillian mine. Mining began in 1893 and a shaft was sunk on what may be regarded as the Mike(?) fault or as its extension southward from its junction with the Pilot fault on the southern slope of Printer Boy Hill. The surface rock is most probably a highly altered member of the Gray porphyry group. A large flow of water, encountered at a depth of about 300-ft where the shaft entered the Manitou dolomite, precluded further deepening of the shaft. A drift was begun, but the flow of water continued to be so large that work was abandoned, despite the reported finding of a good grade of gold ore.

A new firm leased the mine in 1901, the shaft was retimbered, and the contact between the porphyry and the Manitou dolomite was explored; lead carbonate ore was found, which was noncommercial at that time (E.P. Chapman, personal communication). However, geological conditions seem to be generally favorable for the occurence of ore along the contact between the porphyry and limestone or along crosscutting fissures because the shaft is situated on or just east of the pre-mineral Mike (?) fault and only 900-ft southeast of the small plug-like body of Johnson Gulch porphyry that was probably a minor center of mineralization.

Less than 2,500-ft west of the Rex shaft, and also east of the Dome fault, there are several openings in the early White porphyry. Although they are close to the contact between the great sill of early White porphyry and the underlying Leadville dolomite, these prospect pits are far from all known channels of mineralization and would produce but negligible quantities of ore.

DORIS GROUP

The two shafts and one tunnel of the Doris mine (P-114) are located in an old landslide terrain, where bedrock is not exposed. None of the workings are now accessible and local geologic conditions cannot be closely inferred. The shaft is said to be at least 400-ft deep. It is believed that much of the exploratory work was done east of the shaft, along the contact between the Leadville dolomite and the overlying early White porphyry, but some at least was in the Dyer dolomite. On the dump Leadville dolomite and a little quartzose vein matter and limonite are the principal materials; there is, however, a small quantity of specularite indicating, as at the Julia-Fisk group, a relatively high temperature of mineralization.

Mine production records of U.S. Geological Survey and Bureau of Mines, kindly compiled by C.W. Henderson of the U.S. Bureau of Mines, 1934, show that the total output of the Doris mine was about $156,000. Three prospects (No. P-113) 500-ft west of the Doris mine reveal mineralized rock similar to that in the mine.

About 600-ft north of the Doris mine are three shafts and a tunnel (P-53). The Leadville dolomite is at the surface here and exploratory work was apparently done in the upper part of the subjacent Dyer dolomite. The rocks have been altered in ways that are commonly associated with ore formation, including silicification of some beds, the development of "zebra rock" in the Leadville dolomite, and the pyritic replacement of a sandy bed, presumably that separating the Dyer and Leadville. However, no ore was found by the writer in place, or on the dumps.

About 500-ft east of the last-described group of prospects and 1,000-ft northeast of the Doris mine is a large group (O-55) of shallow pits and shafts and a short tunnel. Leadville dolomite (in part silicified and pyritized) and a little sericitized early White porphyry were encountered.

ELLA BEELER-CLEAR GRIT GROUP

Here many geologic details can only be inferred because much of the valley floor is covered by alluvial and glacial deposits, and most of the workings are no longer accessible. Much of the information assembled in the present report was obtained from reports by mining geologists to whom the workings and older reports were accessible. C.J. Moore, E.P. Chapman, G.M. Schwartz, and R.D. Longyear furnished unpublished reports and personal communications. Special thanks for data from a more recent study of the Clear Grit mine are due the E.J. Longyear Co. of Minneapolis and E.C. Congden of Duluth, Minn.

Thin beds of limestone that are essentially inclusions in the sill of early White porphyry appear above and south of the new Clear Grit shaft. Possibly these beds belong to the lower part of the Weber (?) formation or, more probably, to the uppermost part of the Leadville, dolomite, as suggested by their color, texture, and massiveness. If they belong to the upper part of the Leadville dolomite, their position in the sill of early White porphyry, opposite outcrops of basal sandstone of the Weber (?) at the Julia-Fisk shaft, suggests that the porphyry sill was in part transgressive, cutting the Leadville dolomite below its top and lifting its upper beds on the south side of Iowa Gulch, but advancing to a stratigraphically higher position between the Leadville and the basal beds of the Weber (?) north of the gulch near the Julia-Fisk workings.

The mines of this group (**Plate 15**) are the Clear Grit discovery shaft (O-50), on the western part of the Clear Grit ground, the new Clear Grit shaft and workings, the Constance shaft (O-49) and tunnel, and many other tunnels, including, Ella Beeler (O-46, O-47, O-65), Little Troubadour (O-49), Louisa (O-64), Little Julia (O-65, west), and Fortuna (O-46). The workings reached by way of the new Clear Grit and Constance shafts are loosely referred to as the Clear Grit mine. Most of the ore produced from this property in the early days was from shallow workings along the Constance tunnel, reputedly driven on the western branch of the Weston fault. Some ore was also found at greater depth in a "contact" deposit between the Leadville dolomite and a sill of early White porphyry. The chief ore minerals were pyrite and silver-bearing sphalerite. The fissure vein mined was as much as 20-ft in width and locally had a high content of lead. The "contact" body was at least 250-ft long and some assays showed as much as 3,940 ounces of silver to the ton, but the average was 12 ounces. Production of this type of ore began in 1883, but was temporarily discontinued about ten years later. The estimated value of the total output from these operations is, according to an apparently trustworthy unpublished report by C. J. Moore, $14,000 including some $12,000 for 638 short tons mined in 1883-84. This report by Mr. Moore presents sections of these earliest workings with stoping on two levels, one at a depth of 80-ft below the surface.

By 1885 the so-called Clear Grit vein, along the main Weston fault, had been discovered in work east of the Little Troubador tunnel in the northern part of the Clear Grit claim. The ore was much like that from the Constance workings. Two fissure veins were found,1 to 4-ft wide with ore shoots containing 30 to 50 ounces of silver to the ton; a third, about 6 in. wide, contained native silver, ruby silver, and enargite in ore assaying as much as 300 ounces of silver to the ton. Figures quoted by Moore show an output for 1885-89 of 84,600 short tons of ore, with a total average assay of 8.4 percent of lead, 0.06 ounce of gold, and 46.2 ounces of silver to the ton. Some doubt, however, attaches to the total tonnage figure quoted.

In 1885 work was directed chiefly still farther east, mainly to the three Ella Beeler tunnels, operating on the southward extension of the Hellena fault (plate 15). These operations are properly designated the

Ella Beeler workings. The only accounts of them available to the writer are those by C. J. Moore (**Plate 16**). Most of the ore produced came from the Hellena fault fissure itself (**Figure 96**), where masses of rhyolite agglomerate were found. George Hartmann (personal communication, 1932), reports that one ore shoot, about 100-ft long and 7-ft wide, assayed $100 per ton. Subordinate shoots were found where the fault intersected the contact between the Sawatch quartzite and the underlying pre-Cambrian granite, and fairly large bodies of oxidized ore were developed along the Hellena fault at the contact between shale of the Peerless formation and an overlying sill of early White porphyry. An incomplete record of production given by Moore is as follows:

Output of Ella Beeler workings

	Period	Zinc (percent)	Lead (percent)	Gold (ounces/ton)
Upper tunnel, Hellena vein	1889-91	10.2	21.3	0.47
Lower tunnel, Hellena vein	1903-13	11.7	14.4	.40
Contact workings	1885-90	---	---	---

	Silver (ounces/ton)	Weight (short tons)	Value
Upper tunnel, Hellena vein	31.6	138.151	$4,789.71
Lower tunnel, Hellena vein	22.9	494.366	9,852.62
Contact workings	48.1	102.167	2,307.00
Total	---	734.684	16,949.33

The New Clear Grit shaft, located west of the Ella-Beeler workings, was last operated in 1930. It penetrated a sill of early White porphyry and reached the Leadville dolomite at a depth of 398-ft. At this point an unusually vigorous flow of water (probably from one of the branches of the Weston fault, for the ground is described as having been heavily shattered) forced abandonment of the work. As in the Hellena mine, pyrite is one of the most conspicuous minerals of the ore in this group of prospects, especially in the smaller openings in the slope of Long and Derry Hill.

The Ready Cash or Two Mile High adit (O-69, west tunnel) is about 1,800-ft southeast of the new Hellena shaft and approximately 1,200-ft east-southeast of the Ella Beeler workings (plate 15). It is said (W. D. Leonard, personal communication, 1934) to have had a gross output valued at $480,000, chiefly from two small veins in the pre-Cambrian granite. These veins are reported to have strikes of N. 25º E. and N. 45° E., and to dip 50 degrees or more to the southeast, thus trending about like the Union fault; they may be related to the local monocline or, as mentioned earlier, may be regarded as the diverging branches of the Union fault where it fingers out. The ore was siliceous and galena-bearing with large amounts of gold and silver. Considerable free gold and some secondary silver chloride are reported (Emmons, 1886, p. 508). Some ore was produced from the slightly lower Big Chicago tunnel (O-70, east tunnel), the main body of the deposit occurring as a vein said to trend N. 30° W.

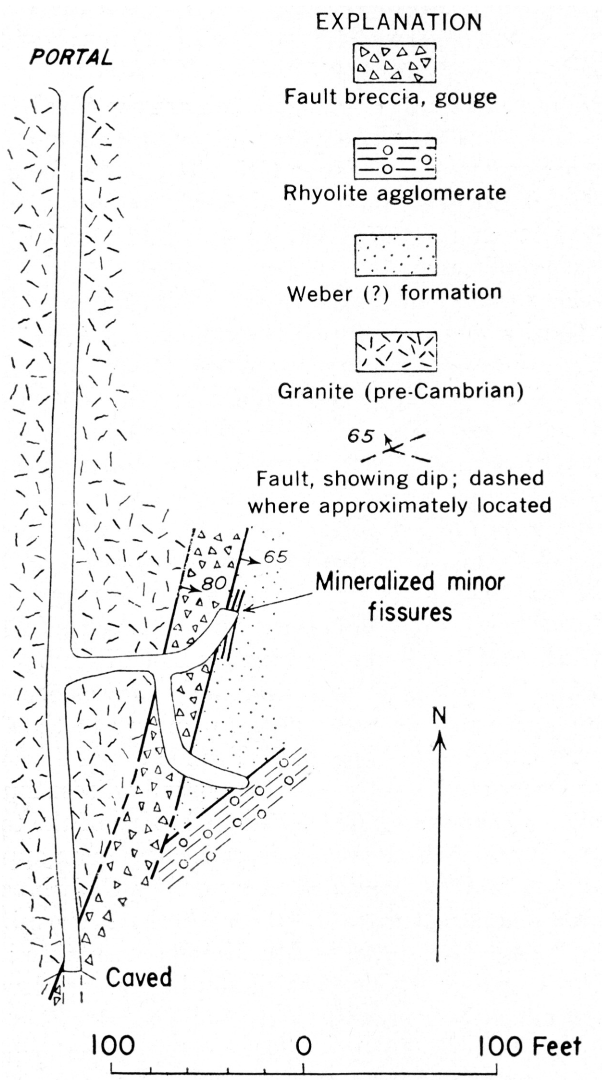


Figure 96. Geologic map of the accessible part of the Ella Beeler tunnel.

LONG AND DERRY HILL

A thick alluvial cover conceals the bedrock geology almost wholly on the lower, western slopes of Long and Derry Hill from the Musk Ox shaft (S-17) westward. Scattered outcrops and deeper workings, such as the Musk Ox shaft, give just enough evidence to indicate that there are two major faults trending about south-southeast approximately 1,500 to 3,000-ft west of the Musk Ox shaft-probably the Dome and Iron faults respectively.

Evidence of the bedrock geology west of the Musk Ox shaft is too scant to merit further discussion. Exposures to the east also are few, up to the point where the road from Iowa to Empire Gulch crosses the crest of Long and Derry Hill. Still farther east exposures are fair on both slopes of Long and Derry Hill, and tunnels and shafts furnish, abundant clues to the geology on the ridge crest where the bedrock is largely concealed by timber and soil. The geology of this part of Long and Derry Hill, east of the road from Iowa Gulch to Empire Gulch, is much like that of Iowa Gulch to the north. The beds dip gently eastward. In the columnar section presented below, the thicknesses of the sills are averages only, since they vary greatly from place to place.

Generalized columnar section of formations exposed on Lower Long and Derry Hill between Mike and Weston faults

	Thickness (feet)
Weston fault	
Sill of early White porphyry	20
Shale and grit of Weber (?) formation	120
Sill of early White porphyry	150
Shale and grit of Weber (?) formation	120
Sill of Gray porphyry group	130
Shale and grit of Weber (?) formation	120
Sill of early White porphyry	460
Leadville dolomite	260
Dyer dolomite member of Chaffee formation	40
Sill of early White porphyry (local)	50
Dyer dolomite member of Chaffee formation	30
P a r t i n g quartzite member of Chaffee formation	40
Manitou dolomite (upper part only)	80
Sill of Iowa Gulch porphyry	100±
Mike fault	

This sequence, like the similar one on the southern slope of Long and Derry Hill, is repeatedly broken by faults. The direction and amounts of these displacements vary, but the faulting has generally brought older rocks to the east against younger ones to the west. Like the faults on Printer Boy Hill, several of those on Long and Derry Hill are occupied by dikes of Johnson Gulch porphyry.

Mineralization here was scattered and nowhere intense. A few short tunnels are located on the northern slope of Long and Derry Hill but the largest openings, by far, are the Belcher tunnel (P-105), the Kenosha mine (T-6, T-7, and T-10), the Musk Ox shaft (S-17), and the prospects near the Faint Hope tunnel along the crest of lower Long and Derry Hill (T-12 to T-35). Much placering has been carried on below an altitude of 10,900-ft on the southwestern spur of Long and Derry Hill.

PROSPECTS AND MINES NEAR CREST OF LOWER LONG AND DERRY HILL

The group of prospects near the crest of Lower Long and Derry Hill consists of two shafts, each about 50-ft deep, and a long tunnel, now caved. Much iron-stained limestone, apparently from the uppermost part of the Leadville dolomite, appears on the tunnel dump; it is typical of the "contact" or "vein material" that so commonly occurs just under the sill of early White porphyry that here overlies the Leadville dolomite.

The prospects, long abandoned, are described by Emmons (1886) under the names Faint Hope (T-15), Diana (T-16), Homestake (T-23), Gildersleeve (T-34), Campbell (T-34 and T-35), Porphyry (T-22), and Himalaya (T-21); they seem to have been designed chiefly to explore the upper beds of the Leadville dolomite. In describing the Faint Hope tunnel, Emmons stated that it was connected with the Porphyry shaft, which was sunk through 46-ft of "vein material" composed of low-grade ore. Most of the mines mentioned above were operated in a single ore body or several closely spaced ore bodies. Collectively, they are commonly called the Long and Derry mines. Apparently a large part of the output was from discontinuous masses extending downward irregularly into the limestone. Parts of these bodies cropped out on the surface and were thus among the earliest ores discovered in the Leadville region. Small bodies of pyritic ore were found, but apparently the chief primary ore mineral was galena, with which were associated noteworthy quantities of cerussite and cerargyrite. The most conspicuous outcrops consisted of black rock that is now identified as silicified Leadville dolomite, thoroughly impregnated with oxides of iron and manganese (Emmons, 1886, P. 509).

BELCHER TUNNEL

The main Belcher tunnel (P-105) and the adjacent minor adits are all caved. They are driven in Leadville dolomite, just a little above the top of the Dyer dolomite, which they enter virtually along the strike of the beds, about S. 20° E. Because they are thus directed, the tunnels fail to reach the top of the Leadville dolomite. Some of the dumps, however, contain galena and a little calamine, and one shows considerable chalcopyrite. Each of the openings clearly follows a small fissure or fault, along at least two of which dikes of Johnson Gulch porphyry have been intruded.

Iron-stained, silicified Leadville dolomite of the kind here so common crops out near the portal of the Belcher tunnel. Emmons (1886, p. 229) records also the presence of an ore body in the "lower Blue limestone" which was developed by the main Belcher tunnel. From this group of prospects E.P. Chapman (Personal communication, 1936) reports the mining of several small ore bodies, chiefly by lessees; the ore assayed 30 to 150 ounces of silver to the ton and occurred in pockets along inconspicuous fissures, presumably related to the faults mentioned above.

KENOSHA MINE

Old workings of the Kenosha mine lie on each side of the Mike fault. The two prospects west of the fault are in early White porphyry. Those east of the fault consist of an old caved shaft and several pits; they penetrated Parting quartzite, Dyer dolomite, and dike rock of Johnson Gulch porphyry. Considerable iron-stained limestone came from these workings; some, nodules, selected by Emmons (1886, pp. 227,557, 602) for analysis, contained 21.10 percent insoluble matter, 7.7 percent Fe_2O_3, 65.98 percent MnO, and 0.12 percent silver. There is no evidence that the outcrop here was large.

MUSK OX MINE

The equipment of the Musk Ox mine (S-17) was extensive and included a boiler house, several cabins, and a well-timbered shaft. The shaft is no longer accessible, and nothing could be learned of earlier operations in it. Material found on the dump and evidence in nearby openings such as the two shafts of prospect S-16 reveal that the bedrock nearest the surface here is a sill of early White porphyry; below this the shaft entered the Leadville dolomite and some of the fragments found were from the Dyer dolomite (as indicated by their slightly sandy texture and their pinkish-gray, buff and yellowish colors). No ore could be found on the mine dump, and records or even rumors of ore discoveries are lacking.

The next prospects to the west (S-12 and S-13) have Leadville dolomite on the dump, suggesting that the prospects are separated from the Musk Ox shaft by a small fault, trending due north. The first large fault (the Dome fault) is about 1,200-ft west of the Musk Ox shaft. As this is a post mineral fault (Emmons, S. F., Irving, J. D., and Loughlin, G. F., 1927, pp. 92–93 and pl. 39) there is no reason to believe that the Musk Ox mine holds special promise of ore. However, it does penetrate to the horizon most favorable for mineralization, the top of the Leadville dolomite.

PLACER PROSPECTING

Minor gold placer diggings are found in the gravels and sands spread over the lower southwestern slopes of Long and Derry Hill, and there are numerous prospect pits on both sides of the northeastern head of Thompson Gulch in the terrace material that lies at altitudes below 10,850-ft. Some attempts to reach bedrock are indicated by several timbered shafts that range from 50 to 100-ft in depth. Examples are S-5 (a two-compartment, timbered shaft), S-9 (an 80-ft shaft), and S-49. A few tunnels (such as S-40) have been driven in the same terrace material, presumably in a vain search for bedrock. This extensive prospecting proves that between Iowa and Empire Gulches, at altitudes lower than 10,700-ft, the alluvial cover on pre-Tertiary bedrock is mostly more than 25-ft thick and, very probably averages 50 to 75-ft in thickness. Bedrock mining has virtually been abandoned because of this alluvial cover.

The origin of the unconsolidated deposits covering bedrock in this area has been discussed in earlier. The gravels and sand that make up these prominent terraces are due to alluviation, possibly connected with glaciation but more probably resulting, from relatively rapid uplift and the consequent deposition from overloaded streams. Therefore, the deposits are not confined to the bedrock valleys but are spread over the divides between, much as desert wash is distributed over mountain spurs by the merging of the alluvial fans of a piedmont plain. The material observed in prospects and other openings consists of poorly sorted particles of all sizes, among which boulders are conspicuous. Some of the boulders are poorly rounded but none of those found on the higher levels was observed by the writer to be either striated or faceted, except in the great valleys of Iowa and Empire Gulches, where the moraines lap against the sides of the terraces. Some terrace cuts expose sandy beds and gravel in which the boulders are embedded. In other places, as in prospects S-33 to S-35, water stands permanently though the pits are only 10-ft deep and are situated nearly 500-ft above the valley floor –an almost certain sign that a moderately continuous silt layer underlies the immediate locality.

There is no record of gold produced from any of these prospects, and the fact that none of them has been enlarged beyond the prospect size indicates their low potentialities as sources of placer gold. All the larger placers in the Leadville district are in stream valleys; the dredging operations in the valley between Half Moon and Lake Creeks at Hayden, the placering along California Gulch, and earlier placering along Colorado Gulch and in the main Arkansas Valley due west, of Leadville are typical examples. In contrast (if the above explanation of the origin of the high terraces is correct) those terraces between Iowa and Empire Gulches are composed of material transported only short distances down the adjacent slopes, partly, by short streams, partly by slope wash. The sorting necessary to build up rich placer deposits would have been relatively slight in these alluvial gravels. Furthermore, the adjacent higher bedrock, though locally containing rich gold ores, generally contained lead-zinc-silver ores characteristic of the marginal, gold-poor facies of mineralization; the hope of finding placer gravels rich in gold on the high terraces is therefore still further reduced. The most promising areas are in the valleys of Iowa and Empire Gulches, below the level of the intervening high terrace whose surface along a given meridian is generally 400 to 500-ft above the floors of the two gulches. These gulches contain deposits made by streams that have been flowing over some mineralized bedrock, and the stream sorting is confined to definite channels in which available gold may have been concentrated into small deposits rich enough for exploitation.

UPPER LONG AND DERRY HILL AND WEST SHERIDAN MOUNTAIN

About 2,000-ft west of the 12,040-ft summit of Upper Long and Derry Hill is the plexus of faults here designated the Hellena-Weston-Iowa fault complex. The Union fault breaks into several smaller fractures whose traces are seen on the north slope of Upper Long and Derry Hill. The crest of the hill is composed of Cambrian rocks and evidence of mineralization is negligible. At the east end (about 1,000-ft east of the 12,040-ft summit) the Ball Mountain fault crosses the crest faulting Manitou dolomite on the east against the Cambrian rocks; what appear to be branches of the same fault repeat the pattern with higher beds for another 1,000-ft eastward. Still farther east (2,000-ft due east of the 12,040-ft summit) the great Mosquito fault crosses the ridge, and the rocks in the east wall of the fault are upthrown 400 to 500-ft, locally bringing pre-Cambrian, rocks against a sill of early White porphyry intruded along the top of the Dyer dolomite. Between the Mosquito fault and the northern peak of West Sheridan Mountain are several smaller faults having the same relative throw as the Mosquito fault.

Aside from these faults, the geology of this area is relatively simple. The sequence is normal and the strata dip uniformly and gently eastward. Several sills of early White porphyry have invaded the Cambrian formations; they are thin west of the Ball Mountain fault but thicken in the downfaulted block between it and the Mosquito fault. The north peak of West Sheridan Mountain is capped by an early White porphyry sill; this sill lies generally above the Manitou dolomite but is slightly transgressive, so that a thin wedge of Parting quartzite lies beneath it on the southern edge of the north peak. Another sill of early White porphyry overlying the Dyer dolomite is exposed on Upper Long and Derry Hill just west of the Mosquito fault and also on the south peak of West Sheridan Mountain. Dikes of Johnson Gulch porphyry occupy faults cutting the block between the main Ball Mountain and the main Mosquito faults. Similar dikes and a prominent, somewhat transgressive, sill occur on the northwestern, northern, and northeastern slopes of the north peak of West Sheridan Mountain. Here also are two sills of Iowa Gulch porphyry, the easternmost exposures of this type of rock. A dike of later White porphyry cuts across the saddle separating West Sheridan Mountain from Mount Sheridan.

There are no large openings or mines in this area. The crest of Upper Long and Derry Hill is pitted with small openings but only a few of them or their dumps are at all promising. Of most interest in this locality are the gold deposits in the Cambrian rocks and lead-zinc-silver deposits in the limestones under the larger sills of early White porphyry. The moderately promising gold prospects include several openings in and near the Latch, Tilton, and Belcher claims, the tunnels at altitudes of 11,500 to 11,750-ft on the north slope of Upper Long and Derry Hill, and the tunnels on the eastern slope of the north peak of West Sheridan Mountain. The most promising example of the lead-zinc-silver deposits comprises the workings on the southern slope of the south peak of West Sheridan Mountain.

LATCH, TILTON, AND ADJACENT CLAIMS

Prospecting on the Latch and Tilton claims is represented by several shafts (N-142, N-143, and O-15), all abandoned long ago and now completely caved. All seem to have been in Cambrian quartzite or shale of the Peerless formation. They are said to have been worked for gold. Although they are located on or near the trace of the main Ball Mountain fault, none seems to have struck large deposits of ore, A little iron-stained rock is exposed.

On the dumps of prospects N-139 to N-141 the dominant rock is Sawatch quartzite, with some fragments from sills of early White porphyry. Here the lowest working (N-139) is a caved tunnel in the lower part of the Sawatch quartzite, in which are many minor fractures, deeply stained with manganese dioxide. About 150-ft higher and 500-ft southwest is a caved shaft (N-140), in a higher zone of deeply iron-stained Cambrian rocks. The tunnel (N-141), in the same type of rock, is no longer accessible. The history of operations on these claims is not available but it is rumored that gold ore was found in small pockets like those on the south side of East Ball Mountain.

PROSPECTS ON EASTERN SLOPE, NORTH PEAK, WEST SHERIDAN MOUNTAIN

An opening (U-13) evidently driven in search for gold in the topmost Sawatch quartzite enters the black top bed of quartzite on the eastern slope of north West Sheridan Mountain. The adit extends 40-ft, N. 70° W. from the portal and has a branching drift extending 20-ft southwest along the jointing. Like those of the two preceding groups, this prospect yielded a few pockets of high-grade gold ore from small-scale operations.

TUNNELS ON SOUTHERN SLOPE, WEST SHERIDAN MOUNTAIN

At an altitude of 12,750-ft on the southern slope of West Sheridan Mountain are two tunnels and a shallow pit (U-34) within a radius of approximately 250-ft. They are located just above or below the Parting quartzite. The minerals on their dumps are typical of all local prospects that are in this approximate stratigraphic position. They include bladed barite, which has replaced the Manitou dolomite, and a little galena, which filled fissures and to a small extent replaced the limestone. The history of these small operations is not known. They are very difficult of access and were never highly productive, but indicate that this ground is moderately favorable for ore deposition.

MOUNT SHERIDAN, CREST AND EASTERN SLOPE

The crest of Mount Sheridan is made up of a sill of early White porphyry at least 200-ft thick. Beneath this porphyry in descending stratigraphic sequence occur a dense blue-gray basal quartzite bed of the Weber (?) formation, a thin zone of black carbonaceous shale, and the sequence of beds common in the Leadville and Dyer dolomites. On the southern slope, however, a sill of early White porphyry, 150-ft thick, lies within the Dyer dolomite. On the northern slope a sill of White porphyry separates the Manitou dolomite from the Peerless formation, but this sill thins abruptly, and ends against a fault a short distance to the southwest. A third sill of early White porphyry, about 30-ft thick, occurs within the Sawatch quartzite and is exposed both on the northwest and southwest slopes of Mount Sheridan. Because of the eastward dip of the beds no rocks older than the Dyer dolomite are exposed on the floor of the Fourmile Amphitheater, just east of Mount Sheridan.

This sequence is broken by several faults. Some of those described for the southern part of the Iowa Amphitheater extend southward across the westward-trending ridge that connects Mount Sheridan with West Sheridan Mountain. Along most of these faults the west side is downthrown. One low-angle fault, striking northwest and dipping northeast, displaces the Dyer-Leadville contact on the southern slope of Mount Sheridan and suggests in strike and in flatness of dip the reverse faults associated with ore bodies on the western slope of Mount Sherman. Between Peerless Mountain and Mount Sheridan this fault is displaced locally by small normal faults. Traces of such normal faults are clearly evident along the steep eastern wall of the Empire Amphitheater.

Few of the dike-like intrusives are large bodies. One small dike and sill of later white porphyry, with good columnar jointing, cuts a sill of early White porphyry and the adjacent beds of the Dyer and Leadville on the southerly slope of Mount Sheridan, about 1,800-ft south-southeast of the summit.

The slopes of Mount Sheridan have been explored in many small prospects. Those on the northern side were described on page 69 (see Nos. U-23 and U-33). Mining and prospecting have never been extensive near the crest of the peak, partly because of the poor accessibility. Prospects on the southern slope (U-29, U-31, and U-32), and in the sag between Peerless Mountain and Mount Sheridan (U-30 and U-65) are moderately promising. These prospects are briefly described below. The Hilltop mine, less than a mile northeast of the summit of Mount Sheridan, was very productive. The area surrounding the Hilltop mine is not included in the topographic base of plate 1, but a description of the mine is given below.

PROSPECTS ON SOUTHERN SLOPE OF MOUNT SHERIDAN

Of the three prospects on the southern slope of Mount Sheridan the two northern ones (U-31, U-32) are caved tunnels and the third (U-29) is a shallow shaft. All are on or very near the contact between the Leadville dolomite and the Weber (?) formation, and all, as shown on the map, are along or near faults and have breccia on their dumps. Ore from the middle opening (U-31) is considerably copper-stained. Rock from the other two openings is discolored with limonite. Nothing is known of the history of these long abandoned openings.

PROSPECTS IN SADDLE BETWEEN MOUNT SHERIDAN AND PEERLESS MOUNTAIN

Prospects U-30 and U-65 are in the saddle between Mount Sheridan and Peerless Mountain, near the contact between the Leadville dolomite and an overlying sill of early White porphyry; they occupy positions in the hanging wall of a very gently dipping fault and just east of its trace. Fault breccia is found on the dumps and the country rock is silicified and iron-stained, but signs of ore are absent.

HILLTOP MINE

The Hilltop mine is just east of the Mosquito Range about 3,000-ft due northeast of Mount Sheridan (**Figure 97**). Though it is outside the area covered by the base map of the Leadville district, this area was visited in 1931 for five days and the surface geology carefully studied. A topographic base was prepared at the time; subsequently a topographic map on a, smaller scale was made by topographers of the U.S. Geological Survey as part of a larger project. The surface geology of this area was examined also by Q. D. Singlewald and R. D. Butler of the Geological Survey, to whom thanks are due for data and helpful suggestions.

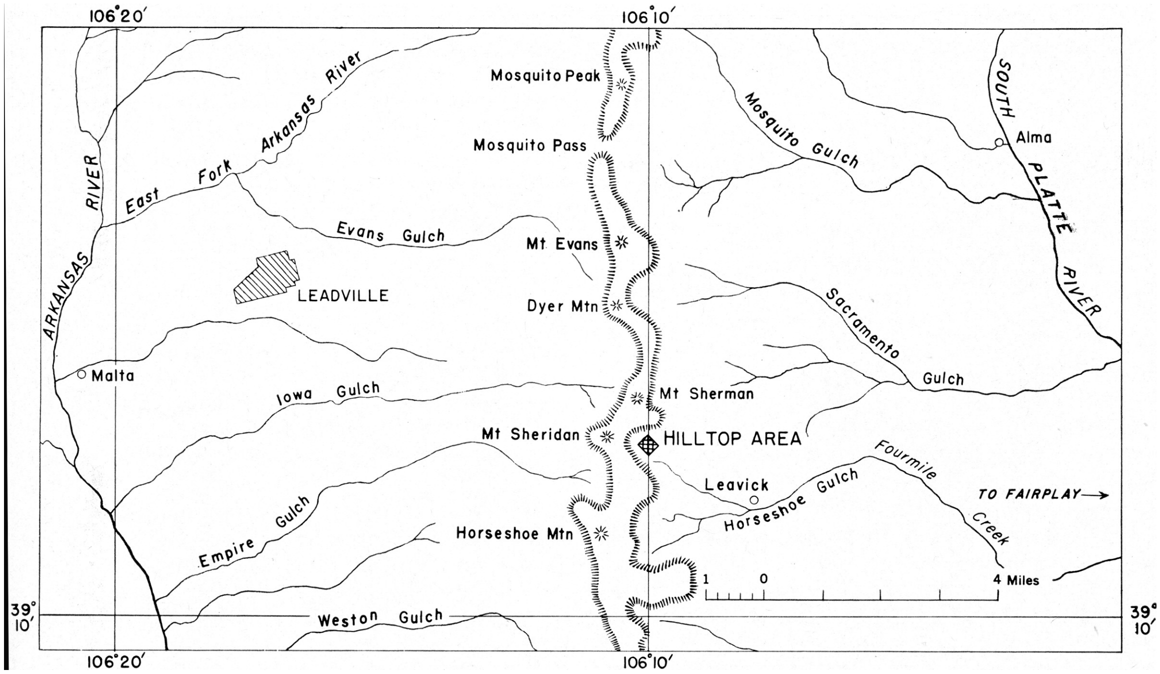


Figure 97. Location of Hilltop area in relation to Leadville and chief physiographic features.

The Hilltop mine (**Figure 98**) consists of two shafts, extensive underground workings, an open-cut, and several small openings. From the mine a trail, plainly marked but not in good repair, extends westward, crosses the Mosquito Range at Hilltop Pass, 13,150-ft above sea level, and joins the road down Iowa Gulch. A poor wagon road extends two miles eastward from the mine to the mill and cabins at the deserted camp of Leavick. From Leavick a road that can be traveled by automobile extends northeast to Fairplay. The mine is in Fourmile Amphitheater, a typical cirque. The camp is at the lower end of Fourmile Amphitheater, at its junction with a similar amphitheater. The local physiographic. features are mainly of glacial origin.

The bedrock geology is much like that along the range to the west (figure 56). The base of the Weber (?) formation is characterized by a white to blue-gray quartzite approximately 35-ft thick, well exposed about 2,400-ft south of the No. 2 Hilltop shaft. The chief ore-bearing rocks are the Leadville and Dyer dolomites, here mapped together as the "Blue" limestone of Emmons because not clearly distinguishable in the few exposures. The dominant igneous rock is a very thick sill of early White porphyry. The lower 800-ft of this sill is found here but the total thickness is 1,200-ft where exposed on the west slope of Mount Sherman. Lenses of the Weber (?) strata are included in this sill; two of these lenses are exposed on the north wall of the cirque in which the mine is located and a third, about 30-ft thick, crops out 1,000-ft east of the mine. A dike with a maximum width of 46-ft and a strike of N. 20º W., said to be composed of a member of the Gray porphyry group, was found in the northeastern end of the mine; if, as is asserted by the former mine operators, this dike dips 70º-90° W, its projection would bring it to the surface about 150-ft east of the No. 2 shaft, but the bedrock here is covered by talus and no outcrop of the dike could be found.

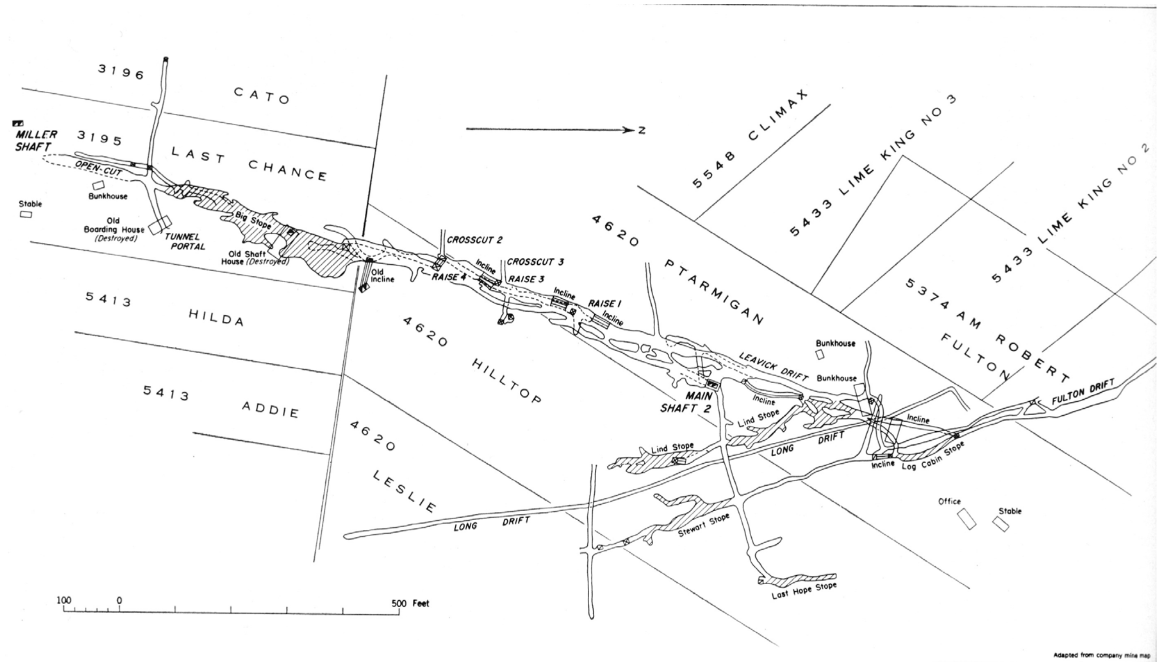


Figure 98. Map of claims and workings of the Hilltop mine.

Structurally the area is a part of the regional homocline typical of this part of the Mosquito Range. Five faults have been inferred or recognized at the surface (figure 56). The Hilltop fault is of considerable economic importance, for the workings of the Hilltop mine are along it. The fault strikes N. 21º E., and dips 70° NW, offsetting the contact between the Leadville dolomite and the Weber (?) formation in a way (figure 56) that suggests that along the northern end of the fault the upthrow is to the east, whereas at the southern end it is to the west. A more reasonable interpretation is that the movement is chiefly horizontal, the eastern side having moved relatively northward. The Hilltop fault is evidently of premineral age as the largest ore shoot in the Hilltop mine lies in or alongside it.

Two minor faults trending N. 35º W. are outlined by the Lind and Stewart drifts in the Hilltop workings and by breccia zones on the surface. The dip of the western fault is 70º SW but that of the eastern fault is not known. The shape of ore bodies developed in the Lind and Stewart stopes (figure 98) has led miners to infer the presence of a postmineral fault trending about N. 33º E., some 250-ft ESE of the No. 2 Hilltop, shaft, but the evidence at hand does not justify this interpretation.

The abrupt discontinuity of lenses of the Weber (?) formation in the northern part of the area mapped is attributed to a fault trending N. 45º W. that is believed to be continuous with one that was exposed in the Last Hope drift of the Hilltop mine. It is here called the Fulton fault because of its presence on the Fulton claim. This fault probably unites with the three faults mapped about 600-ft north of the Hilltop No. 2 shaft.

A small fault trending N. 05° W., with an apparent downthrow on the east side, is seen in the southern part of the area. Probably the chief component of movement along this fault is horizontal, the east side moving relatively southward to set Leadville dolomite in the east wall against quartzite of the Weber (?) formation in the west wall; this may account for a sharp steepening in dip of the quartzite to 55º on the west side of the fault (figure 56). Evidence has been cited of important horizontal movement parallel to the planes of several of these steeply dipping faults, as on the Hilltop fault and the small southern fault. In addition, the Lind fault is said to have been marked by horizontal striae. These strong evidences of horizontal movement are like those seen in the Continental Chief mine, about 1¼ miles north of the Hilltop mine (p. 62).

On the dumps of the Hilltop mine and in several of the neighboring prospects the ore consists of a highly leached and oxidized limestone, partly replaced by rosettes of barite and by irregular, spongy-textured areas of grayish or dull olive-green smithsonite. Locally, quartz, straw-colored siderite, and recrystallized calcite are present. Small amounts of aurichalcite, and of light-blue smithsonite, resembling the well-known specimens from Laurion, Greece, were found on the dump of the Hilltop mine.

In addition to the ores described above, considerable bodies of galena, with small quantities of pyrite and chalcopyrite, were mined, mostly in the deeper workings. The sulfide ore had a high silver content.

Oxidation evidently extended to the deepest parts of the mine. A typical ore shoot is said to be composed of a central mass of galena with very small quantities of sphalerite, bordered by a thick sheathing of smithsonite. A little gold (0.01 to 0.02 ounce to the ton) is reported in a few ore bodies. The known tenor of the ore, like that of the Continental Chief mine, averaged about 25 ounces of silver to the ton and 20 percent of lead. These figures, which probably refer to ore produced before 1901 are from a manuscript by M. F. Crosette, dated 1919. The report was made available through the courtesy of Mr. W.W. Price of Denver, Colo. In later years, the ore mined was chiefly in the form of oxidized zinc minerals, especially carbonates, which contained more than 40 percent of zinc, but included also two carloads assaying 0.06 ounce of gold and 15 ounces of silver to the ton, and 45 percent of lead (J.B. McDonald, personal communication, 1932). In general, these oxidized ores strongly resemble those described by Emmons, Irving, and Loughlin (1927, p. 240, fig. 66-C) from the central Leadville district, and also the ores of the Continental Chief and other mines nearby (p. 66). This type of mineralization is characterized in the primary ore by large proportions of galena and light-colored sphalerite and a moderate to fairly high content of silver in unknown forms, by a relatively large proportion of zinc carbonate in the oxidized ore, by small unevenly scattered quantities of gold and by the conspicuousness of barite as a gangue mineral.

The Hilltop mine is the only mine in the immediate area with a record of large output; the other openings are shallow shafts or short tunnels. The mine is no longer accessible and the following account is based on the maps still available and on descriptions furnished by former operators, especially Messrs. J.B. McDonald of Leadville and S.P. Doran of Denver. The map (figure 98) shows the principal features of the mine. The main ore body was in the Hilltop stope along the Hilltop fault. This ore body had a length of 1,450-ft, a maximum width of 70-ft, and was said to reach a maximum vertical height of 70-ft; it had a cylindrical form, the long axis of which extended northeast and inclined gently in that direction. Access was by the No. 1 shaft (70-ft deep) and by the main or No. 2 shaft (540-ft deep) the latter passed through 400-ft of early White porphyry and presumably 35-ft of quartzite at the base of the basal Weber (?) formation before reaching the Leadville dolomite. The ore shoot came to the surface up the dip, ending on the Last Chance claim in an open cut that marked the southern limit of the ore. Northward the ore body terminated where the Hilltop fault was cut by the Lind fault. In the Hilltop fault the ore extended farther northeast on the upper than on the lower levels.

The Lind and Stewart stopes were in similar ore bodies. The former was 440-ft long and had a maximum width of 40-ft; the latter yielded ore discontinuously for a distance of 840-ft and, according to report, had a width of 10 to 20-ft and a vertical height of 15 to 40-ft. Apparently the two stopes were separated by the nearly vertical dike of a member of the Gray porphyry group, which in one place was in contact with the Lind stope and was there marked by horizontal striae. An eastward cross cut from the Stewart stope developed two small ore bodies shown on the map.

The Lind and Stewart ore shoots die out southward, but no cross fault is known that could account for this fact. Perhaps it may be due to gradual weakening of the solutions as they moved southeastward, away from the main channel of circulation and away from the base of the early White porphyry sill below which the ore is commonly concentrated.

Individual ore shoots of the Hilltop mine strikingly resemble those of the Continental Chief mine (Loughlin and Behre, 1934, pp. 231–232, 242–243) they are replacements near solution channels and not great "blankets" or "contact" deposits like those in the more intensely mineralized areas nearer Leadville (Emmons, Irving, and Loughlin, 1927, pp. 117, 138). In this respect they also resemble most of the ore shoots at Alma, Colo. (Singewald and Butler, 1933, pp. 103–107), and also those at Aspen (Vanderwilt, 1935, pp. 240–241). Apparently the ponding agent at the Hilltop mine was in part the sill of early White porphyry, in part the dense basal quartzite of the Weber(?) formation. A shale, like that forming the roof of the ore in the Continental Chief mine, was exposed in the Last Hope stope, but lay above the ore and quartzite, and was separated from the latter by a sill of White porphyry.

The Hilltop claims were located about 1875, but early work, up to 1883, was confined to the outcrop of the ore body on the Last Chance claim. From there the work was carried northward, at increasing depth. The large stope at the northern end of the Last Chance claim was worked in 1892. In the deeper workings, a drift was extended still farther north, partly through the open cut work, partly through the No. 1 shaft (destroyed by fire in 1910). A few exploratory crosscuts northwest and southeast of the main Hilltop stope disclosed no ore and all work was stopped in 1913.

Fairly accurate estimates of the output of the Hilltop Mine are available for certain periods of operation. Henderson (1926, p. 194) gives the value of production for part of the early period as follows:

	Silver	Lead	Total for year
1888	$323,225	$352,000	$675,225
1889	153,858	148,960	302,818
1890	82,272	67,947	150,219
Total	559,355	568,907	1,128,262

According to the records of the U.S. Geological Survey and Bureau of Mines, the total production from the Hilltop and Last Chance claims from 1901 to 1923 was:

Tons, dry, of ore	31,682
Gold, troy ounces	1,842
Silver, troy ounces	410,438
Lead, pounds	7,842,672
Zinc, pounds	2,530,935
Copper, pounds	160,700
Total value, dollars	850,000

Approximately a quarter of this production was from the years 1920-1923; it amounted to $212,000. For less than half of the year 1910 an almost complete assemblage of settlement sheets shows a production value of $81,556 (J.M. Redman, oral communication, 1950). The latest episode in the history of production from these claims was one of open-cut operations beginning with shallow stripping on the Last Chance claim. This had yielded to January 1, 1950, eight shipments with an average assay of 6.5 troy ounces of silver, 0.02 troy ounce of gold, and lead contents of 12.0 percent, and zinc values ranging from 0.3 to 2.057 percent (Redman, J. M., oral communication, 1950). In 1952, work was resumed at the Hilltop and Last Chance properties by the owner, the Leadville Land Corp. (Redman, J. M., personal communication, 1952).

PEERLESS AND HORSESHOE MOUNTAINS

Southward from Mount Sheridan, the geologic sequence resembles that of the range crest farther north. The most striking difference is the decrease, in the number and thickness of the intrusives, toward the south. On the western slope of Horseshoe Mountain the sequence from pre-Cambrian to Leadville dolomite is well exposed, but there are no sills. Midway between Horseshoe and Peerless Mountains there is a thin sill in the Cambrian quartzite. Still farther north, on the crest of Peerless Mountain, early White porphyry forms a thick sill, and sills of the same rock become conspicuous on the slope to the west, occupying positions within Mississippian, Devonian, and Cambrian formations.

Faults in this area comprise chiefly two sorts: low-angle normal faults dipping east, and normal faults of steeper dip striking east. One low-angle reverse fault is on the eastern slope of Horseshoe Mountain. One conspicuous normal fault trace, locally mineralized, is exposed at an altitude of about 13,150-ft on the western slope of Peerless Mountain; southward in the saddle between Peerless and Horseshoe Mountains it splits into two branches. Several normal faults striking at about right angles to the crest of the range (**Figure 99**) are economically unimportant; along them the northern side is generally downthrown.

Considerable prospecting has been done on the crest and western slope of the range, and the bleached walls of a prospector's cabin, only 50-ft below the highest point of Horseshoe Mountain, are visible for miles. However, only two groups of prospect openings hold much promise. One group is on the ridge crest, approximately 2,000-ft northeast of the highest (13,903-ft) point of Horseshoe Mountain (U-69 to U-71). The other is the Peerless (or Peerless Maude) mine and the adjacent prospects.

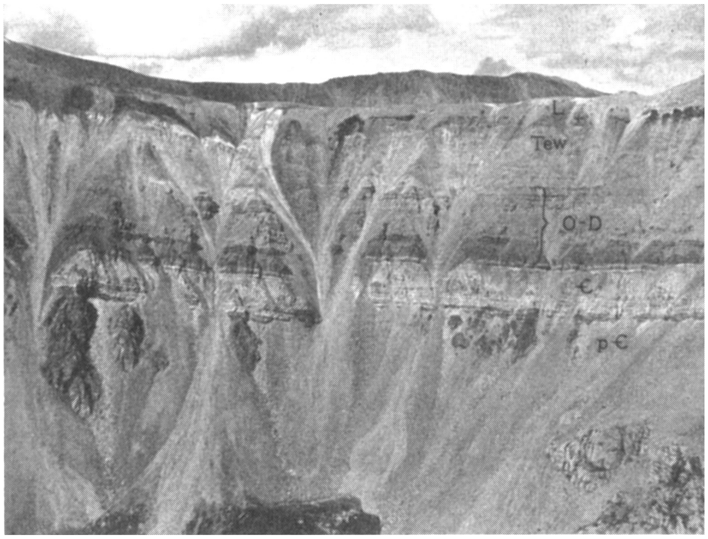


Figure 99. Normal faulting on east wall, Empire Amphitheater, especially well marked in Cambrian beds. Pre-Cambrian *(pЄ)*, Cambrian *(Є)*, Ordivician *(O-D)*, sill of early White porphyry *(Tew)*, and Leadville dolomite *(L)*.

PEERLESS (PEERLESS MAUDE) MINE AND ADJACENT PROSPECTS

The openings of the Peerless group (U-66 to U-68) consist of a short tunnel, five prospect pits, and seven shafts, all shallow. The shafts and tunnel are partly caved and partly filled with water or ice. All are in silicified Leadville dolomite or in the overlying sill of early White porphyry. The silicified limestone is considerably iron-stained and mineralized.

Detailed structural study of the prospects was impossible because they are caved or flooded and rubble conceals much of the bedrock immediately surrounding them. Most of the openings lie along and east of the eastern branch of a split normal fault (plate 1). The four northeasterly shafts in the Peerless group penetrated the sill of early White porphyry and entered the Leadville dolomite, to a depth of 75-ft in the easternmost shaft. The other openings were in Leadville dolomite near its contact with the porphyry.

Mineral deposits here, as on the western slope of Mount Sherman, seem to have been localized at the contact between the sill of early White porphyry and the Leadville dolomite; as in the Continental Chief and Hilltop mines, the ore-forming solutions probably rose along small fractures leading to this contact. The most promising ground is therefore northeast of the openings, under Peerless Mountain, where the uneroded remnant of porphyry rests on the productive limestone zone.

The ore on the dumps consists of galena and a little pyrite, in a gangue made up chiefly of bladed barite, vuggy quartz, and densely crystalline or cryptocrystalline silica. Silica and, to a lesser extent, barite have fairly extensively replaced limestone. In addition, oxidation has produced the common assemblage of much limonite, malachite and azurite, anglesite, cerussite, and a small quantity of grayish "dry-bone" (smithsonite) copper minerals are conspicuous. It has been said that the ore contains appreciable quantities of silver and gold. The chief output, however, was of lead and silver ore; a little of the ore contains as much as 50 percent of lead and 50 to 200 ounces of silver to the ton. No zinc was recovered, probably because the thorough oxidation had removed most of it. Fourteen samples collected from the dumps yielded the following assays:

Assays of samples from dumps of Peerless mine.

	Average	Minimum	Maximum
Gold, ounces per ton ------	0.015	Trace	0.04
Silver, ounces per ton -----	20. 10	0.5	55. 9
Copper, percent ----------	3. 15	Trace	18.0
Lead, percent -----------	8.6	.5	36.4
Zinc, percent ------------	3.8	Trace	25.7

[Bloomfield, A. L., Unpublished report, made available through the courtesy of W. W. Price, Colorado Springs)

Maps of the Peerless and adjacent prospects are no longer available. The deepest shaft was only 165-ft deep. From the main shaft ore was stoped north and south of the shaft, some stopes coming within 50-ft of the surface. Most of the ore shoots, according to a personal communication from Mr. John Cortellini, were elongate north and south as though along fissures parallel to the faults shown on plate 1, but other than the faults shown west of the main stopes, no fissures are evident at the surface.

Most of the work in the Peerless mine was carried on in the years 1884-91. From 1891 to 1898, the property was operated by lessees, and for this period incomplete smelter returns show a total output valued at $36,276, most of which was derived from lead and silver (W.W. Price, personal communication, 1932). Mining was simple and inexpensive, because the frozen ground required little support, but living conditions were not good, especially at so high an altitude, and this seems to have been a major difficulty in maintaining operations. Recently it has been suggested that this difficulty might be overcome by establishing a modern camp at an altitude of about 12,000-ft in Empire Amphitheater, and driving a tunnel eastward at an altitude of 12,200-ft. The tunnel length necessary would be about 2,000-ft. This plan involves raising in steps a total of 1,200-ft; transportation could be down Empire Gulch by road or by aerial tramway to the Denver & Rio Grande Western Railroad on the eastern side of the range. Such a plan presumably would be contingent on the proving of adequate ore reserves.

PROSPECTS ON NORTHERN SLOPE OF HORSESHOE MOUNTAIN

A group of prospects (U-69 to U-71) is situated on the northern slope of Horseshoe Mountain. The southern ones (U-71) comprise a caved and ice-filled adit and a shaft estimated to be 40-ft deep. The adit is driven in Leadville dolomite containing typical black chert lenses. The beds dip 18° NE, and are irregularly folded and shattered but not visibly faulted. Ore deposition occurred after all clearly recognizable deformation rock on the dump contains ore that has replaced limestone and filled fissures in it; the limestone is partly silicified and partly recrystallized to "zebra" rock. The primary ore minerals are galena, a little sphalerite, quartz, and barite. Oxidation has produced much aurichalcite, malachite, azurite, cerussite, calamine (in vugs), and a little smithsonite.

Prospect U-70 consists of a shallow shaft and a 40-ft tunnel. They are on opposite sides of a branch of the fault trace observed at an altitude of 13,150-ft (p. 71). Shattered and somewhat folded rocks are exposed, but they are not visibly fissured and are only slightly mineralized. Prospect U-69 is a group of shallow pits in silicified Leadville limestone between the southern branches of the same fault. A small amount of malachite is the only evidence of mineralization.

As far as can be determined, mineralization at each of these prospects was related either to low-angle faults like those on the western slope of Mount Sherman, as in the case of U-69 and U-70, or to bedding-plane faults of similar origin.

EMPIRE AMPHITHEATER AND FINNBACK KNOB

Finnback Knob, the 13,405-ft peak, is the center of an area in which a few porphyry dikes are the only country rocks younger than the pre-Cambrian (plate 1).

Throughout the area the geology is relatively simple insofar as it has an economic bearing. Granite predominates; most of it is Silver Plume (?), but some is Pikes Peak (?) granite. The largest exposures of

Pikes Peak (?) granite form a triangular area whose base is north of Empire Gulch and whose center is about 5,000-ft northwest of Finnback Knob. There are also small areas of schist that are xenoliths in the granite; prominent examples are on the cliffs of the northern slope of Finnback Knob. Two lamprophyric dikes, believed to be of pre-Cambrian age, crop out in the head of Empire Amphitheater, 1,000-ft east of Finnback Knob. Pegmatite dikes are common in the granites.

Two long dikes of later white porphyry are exposed on the western slope, and one on the eastern slope of Finnback Knob. They are probably continuous, and though in places talus covers them each has a length in excess of 4,000-ft. They trend northeastward, generally parallel to most of the smaller, postmineral faults of this immediate area. The easternmost of these dikes is exposed on the floor of Empire Amphitheater near Finnback mine, and is connected with an irregularly elliptical ring of dark-gray igneous rock, about 500-ft long and 100-ft wide, that has been intruded into the Silver Plume (?) granite. The rock of this ring has a stony ground mass, conspicuous flow lines, and scattered plagioclase phenocrysts. It may represent the central facies of a plug-like mass of later white porphyry. Although the more central part of the plug is darker than normal later white porphyry, its margin is typical of that rock, and gradation between the two varieties clearly shows that both are facies of later white porphyry.

The predominant north-northeasterly faults are inconspicuous in the rather uniform pre-Cambrian rocks. Erosion along these faults appears to be the cause of some of the narrow ravines on the northwestern slope of Finnback Knob. Some faults are recognized by the lines of breccia or zones of exceptionally prevalent iron-staining. Dikes of later white porphyry occupy several faults.

There is no record of production from any prospect in this area. Several pits have been dug along the later white porphyry dikes (for example, U-74 to U-76), and others along typical pegmatite veins and thin veinlets of pegmatitic quartz.

The old Finnback tunnel (U-61) that extends S. 80 W. into the hillside is caved about 50-ft from the portal. Nothing is known of its history. It was driven in granite, biotite schist, and later white porphyry. Neither the tunnel wall nor the dump materials are mineralized.

Several shallow pits (U-56 and U-81) are in pre-Cambrian rocks along a subsidiary fault about 300-ft east of the Mosquito-Weston fault zone and 4,500-ft west-southwest of Finnback Knob. The only ore mineral found was malachite, although the fault fissure is filled with quartz and the adjacent granite is silicified. These openings are not promising, but they do indicate that some mineralization has taken place along the fault zone in this vicinity.

EMPIRE HILL

The body of pre-Cambrian rocks forming Finnback Knob and its western slope is terminated on the west by the Mosquito-Weston fault zone, which crosses the ridge between Finnback Knob and the crest of Empire Hill. For some distance west of this fault zone the surface rock is Weber (?) formation; northward it is early White porphyry, Leadville dolomite, or in the bottom of Empire Gulch, still older formations. On Empire Hill the Mosquito-Weston fault zone is itself largely bounded by two faults between which other branches appear, uniting and diverging irregularly. Parallel to the zone but outside it are minor faults, notably on the hanging wall side. Due east of the crest of Empire Hill, the Leadville dolomite, Parting quartzite, and slivers of the Manitou dolomite lie between the two bounding faults.

West of the summit of Empire Hill the eastward dip of the beds and the decrease in altitude bring to the surface rocks stratigraphically below the Weber (?) formation (section D—D', pl. 2). pre-Cambrian Silver Plume(?) granite crops out at an altitude of approximately 11,650-ft and below, but the top of the pre-Cambrian ranges considerably in altitude; Rocky Point (altitude 12,078-ft), near the south edge of the area, is made up of granite.

Many faults introduce minor irregularities into the orderly succession of rocks below the outcrops of Weber (?) strata on Empire Hill. Although a few faults are oblique to the strike or parallel to the bedding, most of them are essentially at right angles to the strike and offset the beds, resulting in an irregular outcrop pattern.

Despite the many small prospects on Empire Hill, the effective mining has been slight. Prospect pits, shallow shafts, and short adits are especially numerous on the western slope of Empire Hill between the 12,000-ft contour and the top of the pre-Cambrian rocks. Almost all of these openings are near transverse faults but are situated stratigraphically below the, contact of the Leadville dolomite and the overlying sill of early White porphyry, or the thin band of Weber (?) strata which in most places separates these two. It is noteworthy that no northward trending faults, with which most ore bodies in the marginal Leadville district are associated, have been recognized in this area. Prospects that merit brief descriptions are treated in the following paragraphs.

PROSPECTS ALONG MOSQUITO-WESTON FAULT ZONE

The northern group of prospects (U-47 to U-53) along the Mosquito-Weston fault zone, whether in the Weber (?) formation west of the fault or dolomite, within the fault zone, are for the most part in shattered country rock. The dolomite is silicified or recrystallized; some quartz has been deposited in veinlets, but no ore minerals.

Near the southern group of prospects (U-78 to U-84) mineralization was more intense than farther north. The northernmost pit of the U-84 group and the tunnel of the U-83 group is in closely sheared granite slightly stained by malachite. Farther south the prospects of the U-82 group are in sheared Leadville dolomite and sheared, greatly silicified pre-Cambrian granite. Similar shearing and alterations are seen in the hanging wall of pre-Cambrian rock all along the fault zone, but the block of Leadville dolomite exposed between the eastern and western faults of the zone is not strongly mineralized, despite extensive bedding-plane faulting and shattering of the beds, accompanied by dragging along the fault so severe that the shale beds of the Weber (?) formation west of the zone are overturned and dip 75° E.

It is striking that in this locality the hanging wall of granite is more mineralized than the dolomite within the fault zone. This difference is similar to that in other mining districts where shattering and mineralization have been generally more effective in the hanging walls of great. reverse faults, than in the footwalls, partly because the hanging walls have undergone less vertical compression and partly because the "chattering" nature of fault movements has produced more fracturing and communition.

PROSPECTS SOUTH AND SOUTHWEST OF EMPIRE RESERVOIR

Search for ore in prospects south and southwest of Empire Reservoir has been intense, but has revealed too little mineralization to encourage further exploration. This group of prospects includes one shaft (T-232) estimated to be at least 200-ft deep. Material on the dump shows that the shaft was sunk through grit and shale of the Weber (?) formation, the sill of early White porphyry, and the thin black basal shale bed of the Weber (?) before entering the topmost Leadville dolomite. The eastern of the two shafts in group T-231 is 30-ft deep. Its dump contains altered, pyritized early White porphyry. The two T-231 shafts are located along a fault.

PROSPECTS ON THE NORTHERN SPUR OF EMPIRE HILL

Prospects T-150 on the northern spur of Empire Hill, 4,500-ft north-northwest of the summit are in the upper part of the Leadville dolomite, stratigraphically about 60-ft below the base of a thin black shale bed of the Weber (?) formation. A sill of early White porphyry overlies the Leadville dolomite. The beds generally strike N. 20° E. and dip 20° SE. The two largest openings here are a shaft and tunnel, both caved. In the tunnel, a fissure that strikes N. 75° E. and dips 75° NW is associated with limonite stains and with tiny vugs coated with a little malachite.

A more promising prospect is the tunnel, beyond the first 40 ft, on the Eclipse claim (T-151). The beds have the same attitude as at prospects T-150; however, no fissuring is visible on the surface or in the accessible part of the tunnel. The prospect has a loading chute, and a large dump contains rock considerably stained by iron and manganese oxides and by copper carbonate. The mine is said (J.W.

Mitchell, personal communication, 1930) to have yielded sacking ore containing as much as 45 ounces of silver to the ton; nothing more is known of its history.

Several prospects (T-163) about 600-ft northeast of the Eclipse tunnel have revealed mineral-bearing rock of the type just described but only slightly mineralized.

The dump of a caved tunnel (T-152) 2,000-ft northwest of the Empire Reservoir contains barite and calcite. About 200-ft to the north is another largely caved tunnel-the northern of two marked T-152. The cement between the sand grains of the Cambrian quartzite is extensively oxidized. Cubical casts in the cementing material indicate replacement of the quartzite by pyrite but the mineralized ground is not extensive and shows nothing of value.

HEAD OF UNION GULCH

The Union fault extends southwestward from Empire Gulch toward the head of Union Gulch, from which it derives its name. Southeast of it lies pre-Cambrian granite. The rocks along the northwest side of the fault range from the Weber (?) formation to the pre-Cambrian granite, the latter appearing northwest of the fault at the southern border of the area mapped. Rocks bordering the fault to the northwest include also a sill of early White porphyry in the Weber (?) formation, sills of Iowa Gulch porphyry in the Dyer and Manitou dolomites, and several dikes of Johnson Gulch porphyry.

There are several eastward-trending faults that, with the Union fault, break the rocks into a series of highly irregular blocks. These faults have the dropped side to the south at some places, but elsewhere to the north. Commonly, the dips of the fault planes cannot be measured but they are steep wherever discernible. These faults are most conspicuous in an area whose center is about 3,500-ft south-southeast of Mitchell Ranch and an equal distance north-northeast of the junction between the northern forks of Union Gulch. Here the geology is especially complicated because the faults cross the axis of a sharp syncline almost at right angles.

The most striking structural details are the reverse faults, and they are also closely connected with mineralization. Some reverse faults almost parallel the bedding and cannot be traced with sufficient accuracy to warrant representation on plate 1. Two small reverse faults that cut the Leadville dolomite, strike almost due north, and dip east at low angles; they are exposed about 4,500-ft south of the Mitchell Ranch near prospects T-209 and T-210. Two greater faults lie farther east and are most clearly exposed about 4,000-ft east-southeast of the Mitchell Ranch. These last two faults may be normal or reverse, and the western of the two may be the Mike fault (plate 1). No ore was seen along the traces of these two larger faults, though silicified and iron-stained rock is conspicuous in the outcrops. The two small reverse faults are not only similarly silicified but both seem to have been the sites of ore deposition.

PROSPECTS NEAR HEAD OF GULCH

Only two groups of prospects merit description, and both are within a mile of the Mitchell Ranch. The openings at prospect T-219 consist of a short, partly caved tunnel, two shallow prospect pits, and two shallow caved shafts. All the workings are in the middle to upper part of the Leadville dolomite; the rocks are much shattered and conspicuously silicified, but no ore is exposed. Despite its relative inaccessibility, this area merits careful prospecting to shallow depths because the silicification of the rocks is indicative of movement of mineralizing solutions, and the shattered ground may have provided a favorable site for ore deposition.

Prospects T-209, T-272, and T-273 are all in the Leadville dolomite or upper part of the Dyer dolomite, near the southern end of one of the two small reverse faults mentioned above. At T-209 bedding-plane faults with conspicuous slickensides are exposed, and the rocks adjacent to the planes of movement are considerably silicified and iron-stained. Farther south, at T-272 and T-273 where the same conditions prevail, some galena is present.

The openings include a 50-ft vertical shaft, an incline and a vertical shaft southwest of the first, and a caved shaft between. Grouped around these shafts are several shallow prospect pits. The rocks near the northernmost shaft are shattered, silicified, and iron-stained. Specimens on the dump contain disseminated galena and a little sphalerite; considerable cerussite and anglesite have formed around the galena. The absence of barite is striking in an ore of this kind. The mineral assemblage and structural relations are much like those at Weston Pass, 10 miles south of Leadville (Behre, 1932, pp. 61–71).

The incline at the southern end of this group descends N. 85 E. at an angle of about 35º but is caved at slight depth. The vertical shaft at its mouth is also inaccessible. Both openings are in the Leadville dolomite but, because of the eastward dip of the beds, the vertical shaft doubtless penetrated the Dyer dolomite at shallow depth, whereas the entire incline, essentially parallel to the bedding, probably was dug in the Leadville dolomite. A little of the ore on the dump consists of cubes of galena, which was disseminated largely along certain thin beds that seem to have been more permeable or more soluble than the others. Each galena mass is surrounded by a halo of anglesite and cerussite. As in ore from the shaft to the north, sphalerite is rare and barite is absent. The rock is crisscrossed by calcite veinlets and has been extensively leached during oxidation.

These striking effects of mineralization are little known. The area is far from any settlement, and the only road near these prospects is very poor. The minor reverse faults are of special interest because elsewhere in the Leadville district such faults are closely related to ore deposition.

EMPIRE GULCH

A line from West Sheridan Mountain to Finnback Knob makes a convenient boundary between Empire Amphitheater and Empire Gulch. The geology of the area east of the Mosquito-Weston fault complex was described in the section on the Empire Amphitheater.

The rocks in Empire Gulch east of the faults are almost wholly pre-Cambrian granites. The Mosquito-Weston fault extends northward from Empire Hill into Empire Gulch where it joins the Union fault. The fault complex farther north on Upper Long and Derry Hill has four recognizable parts which are, from west to east: the Weston, Hellena, Ball Mountain, and Mosquito faults. Because the fault complex is in Empire Gulch where the faults are not exposed in mine workings and are deeply covered by glacial material, relationships of these faults are not known in detail. It is clear from study of the area north of Empire Gulch that all the faults except the Ball Mountain fault are of one type: they dip eastward rather steeply, they are upthrown on the eastern side, and for most of their courses the beds have been dragged upward to a steep westward dip at the footwall.

The beds in Empire Gulch west of the fault complex are in normal succession as far west as the Union fault, which crosses Empire Gulch approximately 2,500-ft southwest of the 12,040-ft summit of Upper Long and Derry Hill. The Union fault, which trends northeast, is upthrown on the southeastern side and has pre-Cambrian rocks on the east against the sill of early White porphyry, which here is separated from the Leadville dolomite by as much as 75-ft of quartzite and shale of the Weber (?) formation. Downstream to a point one-half mile due east of the Mitchell Ranch, the succession is normal. Still farther downstream other faults are encountered, as shown on the geologic map (plate 1), but the bedrock is not close enough to the surface to excite interest in mining.

Few mines or prospects in the bottom of Empire Gulch and on the slope overlooking it merit detailed description. Openings in the valley itself are numerous but the depth through the glacial deposits to bedrock has been an obstacle to exploration. Furthermore, the rocks prospected on the valley flanks. are but scantily mineralized. For example, the closely clustered prospects about 5,000-ft southwest of the Mitchell Ranch, several of which are on or near the Union fault, have no ore exposed on the tunnel walls or on the dumps, and the inference seems justified that the Union fault is of postmineral age. A single prospect pit or caved tunnel (the north pit of T-77) has exposed a small quantity of bladed barite that has replaced Leadville dolomite.

The lower slopes of Upper Long and Derry Hill, facing toward Empire Gulch, are not mineralized to any noteworthy extent. Geological considerations might lead to expectation of ore along the trace of the

Mosquito-Weston fault zone where it traverses the south slope of Upper Long and Derry Hill, but rocks in the prospects examined there (T-60 to T-66 and U-5, U-40, and U-41) are not mineralized.

A large dump (T-29) and several small openings high up on the slope of Long and Derry Hill at an altitude of 11,350-ft are in altered early White porphyry, the sill that so generally rests directly upon the Leadville dolomite or is separated from it by a few feet of quartzite or black shale of the Weber (?) formation. The dump indicates an operation of considerable size. Its partly filled ore bin contains a gossan, consisting of highly ferruginous and manganiferous cement around blocks of iron-stained, altered limestone(?). No other mineralogical information is available but presumably, like the other prospects on Lower Long and Derry Hill to the west and north, this pit yielded an oxidized lead ore, rich in silver.

PLACER PROSPECTS IN UNION AND EMPIRE GULCHES

Union and Empire Gulches below an altitude of 10,500-ft are almost entirely covered by glacial moraines or outwash. Presumably the country rock is all of pre-Cambrian age and mostly if not all granite. There is no evidence of mineralization, and no known placer gravel. The unconsolidated deposits no doubt resemble those that cover the slopes of Lower Long and Derry Hill west of the 10,750-ft contour (p. 84). Placer gravel may exist in the wide valley bottoms of Iowa, Thompson, and Empire Gulches, between the bordering terraces but there has been no careful placer prospecting in these areas.

Mines of the Central Leadville District

During the course of the study of the marginal part of the greater Leadville region, some time was devoted to underground studies in certain properties in the central part of the Leadville district, partly to clarify various features of the geology that might have been revealed since the publication of Professional Paper 148, partly to aid in the development of these or adjoining mines. The results of these studies, which include items of considerable economic importance, are briefly recorded below. No changes have been necessary in the geologic mapping of the central area, as shown in plate 13 of Professional Paper 148, except in the neighborhood of the Eclipse and Nevada mines (M-36 and, M-24) on the northwestern slope of Ball Mountain.

DESCRIPTIONS

NEVADA TUNNEL

With the assistance of the late Paul Schmidt of Leadville, the writer studied the geology of the Nevada tunnel (M-24). The structure is highly complicated. The rocks seen in the workings comprise rhyolite agglomerate, early White porphyry, a member of the Gray porphyry group resembling the Johnson Gulch porphyry, both members of the Sawatch quartzite, and pre-Cambrian granite. For data beyond the caved areas (figure 58) reliance was placed on information furnished by Mr. Schmidt. The two eastward crosscuts have intersected and partly exposed two major faults striking north-northeast; the western of these two faults apparently splits and appears as two faults in the southern crosscut. The three faults thus recognized are correlated with the Silent Friend fault as described in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 82–83). Apparently a block of early White porphyry has dropped between the eastern and western faults of this group. East of this block is pre-Cambrian granite and west of it are a member of the Gray porphyry group, the Peerless formation, rhyolite agglomerate and irregular sills of early White porphyry. The two north-northeastward trending faults might be interpreted as branches of the Ball Mountain fault, but their displacement would seem to be less than the 2,000-ft typical of the Ball Mountain fault in this area (Emmons, Irving, and Loughlin, 1927, p. 76).

Crossing the workings in a west-northwest direction are several offset faults that may represent the Colorado Prince fault. The Colorado Prince is a reverse fault with the northeastern side upthrown (Emmons, Irving, and Loughlin, 1927, p. 75) it should be offset by the faults striking north-northeast, but the relations are nowhere exposed. The position of the reverse fault in the main tunnel is indicated by an ill-defined shattered zone; between the two branches of the Silent Friend fault its position can only be inferred.

Studies in the Nevada tunnel do not reveal the position of the Ball Mountain fault. According to plate 13 of Professional Paper 148, it must lie a short distance southwest of the southernmost point of the main Nevada tunnel.

In addition to these two major fault systems, there are several minor, practically vertical, faults striking approximately due north. Most of the main tunnel is driven so as to develop faults of this system. These faults, in contrast to the Silent Friend fault, are either offset by or end against the Colorado Prince fault (figure 58). One such fault, mineralized and well exposed in the main tunnel north of the Colorado Prince fault, seems to have an exact counterpart, interpretable as its offset segment, exposed in the main tunnel south of the Colorado Prince fault. The other north-south faults are believed to be tensional and compensating fractures that developed simultaneously with the compressional movement of the Colorado Prince fault, or immediately afterwards.

Of special interest are conspicuous bodies of rhyolite agglomerate associated with several of the northward trending faults, and also along the westernmost branch of the Silent Friend fault (Emmons, Irving, and Loughlin, 1927, p. 82, pl. 13).

Ore is exposed along the north-south faults in two small stopes along the main tunnel, 30 and 85-ft south of the point where the northern crosscut turns east off the main tunnel. In the northern stope the ore is an oxidized, iron-stained, low-grade zinc carbonate, and lies along one of the lesser north-south fissures. The southern occurrence lies in a finely comminuted gouge and consists of disseminated pyrite that is unusually free from oxidation. This shoot lies in the footwall of another north-south fault, almost parallel to the tunnel. Locally, the ore here yields a little gold on careful panning.

At the eastern end in the face of the southernmost east crosscut, is a gouge zone, here as much as 15-ft wide and made up of decayed granite, heavily limonitized. This zone is believed to be in the east branch of the Silent Friend fault. Gold, silver, and a little lead have been recovered from it. Through the kindness of Mr. Paul Schmidt, in 1928, samples from the early White porphyry of the hanging wall were assayed and found to contain 3 to 4 percent lead. Samples from the footwall commonly contain as much as 2 or 3 ounces of gold to the ton but the metal is finely divided and difficult to extract. Between the footwall and hanging wall, two parallel zones of shattered granite contain patches of very high grade gold ore in which gold is locally visible. Iron stains in the gouge suggest that it has been enriched by oxidation. However, it is reported that there was much less gold farther north where the fault is intersected by the northern crosscut.

The ore found in the eastern branch of the Silent Friend fault and in the subparallel lesser faults suggest that here the north-south faults are premineral and that they should be explored. An especially favorable direction for prospecting would be southward along the east branch of the Silent Friend fault.

VENIR MINE

The shaft of the Venir, or South Ibex, mine is on the western slope of Ball Mountain, near the crest of Breece Hill. The shaft (L-59) is about 400-ft, S. 50° E. from the Antioch quarry, 2,850-ft, S. 25 W. from the Ibex No. 2 shaft, and 21,300-ft, N. 15° W. from the portal of the Garibaldi tunnel.

The collar of the shaft, which is the only working connection with the surface, is at an altitude of 11,697-ft. Four levels and several intervening stopes have been developed (see table below, **and plates 17, 18**).

Levels of the Venir mine (1935)

Level	Altitude at shaft (feet)	Approximate length of tunnel(feet)
First --------------------------	11,560.3	3,180
Second ---------------------	11, 502. 0	11,740
Third (or intermediate) ----------	11,460.0	430
Fourth -----------------------	11,410.0	6,210

Grit of the Weber (?) formation and a member of the Gray porphyry group appear on the surface (Emmons, Irving, and Loughlin, 1927, pl. 13). Underground, most of the work was done in rock that is clearly a member of the Gray porphyry group, but the rock has been sericitized and silicified so that it cannot be identified with any member of that group; however, its relations to the areas north and south, where alteration is less intense, indicate it to be Johnson Gulch porphyry. On the fourth level (plate 18), the country rock in the long northeast drift is in a porphyry less conspicuously altered than elsewhere, but even here more exact identification is impossible. On the first level a small amount of much-altered shale of the Weber (?) formation appears in the roof about 360-ft northeast of the shaft; similar inclusions appear in the southeastern workings of the fourth level. A sample from the third level, apparently identical with altered, silicified rock of the Gray porphyry group, proved on very detailed microscopic examination to be a greatly sericitized grit of the Weber (?) formation. This extreme effect of alteration means that even careful microscopic study of specimens from other parts of the mine does not exclude the possibility that a part of the rock exposed is a silicified and partly sericitized early White porphyry This uncertainty is increased by the strong bleaching that has affected the country rocks.

The Venir mine is just east of the Weston fault and southwest of the South Ibex stockwork (Emmons, Irving, and Loughlin, 1927, pp. 301–302, pl. 13). It lies west of the Garbutt and No. 4 Ibex fissure lodes, two subparallel veins which here strike about N. 15˚ E. The workings reveal a series of fractures approximately parallel to the No. 4 Ibex and the Garbutt veins. The fissures in the Venir workings generally trend about due north in the extreme southern and southwestern parts of the mine but curve to northeast in the northern parts of the workings. The greatest fissures trend northeast. A mere azimuth plotting of the fractures would not be significant, as it would not indicate the changes in direction of single fissures, nor could it show the strong contrast in direction between the major and the minor fissures. A study of the mine maps (plates 17, 18), and especially of the very extensive fourth level, is most instructive. The veins in the Garbutt and Negro Infant workings in and south of the South Ibex stockwork behave very similarly (Prof. Paper 148, pl. 57).

On the first level (plate 17) two important vein systems were exploited-one at the shaft station and one about 250-ft east of the shaft. In addition, a small and relatively unproductive simple fissure (the "Little vein") was found 45-ft west of the shaft in the southwest workings. The West vein system trends N. 5°-10° E. near the shaft, but at its northernmost end the strike is N. 25°-30° E.; generally it dips 60°-90° NW, averaging about 75°. About 280 ft north of the shaft the vein is broken by a transverse fault, north of which it is shifted about 20 ft to the west. There is considerable branching and reuniting of several subparallel fractures, causing difficulty in development work. The stopes follow the vein up the dip to the southeast, in places reaching the surface.

The East vein or system maintains a more northerly course, and virtually unites with the West system where the two connect with those of the Negro Infant mine. The separate branches of the East vein dip mostly westward; locally they are broken by small transverse faults.

Both veins have conspicuous local shear zones, such as those that lie parallel to the East vein in the south-eastern part of the workings on this level. Further, in several places smaller fissures enter the main fissures at acute angles. Examples are clearly visible along the western wall of the East vein, near the 40-ft raise shown on the map, and also at the three strong fissures, each somewhat mineralized, exposed in the main crosscut. A breccia zone is developed where the two principal veins converge in the northeastern part of the workings. Breccia, is characteristic of such junctions, as demonstrated by the South Ibex stockwork where the No. 4 Ibex vein and the Garbutt vein approach each other most closely.

Most of the fissures are faced with gouge and are filled with clay and limonite, indicating the former presence of pyrite, now oxidized. Where cleaned by mining, the walls show steeply. dipping or vertical striae, which strongly suggest that the movements were not prominently or generally horizontal, as they were farther south in mines of the marginal parts of the Leadville district. (See, for comparison, the Continental Chief and Hilltop mines, pp. 62–67 and 88–92.)

Mineralization produced chiefly fissure fillings of quartz and of pyrite and silicification of the country rock near the vein. Such veins are narrow, averaging 2 inches in width and very rarely exceeding a foot; they are frequently so rich in gold that the ore mined from them is sacked. Much of the ore mined ranged in value from $2 to $41 per ton at a time when the base price of gold was at $20.67 per ounce. The minable rock usually extended no more than six inches into the wall. Some mineralized material along the shear zones formed stockworks, in which the veinlets were so closely spaced that the country rock containing them was mined. Locally the pyrite is slightly cupriferous, and the enclosing rock is stained by malachite; this is especially true along the East vein, notably at the southeastern end of the east drift, where some fracture surfaces are coated with thin films of sooty chalcocite.

As a consequence of the narrowness of the veins and of their steep dips, the stoping typically yields very narrow, steeply inclined openings, just wide enough to be worked by one man, who uses planking as a floor. Such ore bodies may be more than 100 ft high, yet less than a foot wide, though the stope is generally widened somewhat beyond that amount to provide working space.

The lower levels are essentially like the first, except that oxidation is less conspicuous on the second level (plate 17) only the Little vein and the West vein have been developed. Actually, the West "vein" near the shaft consists of three fissures trending north-northeast. The two marginal fissures are not over 30-ft apart. All the fissures are mineralized, and all end at the south against a northwestward-trending mineralized fissure that is the southernmost feature exposed along the West vein. West of the shaft are at least two fissures trending generally northward and developed by drifts. Of them, the westernmost resembles and corresponds to the Little vein of the first level. On this and the next lower level, the vein was very rich, some assays showing as high as 7 ounces of gold per ton.

The third (also called "Intermediate") level (plate 17) is the least extensive. Here also the West vein system was explored and the several westward-dipping branches were stoped. In a westward crosscut located about 150 ft south of the shaft the Little vein was intersected and some stoping followed it, but the ore here was not rich. On the other hand, the eastern branch of the West vein was intersected about 25 ft east of the shaft and contained very rich ore, some assays of oxidized ore indicating as much as 9 ounces of gold to the ton. This rich ore was in a small fissure striking northwest and intersecting the main eastern branch of the West vein at an angle of 40°. The eastern branch itself contained some pockets of unoxidized ore assaying 1 ounce of gold and 9 ounces of silver to the ton. Along what is probably the northward continuation of the Little vein (as developed in the large stope trending north-northeast and situated west of the shaft), assays showed ore that ranged in tenor from traces to 7 ounces of gold per ton; one small shipment yielded 15 ounces to the ton. These richer ores were all highly oxidized. Oxidation and high gold contents like those just cited were most pronounced in the area south of the shaft where, because of confluence of fissures, the ground was more open and shattered. North of the shaft the gold content on this level, as on the others, declined markedly.

On the fourth level (plate 18) a long crosscut from the shaft trends east-southeast, intersecting one well-defined vein which strikes about due north and along which there has been some stoping. In the neighborhood of the shaft a series of north-northeasterly fissures, the equivalent of the West vein of higher levels, is conspicuous. Several veins of this series were mined profitably. The Little vein seems to be represented by two shear zones about 50 ft west of the shaft and 15 ft apart that contain some pyrite, but too little gold to justify stoping. The main West fissure extends northward, curving eastward as on higher levels. The drift developing this fissure unites to the northeast with another drift, now caved and inaccessible, which apparently developed the East fissure; therefore the two fissures are inferred to join northward, much as on the first level. On the long east crosscut in the southeastern workings of the fourth level, the southern part of the East fissure was also developed and here actually trended northwest, the strike swinging to a due north course about 200 ft north of the latitude of the main Venir shaft. Much breccia occurs at the intersection of these two principal fissure systems.

About 150 ft north of the main shaft two long crosscuts have been driven across the north drift. The eastern crosscut reveals little that is new, whereas the western one penetrates new ground in which another important vein trending north-northeasterly was found and stoped. Near its western end this crosscut passes into a well-defined breccia zone–a part of the South Ibex stockwork. The breccia consists of somewhat rounded fragments of an altered porphyry of the Gray porphyry group, bleached, pyritized, and largely oxidized after pyritization. The contact between this breccia and the less shattered but otherwise similar country rock is irregular but as far as exposed, follows an irregular course that partly outlines a polygon, directed first northeast, then in turn north, southwest, and west. The zone may be part of an explosion vent like those of Cripple Creek and the Bassick mine, (Loughlin and Koschman, 1935, p. 273; Emmons, 1896, pt. 2, pp. 430–447) or a collapse breccia (Locke, 1926, pp. 431–458). The ore in this mass has been mined through other workings. It is a pyritic gold ore, richest where oxidized, and averaging about 0.6 ounce of gold to the ton; no other products of value are derived from this ore.

Oxidation is least extensive on the fourth level but, despite the fresher condition of the sulfides, almost no primary ore minerals except pyrite can be seen. Gold, the incentive to mining, seems to be concentrated in the pyrite or in its oxidized residue. Neither galena nor sphalerite was found. Films of chalcocite are common along fracture walls and on pyrite crystals; the quantity is small. However, widespread occurrence of these sulfide minerals and the scarcity of oxidized materials such as is found on the higher levels show clearly that below the fourth level the rock has been saturated with ground water most of the time since primary mineralization.

Pyrite is abundant, especially near shear zones or brecciated areas; it occurs mostly in veins as on the first level. The pyrite of crustified veins is central, and crystalline quartz, the only gangue mineral, is marginal. However, several veins that pinch out along their strikes contain quartz far beyond the last traces of pyrite. These relations suggest that quartz entered the crevices, but failed to fill them completely, commonly occupying only certain lenticular openings –then the pyrite was deposited in the open parts of the vein.

The Venir was operated at intervals between 1920 and 1935 as a small but profitable mine. Careful sampling of the underground workings has proved the presence of low-grade pyritic bodies containing approximately 0.15 to 0.25 ounce of gold to the ton. This content is typical of the larger bodies in or near shear or breccia zones. The richest ore is in the fissures or their small accessory fractures. Experience indicates that generally the veins are leaner to the south, so prospecting southward has been discouraged. As the veins have been prospected northeastward as far as the Negro Infant workings, there is little hope for rich ore beyond, even at depth, because oxidation and enrichment are reduced with increase in depth. The best direction for exploration is eastward, as the fissures developed on the fourth level in the long southeastern crosscut show.

Of great interest for the future, in view of increased gold prices, is the fact that much of the surface area has been sampled and proved to contain low-grade ore bodies. Mr. John Cortellini of Leadville reported (as quoted by E.P. Chapman, personal communication, 1929) that in the rock underlying the area near the Venir shaft, which is now mapped as Gray porphyry, samples reveal the following metal content: gold, 0.20 ounce to the ton; silver, 8.0 ounces; lead, 1.0 percent; copper, 1.2 percent; iron 25.0 percent. His estimate of the total quantity of such ore is 50,000 tons, and this known reserve might be very greatly increased by similar examination of the ground east of the collar of the Venir shaft. Such low-grade ore bodies are well situated for treatment at mills in California Gulch.

The general geology and economic development of the bordering region, in particular the area to the north along the Negro Infant and Garbutt workings, have been described by Emmons, Irving, and Loughlin (1927, pp. 300–306). Fissures in the Venir mine strikingly resemble and are parallel to those of the Forest Queen vein, of the Antioch stockwork, and of several smaller north-south veins west of the Garbutt vein, as described by Emmons, Irving, and Loughlin. Moreover, those veins and the nearby South Ibex stockwork have other features much like those in the Venir mine, especially the occurrence of the stockworks at intersections of major faults.

GARIBALDI TUNNEL AND SUNDAY VEIN

The Garibaldi tunnel (P-12), whose main haulageway is about 2,400 ft long and extends in a N. 58º E. direction, was studied by G. F. Loughlin in 1934. His map has been slightly modified as the result of a brief study in 1942 by the author of the present report, aided by Mr. E.D. Dickerman of Denver (**Plate 19**). The portal is at the head of California Gulch. The tunnel was driven northeastward, toward Ball Mountain, to explore the Weston fault and the Sunday vein (originally opened through the Sunday shafts on the western slope of Ball Mountain).

For 550 ft the tunnel goes through porphyry, presumably of the Johnson Gulch type but too highly altered for positive identification. About 550 ft from the portal a shattered zone is intersected, with shale of the Weber (?) formation appearing just beyond, on the northeast side, but the displacement along it is slight. The shattered zone contains streaks, as much as an inch in width, of sulfides (including pyrite, sphalerite, and galena), and a little gold. The Dickerman drift was driven in this zone along a weakly mineralized streak.

The northeastward extension of the adit beyond the Dickerman drift is in shale for a distance of 350 ft. Part of the shale is dark and bituminous, locally containing disseminated pyrite, and part is light-gray and siliceous. It is cut by several subparallel fissures and shear zones that trend about due north and dip generally eastward, and by one irregular body of a variety of the Gray (?) porphyry group. Where the veins cross the shale, the drag of the beds indicates that the eastern side was raised along several, if not all, of the fissures. Most of these fissures are occupied by lean veins. The Cooper drift is along a vein similar to the others, but larger; it strikes due north and dips 50° to 58˚ E. where the country rock along it is an altered member of the Gray porphyry group, the vein was rich enough to justify stoping, but south of the tunnel, where the vein passes into shale, it was not productive. Northeast of the Cooper drift several similar veins were found, but they were all in shale and were barren.

Beyond a point 1,050 ft from the portal a series of veins striking about N. 50° W. and dipping 65° NE border a broad, gouge-filled fault zone. All the veins contain pyrite that yields a little gold. Across one of them, 1,000 ft from the portal, an abrupt change takes place from porphyry to a width of 60 ft of rhyolite agglomerate, followed by highly contorted shale, which apparently represents a bed that was dragged up along the fault from beneath the porphyry sill. Beyond this is a timbered shattered zone, 20 ft wide, and farther northeast the porphyry reappears abruptly along what is interpreted as the northern side of the fault. As the projection of this fault zone with a dip of 55° E. brings it to the surface only about 200 ft northeast of the Weston fault as shown on plate 13 of Professional Paper 148, it is believed to be the Weston fault. The fault is clearly premineral: on both sides of the fault zone the rock has been extensively replaced by chalcopyrite and pyrite. Strongly replaced rock extends far into the porphyry and locally masks the structure.

Two minor fissures, respectively 1,025 and 1,185 ft from the portal, strike northeastward and dip 50° to 85˚ SE; some stoping and raising has been done along them. The northeastern of the two fissures is called Vein No. 6. Beyond it there is little of importance except at a point about 1,875 ft from the portal, where the tunnel passes through a large, gouge-filled, unmineralized fissure, trending N. 05° W. and dipping 50° E.

The main tunnel ends where it intersects the Sunday vein near the northeastern end line of the Greater New York claim. From a point south of the breast of the main tunnel an oblique crosscut eastward from the tunnel intersects the same vein. The Sunday vein has been stoped for about 360 ft north of its intersection with the main tunnel and at intervals for 430 ft to the south. Some of this work was done during the years 1930 to 1935, but most of it was done at an earlier period. The vein is said to have been entirely in a Gray porphyry and grits of the Weber (?) formation on the tunnel level. Too little is known of the rocks in the east wall to determine the amount of faulting along the vein. Local shattering within the Sunday vein suggests that some postmineral movement took place. The vein trends N. 17° to 18° E., dipping 82° to 88° NW (Emmons, Irving, and Loughlin, 1927, p. 322; Ramboz, unpublished report, 1912, made available through the courtesy of E.D. Dickerman, Leadville Colo.). Its strike and dip are somewhat different, and its direction of dip opposite, from those of the Hellena vein, which is regarded by many as the southern extension of the Sunday vein. Moreover, the Sunday vein here appears 100 to 200-ft west of the northward projection of the Hellena vein if the latter maintains the average strike observed in the Hellena mine. Nevertheless, these two may well be parts of one mineralized zone or even one fissure.

The vein has been far more productive south of the Garibaldi tunnel than north of it, where it is largely composed of gangue. Emmons, Irving, and Loughlin (1927, p. 322) state that it ranged in width from 1½ to 8 ft, averaging 3 to 4 ft, and contained chiefly pyrite, galena, sphalerite, and chalcopyrite. Sphalerite and chalcopyrite were scarce, except locally. The ore was well oxidized at levels above an altitude of 11,600-ft and showed sulfide enrichment to depths of at least 600 ft from the surface.

The output from 1901 to 1912 (Dickerman, personal communication) amounted to a total of 18,558 short tons of ore; individual shipments ranged in content as follows: gold, 0.05 to 0.97 ounce to the ton; silver, 1.90 to 24.90 ounces to the ton; lead, 0.70 to 66.50 percent; copper, 0.10 to 2.51 percent; zinc, 0.20 to 11.80 percent. The ore was hoisted through the Sunday shafts. Operations were suspended from June 1912 until October 1917, continuing thereafter until March 1920. During the second period 1,323 short tons of ore were shipped. This ore ranged in content as follows: gold, 0.07 to 0.49 ounce to the ton; silver, 2.75 to 14.05 ounces to the ton; lead, 5.05 to 33.10 percent; copper, 0.105 to 0.15 percent; zinc, 4.20 to 9.50 percent. Careful sampling (Ramboz, unpublished report, 1912) of the vein in 1912 led to an estimated average content of 0.14 ounce gold to the ton, 2.35 ounces silver to the ton, and 3 percent lead. According to smelter returns, the total output for the entire period, 1901-20, was valued at $190,116.

RESURRECTION MINE

In 1935 the writer studied the new work carried on by the Zenda Mining Co. along the Yak level from the Resurrection No. 1 (main) shaft (D-40). According to Emmons, Irving, and Loughlin (1927, pp. 320–322) the Resurrection group developed nine veins that lie generally north of the No. 1 shaft. They state in part:

Four of them-Nos. 1, 2, 7, and 8 have a roughly cresentic form with large radii of curvature * * *the veins were all accidentally discovered by underground workings driven for the purpose of developing the blanket ores * * * All the veins belong to the north-northeast system * * *These veins range in width from a few inches to 4 feet. The No. 7 vein, which lies east of the Yak tunnel, is well defined and has been followed downward from the contact for large tonnage of siliceous gold ore, much of which contained galena and zinc blende with subordinate silver.

Along this fissure there has been a displacement of 40 ft, which has brought Cambrian quartzite in the east wall up against eastward dipping shale of the Peerless formation.

The writer was able to study the work on the Yak tunnel level only, which was being actively carried on at the time (**Plate 20**). Here the No. 7 fault vein just west of the main shaft strikes about N. 15° E. and dips 75° to 80° W. The No. 7 fault fissure is 20-ft wide with distinct boundaries. The ore in part replaces country rock, in part fills in between rock fragments, forming a mineralized fault zone much wider than the four feet mentioned above by Emmons, Irving, and Loughlin. The hanging wall of the vein is an altered member of the Gray porphyry group, broken still farther west by other faults.

This conspicuous fissure vein is not recognized with certainty in the first lateral (also called the Bryant lateral) south of the Main (No. 1) shaft. Two faults on this lateral situated 190 ft east of the Yak tunnel may represent the walls of the No. 7 vein, as they are about the same distance apart and have the same general strike; but the faults dip 65° E. and are not appreciably mineralized. It is equally probable, however, that the vein joins a fissure, also mineralized, that strikes S. 40° W. near the Resurrection No. 1 shaft and is exposed 165 ft east of the Yak tunnel in the Bryant lateral.

Farther east, where the Bryant lateral turns from an east-southeast to an east-northeast course to explore the Christmas claim, it enters Cambrian quartzite. About 120 ft east of the turn two conspicuous fault fissures striking N. 20° E. and N. 50° E., with associated shear zones, repeat the Gray porphyry and are somewhat mineralized; another mineralized shear zone (the Christmas fissures) is cut 300 ft farther east. Approximately 525 ft east of the turn a raise was put up at the end of a blind drift on a mineralized fissure striking N. 10° E. in the Peerless formation. At a point 855 ft east of the Yak tunnel the main lateral was turned east-southeastward, cutting through the N. 10° E. fissure and another, striking about N. 30° E.; both of these veins are in shale of the Peerless formation. Farther southeastward this crosscut passes through Manitou dolomite, an overlying sill of the Gray porphyry group, another mineralized fault (not shown on plate 20), more shale, and entered another mass of the Gray porphyry group. The rocks west of this fault dip eastward whereas those east of it dip northward. The lateral was stopped because it neared the side lines of the Christmas claim.

Of the several fissures cut by the Bryant lateral the Weil fissure is the most conspicuous, as it borders a shear zone 8 ft wide. The Weil raise along this fissure found nothing of interest but merits being extended into higher, more favorable rocks. The N. 10 ° E. fissure that crosses the Bryant lateral about 90 ft east of the fork 930 ft east of the tunnel, also should be explored where it cuts more favorable rocks.

IBEX MINE

The Ibex mine, one of the oldest near Leadville, is known mostly for its output of gold in the early days of mining in the district. The general features of its ore deposits were well described by Emmons, Irving, and Loughlin (1927, pp. 295–300). In 1932 a part of the output came from higher levels in the ground north of the No. 2 shaft, where rich gold ore in small quantities was being mined. Most of the interest, however, centered on the seventh and lower levels, and especially on the possibility of finding blanket deposits and rich gold-bearing veins like those of the Golden Eagle workings and elsewhere. Chief interest lay in the possibility of finding replacement deposits in the Manitou dolomite and shale of the Peerless formation and in veins in these formations and the Cambrian quartzite. Intercalated at various horizons in this part of the sequence are sills of early White porphyry. As the search for blankets at the lower horizons must largely be confined to the Manitou dolomite or to calcareous layers in the Peerless formation, the problems of further exploration were mainly structural; hence the writer spent a part of the summer of 1928 in studying the geology to revise the maps already published in Professional Paper 148, in particular of areas north of the No. 2 Shaft. The new maps are presented in **Plates 6-8**. A brief discussion of the northern part of the mine at the seventh level and below is given in the following pages. The altitudes of the various levels are as follows:

	Altitude (feet)
Seventh level	10,915
Fourth level from Kyle winze	10,760
Tenth level	10,687
Bott level, above twelfth level	10,569
Twelfth level	10,508

The main north haulageway of the seventh level north of the No. 2 shaft (Emmons, Irving, and Loughlin, 1927, p. 300) is driven essentially across a syncline having Parting quartzite downfolded to this level between limbs of Manitou dolomite (plate 6). About 430 ft north of the shaft and a little west of the main haulage drift, the axis is crossed obliquely by a fault fissure striking north-northwest and having a displacement essentially parallel to the strike of the fault plane, the east side having moved south. This is one of the larger faults of the mine. To the north its course curves northeastward and its displacement decreases until apparently (in Block 44, about 800 ft north of the No. 2 shaft) it is reduced to two fissures which strike north-northeast and have almost no displacement (plate 6). Most of the country rock is the unfavorable early White porphyry and the fissures are mineralized only in a narrow band of shale of the Peerless formation along which considerable stoping has been done. These two fissures are recognizable on a sublevel 10 ft above the seventh level at the northeastern end of the workings, where Parting quartzite is faulted against early White porphyry; mineralized ground on this sublevel is negligible.

Along the northeastern part of its course, the seventh level crosses numerous small faults with strikes ranging from due north to about N. 50° W.; none of them is markedly mineralized. A raise in Block 300 connects the seventh level with the previously mentioned level, 70 ft higher. This sublevel splits northward into two branches, of which the western one follows a northwestern fissure in early White porphyry, and the eastern one follows a north-northeasterly fissure east of which Manitou dolomite, Parting quartzite, and volcanic agglomerate appear in a complex relationship, as shown on the map (plate 6). At least two northwest-trending faults are mineralized in this end of the mine.

The fourth level from the Kyle winze (plate 8) developed little of interest except a fault contact between a sill of early White porphyry to the northeast and the Manitou dolomite to the southwest. This fault strikes N. 45°-70° W., parallel to the strike of the beds, and dips 30°-60° NE, but it curves irregularly in ground plan and is offset by several lesser faults of northeast strike. Especially disappointing here is the failure to find any important ore shoots in the Manitou dolomite, which is generally productive though not as favorable to mineralization as the Leadville dolomite.

The tenth and closely adjoining levels (plate 7), north of the No. 2 shaft, cut two sills of altered early White porphyry between which is a thickness of 50 ft of shale of the Peerless formation that contains some thin beds of almost pure limestone. Most of the mineralized fissures trend north or northeast, but the vein matter is not rich. The contrast between the mineralized northeast-trending fissures and the postmineral fissures of north to northwest trend is most striking, especially in the northern part of the workings, where the barren northwesterly fissures intersect and offset the veins of northeasterly strike. Of most economic interest is the ore in the Peerless formation near Swanson's incline. Ore shoots of this group lie along mineralized fissures that trend east-northeast and beneath shaly beds or the overlying sill of early White porphyry. A group of such shoots is exposed south of Swanson's incline. At the southern end of this mineralized area the Peerless formation was so intensely mineralized above the tenth level and west of it (that is, up the dip) that a continuous blanket ore-body could be mined; but farther north, and down-dip from the level, replacement was less continuous between the neighboring feeding fissures. Here the elongate form of the stopes defines the fissures; they average 10 to 50 ft in width. The ore shoot has been opened by Swanson's stope and Swanson's incline for a distance of 270 ft. The main mineralized fissures in this ground trend N. 30°-50° E., and generally dip 75°-90° E, but some curve so as to produce a reversal of dip. An abundance of small feather fractures meet these major fractures at small angles and strike N. 10°-20° E.; an especially good example is in the short exploratory drift extending S. 20° W. about 20-ft from the lower (northeast) end of Bowden's stope; the drift itself is driven along the minor fissures, which are vertical, gaping, and partly filled with crusts of sphalerite and pyrite.

Variously dipping faults that strike parallel to the beds and are distinctly though not abundantly mineralized, occur locally and perhaps more generally than is recognized. Such faults are common in the northern end of this level, but the best example is that at the northeastern end of Swanson's incline (**Figures 100 and 101**). Here the shale of the Peerless formation, containing much shaly limestone, has been largely replaced by ore and a fault brings the sill of early White porphyry (normally above the shale) against it. The fault dips about 50° NE; the dip of the beds is similar in direction but only 25°. Up the dip of the beds, the dip of the fault gradually flattens so that the two planes are parallel. In the hanging wall the porphyry is greatly shattered.

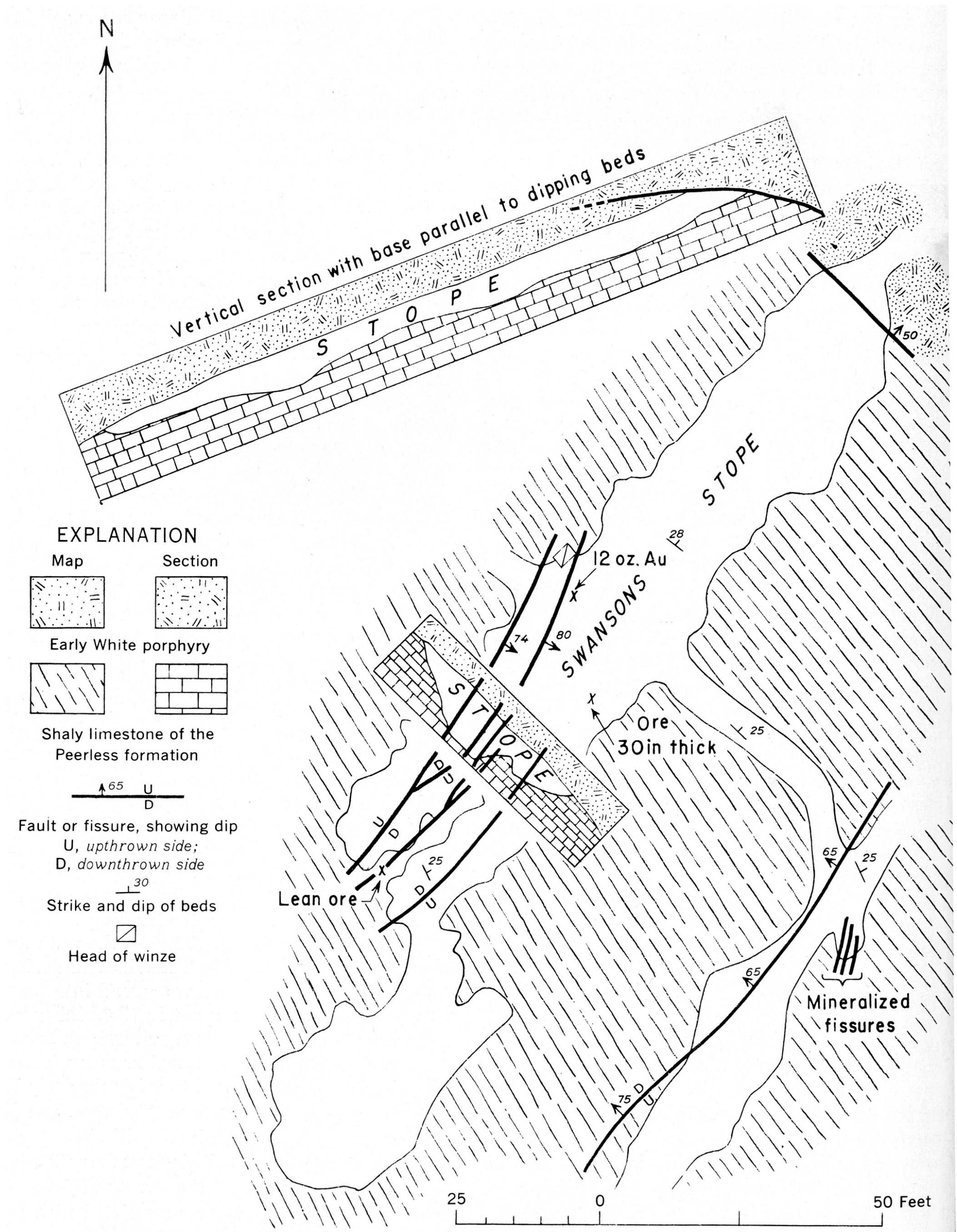


Figure 100. Detailed map of Swanson's stope, Ibex mine, and vertical sections parallel and transverse to its length. Note relations of faults to mineralization.

Though the main fissures of Swanson's stope cannot be traced into the fault, mineral-bearing accessory. fractures extend into the fault breccia and cross it, dying out in the solid porphyry northeast of the stope. It is not clear from these relations whether the fault is normal or reverse; less displacement would be required to bring the early White porphyry against the upper part of the shale if the porphyry were assumed to be the sill above the shale rather than one below it. This fault may therefore be assumed to be normal, but the structural features are more like the "zigzag" fissures associated with reverse faulting (Behre, 1937, pp. 525–527).

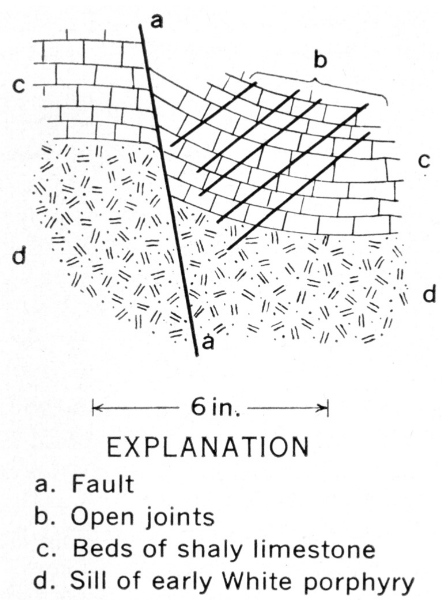


Figure 101. Detaileds of fractures in Limestone bed at head of Swanson's Stope, Ibex mine. Note open joints Locally mineralized, apparently Related to main fault.

In the upper end of Swanson's stope the relation between the positions of fissures and the local thicknesses of replacement bodies is especially conspicuous. The richer, thicker parts of the ore shoots along fissures are 30 in. or more thick; between the fissures, within distances of no more than 20 ft, the thicknesses decrease to 6 in. or less, and the grade of ore becomes poor. The southwestern edge of the stope is thus lobate, consisting of alternate fingers of rich ore following fissures and intervening prongs of lean or barren country rock. Most of this ore was cupriferous pyrite that had extensively replaced the calcareous beds of the Peerless formation; in addition to the copper, as much as 1 ounce of gold to the ton was recovered. But along certain fissures, such as the eastern fissure in Swanson's stope, the gold content was as much as 12 ounces to the ton. The richness of the ore in and immediately adjacent to places where a vein crosses the sulfide blanket body suggests that the gold was deposited later than the sulfides and was precipitated through interaction of the solutions with the sulfide ores. Along several of the fissures replacement has been so extensive that the original feeding fissure is completely hidden; this probably accounts for the absence of a distinct fissure in Swanson's incline, despite the local intensity of mineralization. Directly beneath the blanket deposits the calcareous shale in places is largely silicified. At the northern end of the workings winzes have been sunk to connect the tenth level with drifts 54 and 74 ft below the main level, and in this lower work some northeast-trending mineralized fissures have been found cutting the sill of early White porphyry that overlies the Peerless formation. The mineralized ground was not rich enough here to merit further exploration; nevertheless, sinking along such fissures to search for ore in calcareous beds of the underlying Peerless formation offers a reasonable hope of success. Some of these fissures are cut and offset by postmineral faults of northwest trend.

The Bott level (plate 8) crossed three mineralized fissures trending northward and dipping moderately to steeply eastward; however, the country rock at this level is almost wholly in a zone of little promise -the early White porphyry of the sill below the Peerless formation. At the southern end of the workings a raise of 25 ft broke into a small but rich body of ore in the overlying calcareous beds of the Peerless formation. A fault of northwesterly trend exposed in the northern part of the workings is interpreted by some as the Colorado Prince fault but it proves to be a deeper fault, nowhere recognized at the surface; the writer has named it the Bowden fault (Behre, 1929, pp. 54–55) after its discoverer, W.E. Bowden, one of the men most active in deeper explorations in the Ibex mine.

On the twelfth level (plate 8) little encouraging evidence was found. Stoping at the southeastern end of this level in the Peerless formation above the main level revealed a lower part of the ore body mentioned in the description of the Bott level. Complex faulting has cut out the Cambrian quartzite at the northern end of the mine, and pre-Cambrian granite has been brought up on the north against early White porphyry on the south. The main fault here is the Bowden fault. The ground is locally shattered and slightly mineralized along a fissure of north-northeasterly trend that was seen as a highly mineralized fissure on the Bott and the tenth levels. The part of the Ibex mine north of No. 2 shaft and below the seventh level has proved disappointing, except where northeasterly fissures cross the calcareous beds of the Peerless formation.

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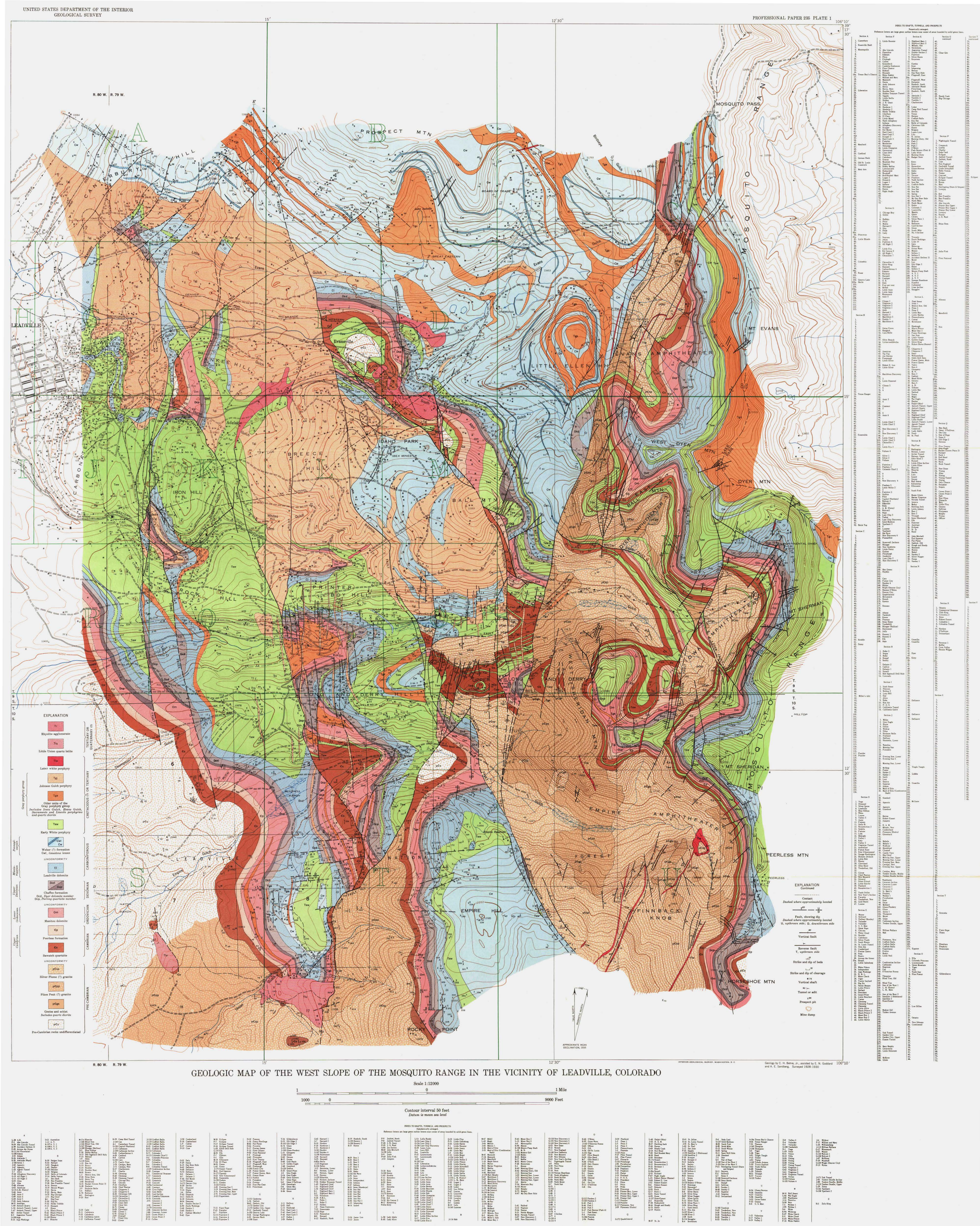

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
PROFESSIONAL PAPER 235 PLATE 1
EXPLANATION
GEOLOGIC MAP OF THE WEST SLOPE OF THE MOSQUITO RANGE IN THE VICINITY OF LEADVILLE, COLORADO
Scale 1:12000
Contour interval 50 feet
Datum is mean sea level
INDEX TO SHAFTS, TUNNELS, AND PROSPECTS
LEADVILLE
PROSPECT MTN
MOSQUITO PASS
MOSQUITO RANGE
MT EVANS
BREECE HILL
IRON HILL
BALL MTN
DYER MTN
WEST DYER MTN
MT SHERMAN
MT SHERIDAN
EMPIRE HILL
PEERLESS MTN
HORSESHOE MTN
FINNBACK KNOB
ROCKY POINT
EMPIRE AMPHITHEATER
Evansville

Plate 1.

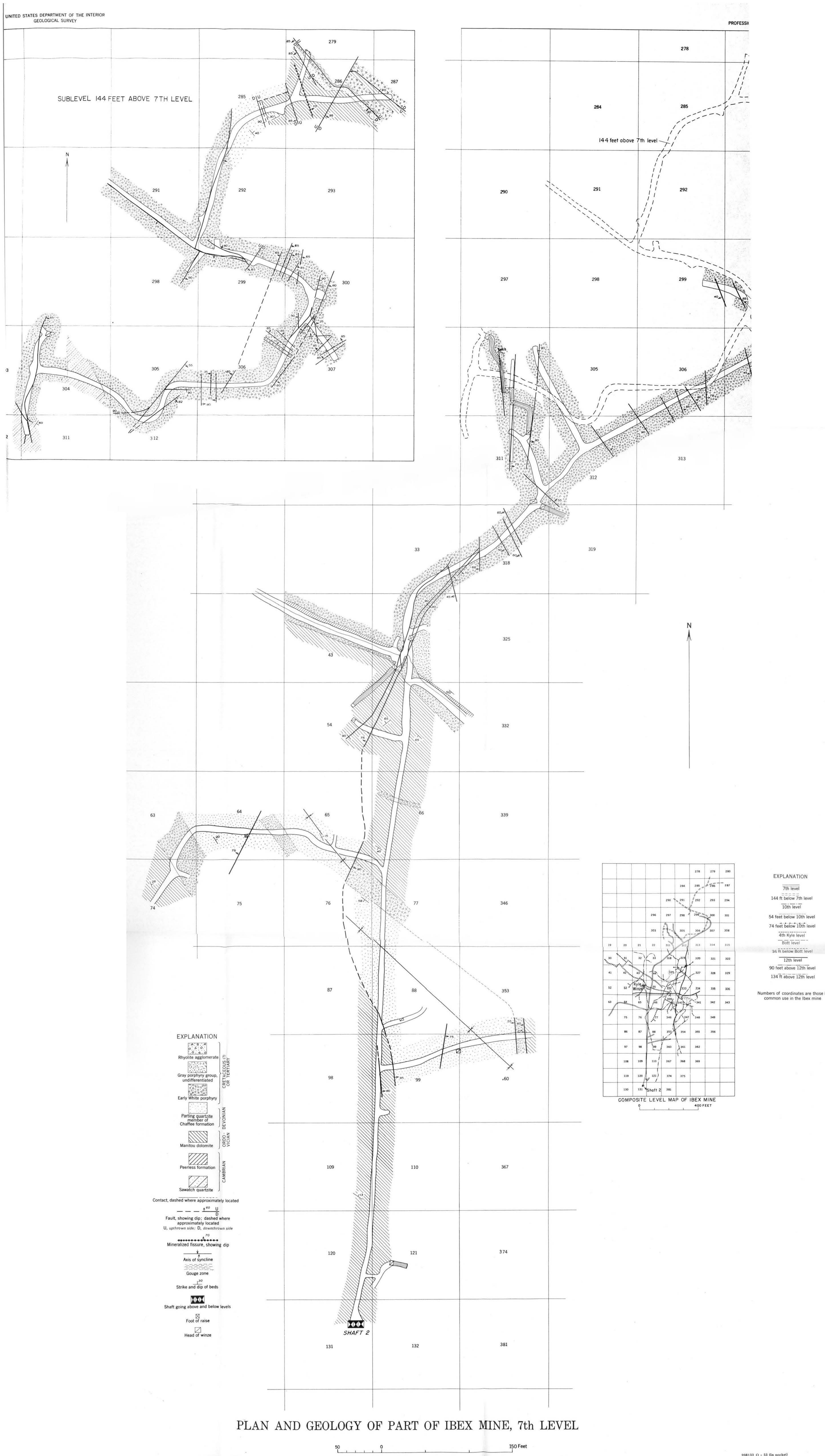
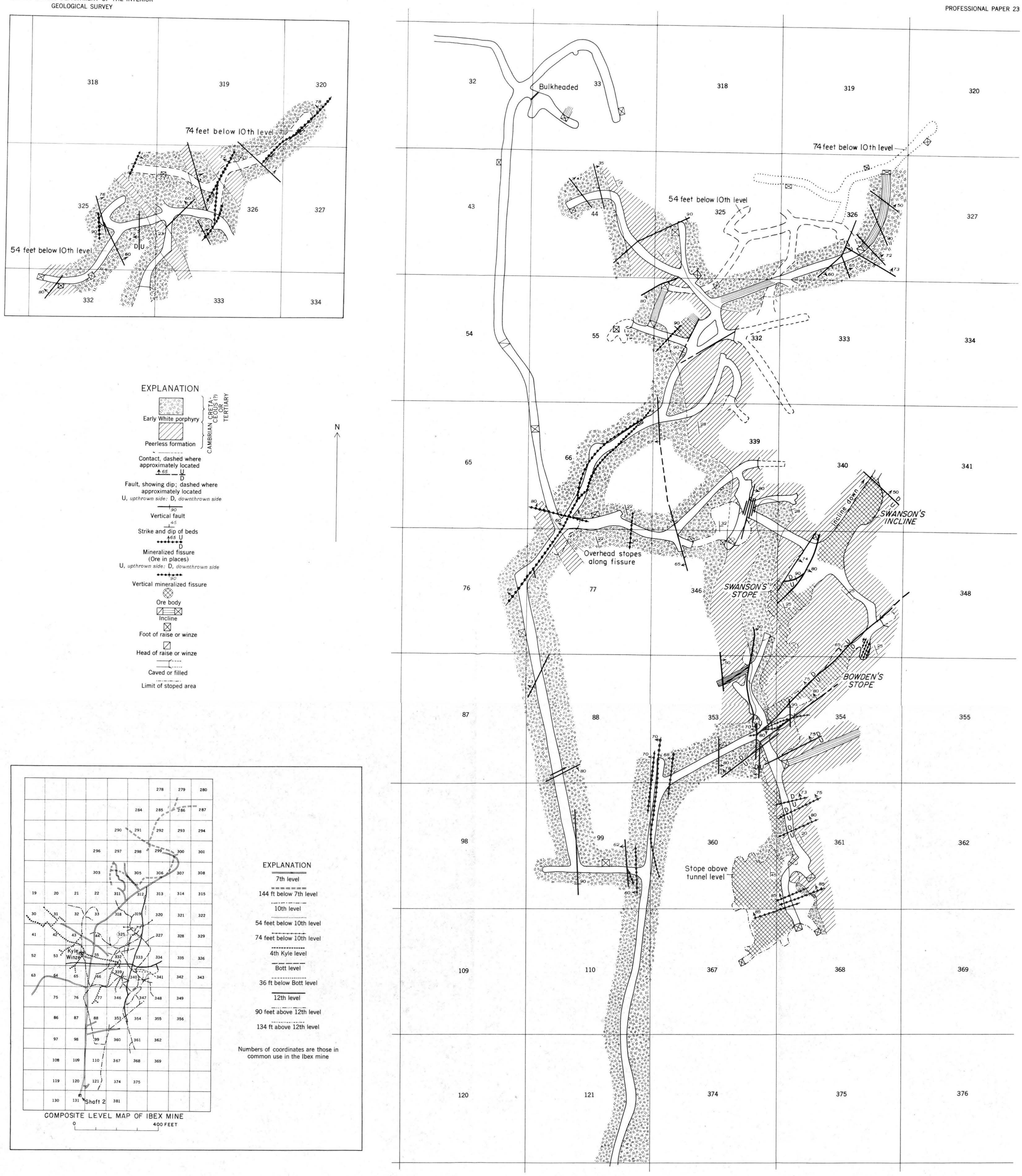

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
PROFESSI
SUBLEVEL 144 FEET ABOVE 7TH LEVEL
144 feet above 7th level
N
SHAFT 2
EXPLANATION
Rhyolite agglomerate
Gray porphyry group, undifferentiated
Early White porphyry
CRETACEOUS(?) OR TERTIARY
Parting quartzite member of Chaffee formation
DEVONIAN
Manitou dolomite
ORDOVICIAN
Peerless formation
Sawatch quartzite
CAMBRIAN
Contact, dashed where approximately located
Fault, showing dip; dashed where approximately located
U, upthrown side; D, downthrown side
Mineralized fissure, showing dip
Axis of syncline
Gouge zone
Strike and dip of beds
Shaft going above and below levels
Foot of raise
Head of winze
EXPLANATION
7th level
144 ft below 7th level
10th level
54 feet below 10th level
74 feet below 10th level
4th Kyle level
Bott level
56 ft below Bott level
12th level
90 feet above 12th level
134 ft above 12th level
Numbers of coordinates are those in common use in the Ibex mine
Kyle Winze
Shaft 2
COMPOSITE LEVEL MAP OF IBEX MINE
0
400 FEET
PLAN AND GEOLOGY OF PART OF IBEX MINE, 7th LEVEL
50
0
150 Feet

Plate 6.

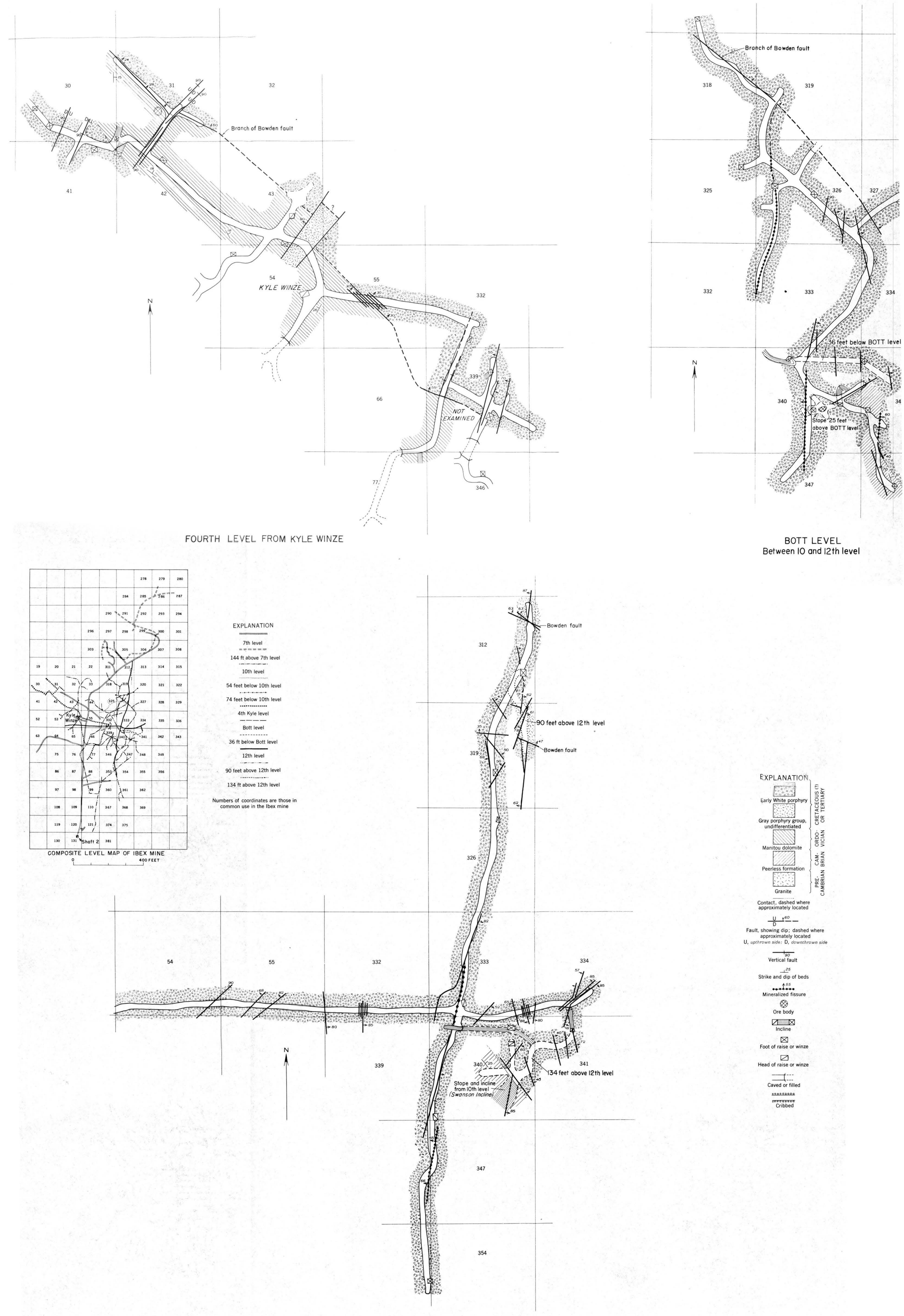


PLAN AND GEOLOGY OF PART OF IBEX MINE, 10th LEVEL

50 0 150 Feet

998133 O - 53 (In p

Plate 7.



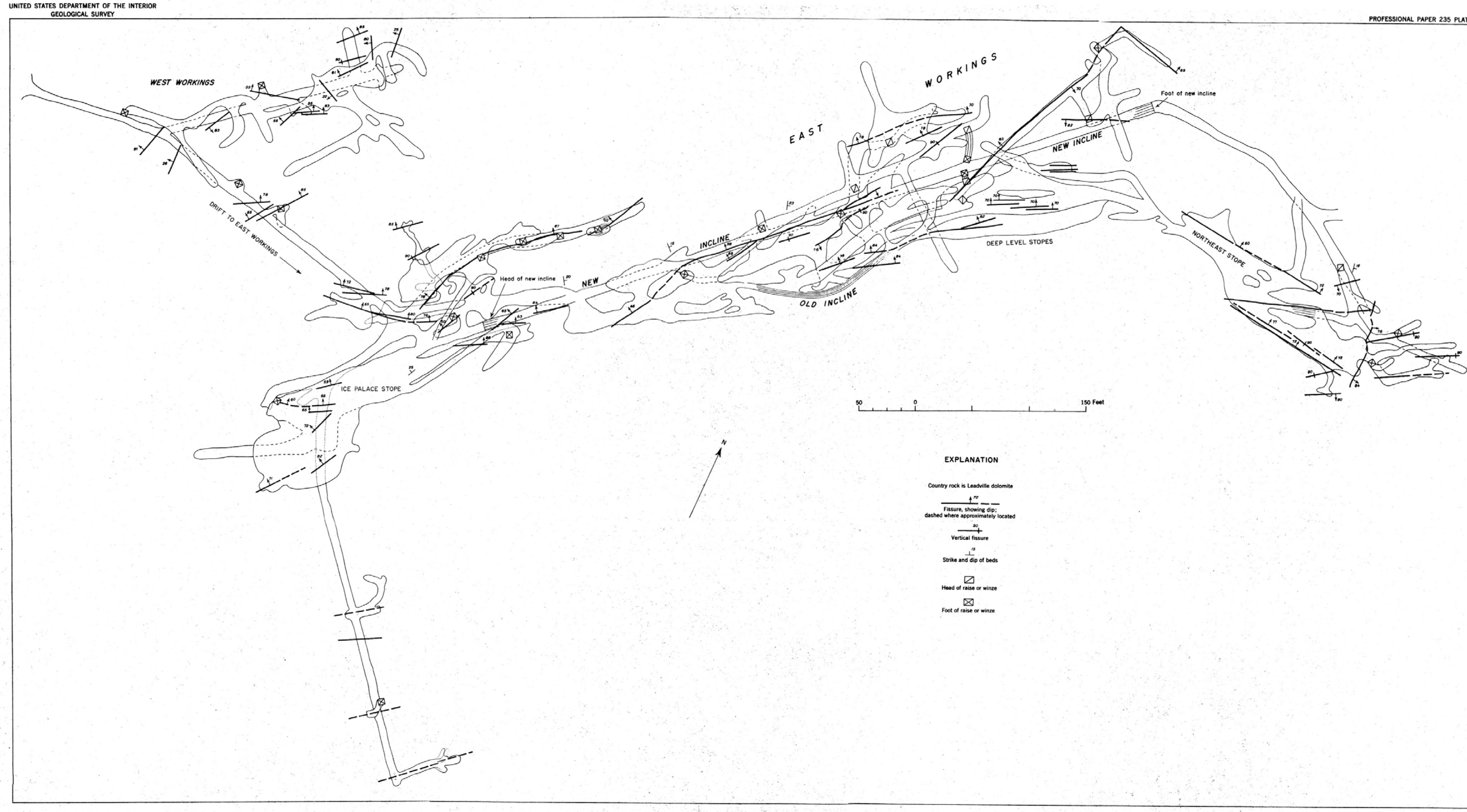
PLAN AND GEOLOGY OF PART OF IBEX MINE, 4th LEVEL FROM KYLE WINZE, BOTT LEVEL, AND 12th LEVEL

50 0 150 Feet

Plate 8.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROFESSIONAL PAPER 235 PLATE 12

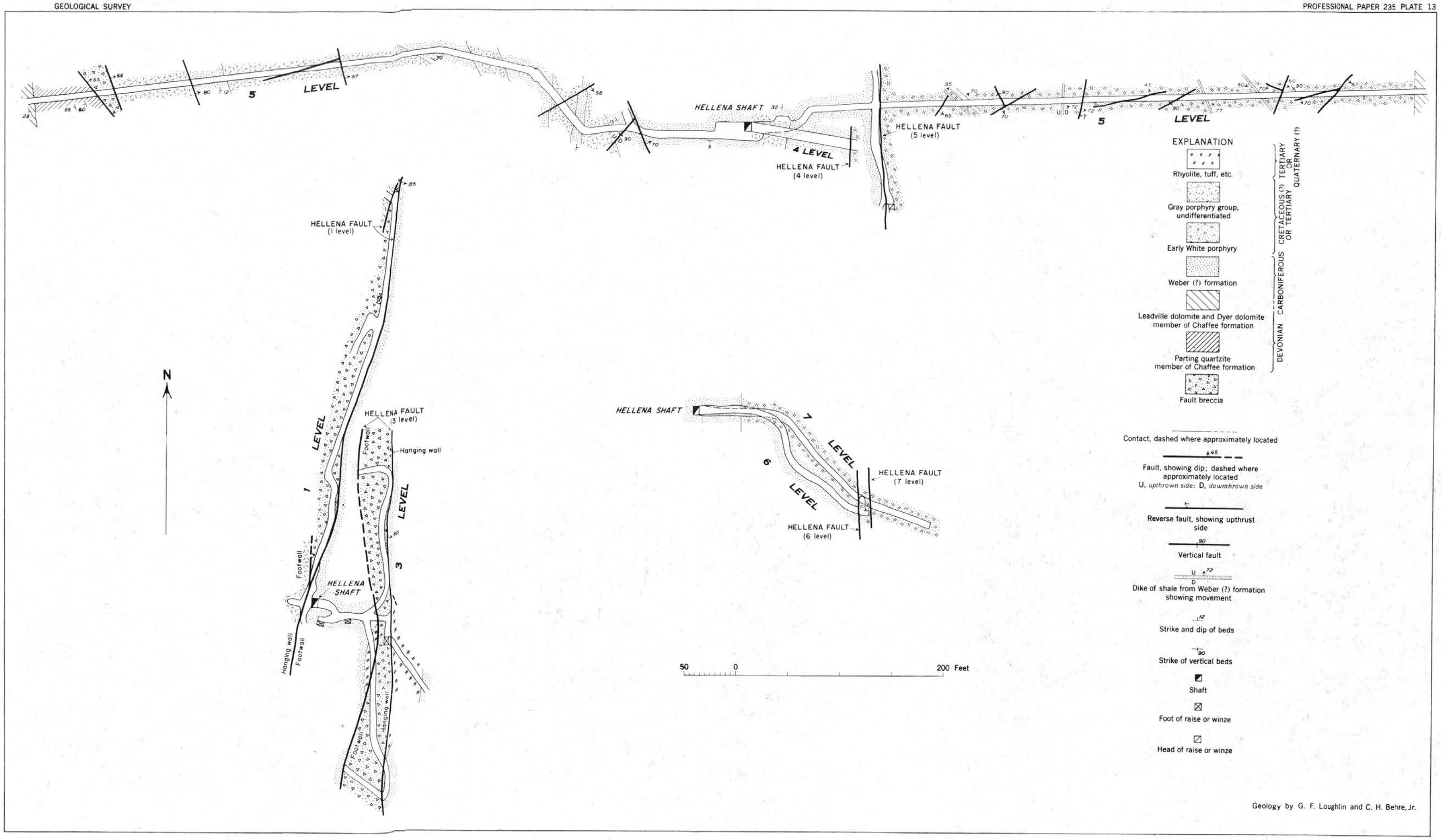


MAP OF THE CONTINENTAL CHIEF MINE

Plate 12.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROFESSIONAL PAPER 235 PLATE 13



GEOLOGIC MAPS OF LEVELS OF HELLENA MINE

998133 O - 53 (In pocket)

Plate 13.

UNITED STATES DEPARTMENT OF THE INTERIOR
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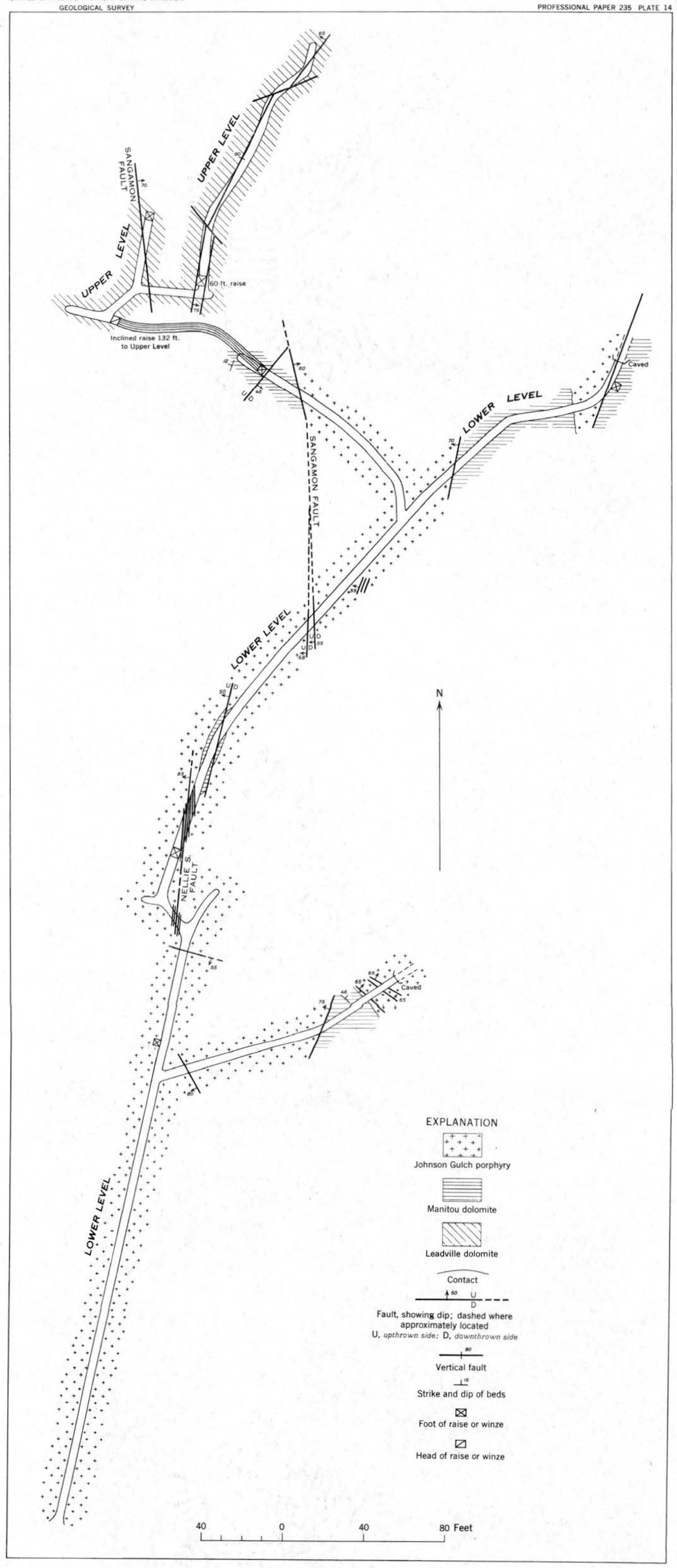
PROFESSIONAL PAPER 235 PLATE 14



GEOLOGIC MAP OF MAIN LEVEL, ALTOONA TUNNEL

998133 O - 53 (In pocket)

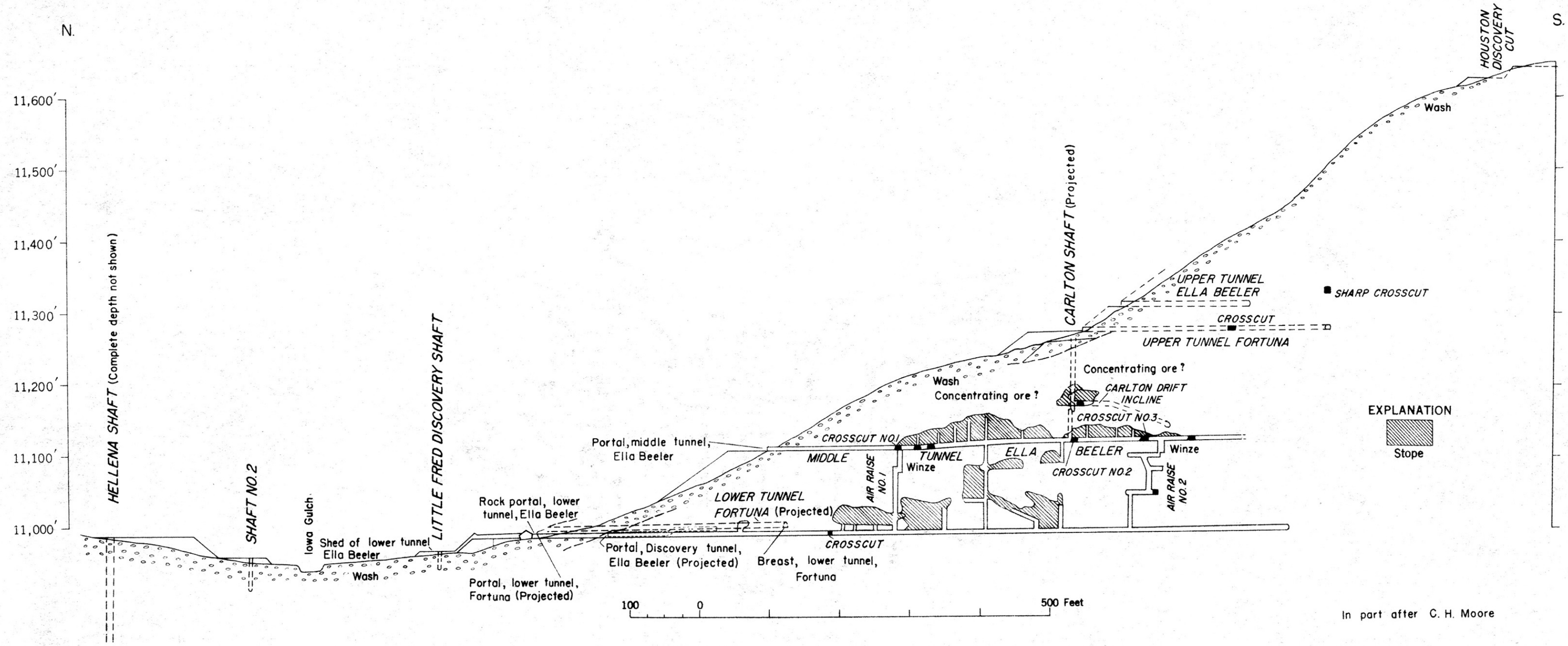
Plate 14.

MAP OF CLAIMS AND WORKINGS OF THE CLEAR GRIT MINING GROUP AND ADJACENT MINES

Plate 15.

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROFESSIONAL PAPER 235 PLATE 16



LONGITUDINAL SECTION ON EAST SIDE LINE OF ELLA BEELER CLAIM

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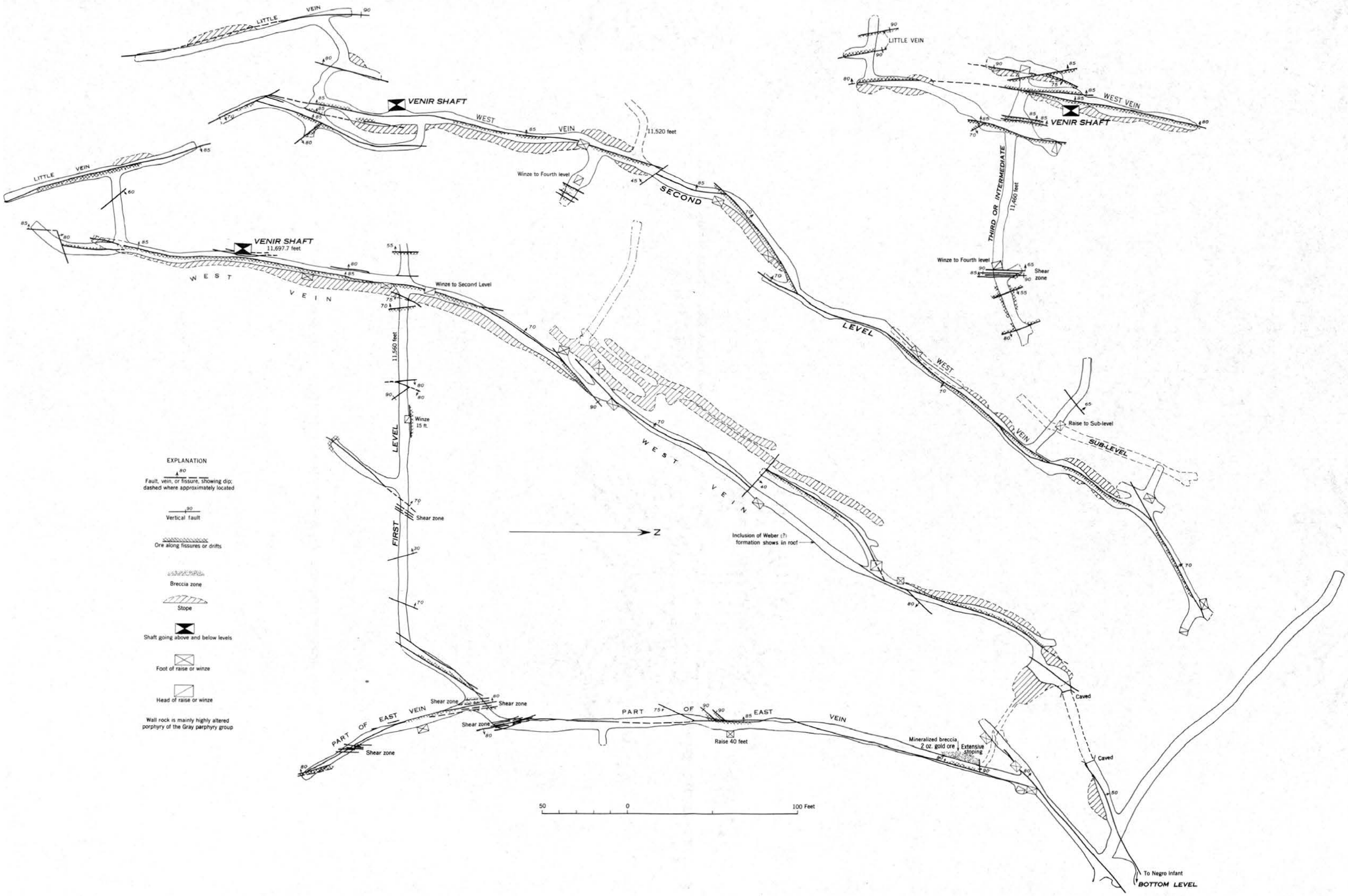
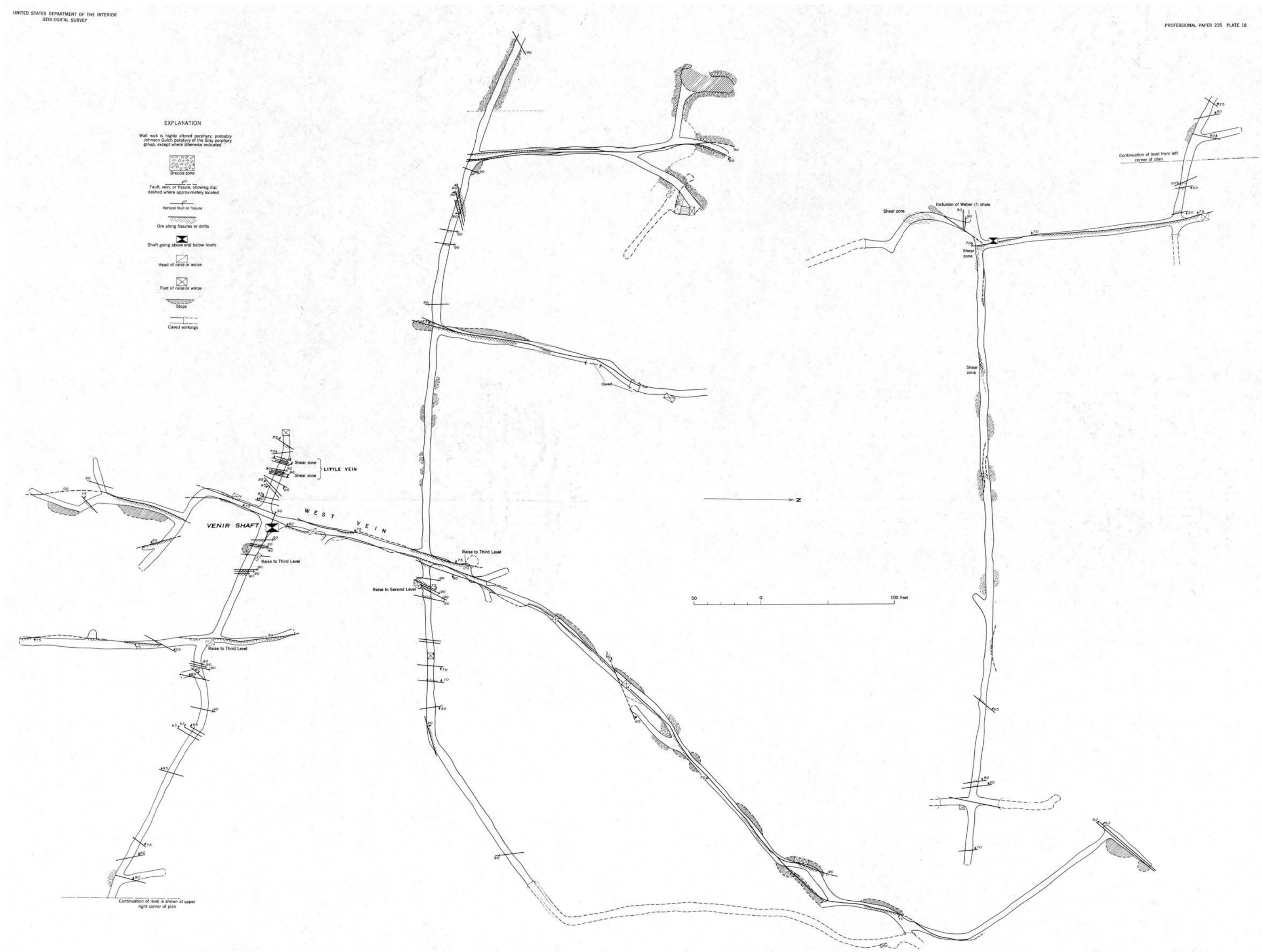
Plate 16.



GEOLOGY AND PLANS OF VENIR OR SOUTH IBEX MINE, 1st, 2d, AND 3d LEVELS

998133 O - 53 (In pocket)

Plate 17.



GEOLOGY AND PLAN OF VENIR OR SOUTH IBEX MINE, 4th LEVEL

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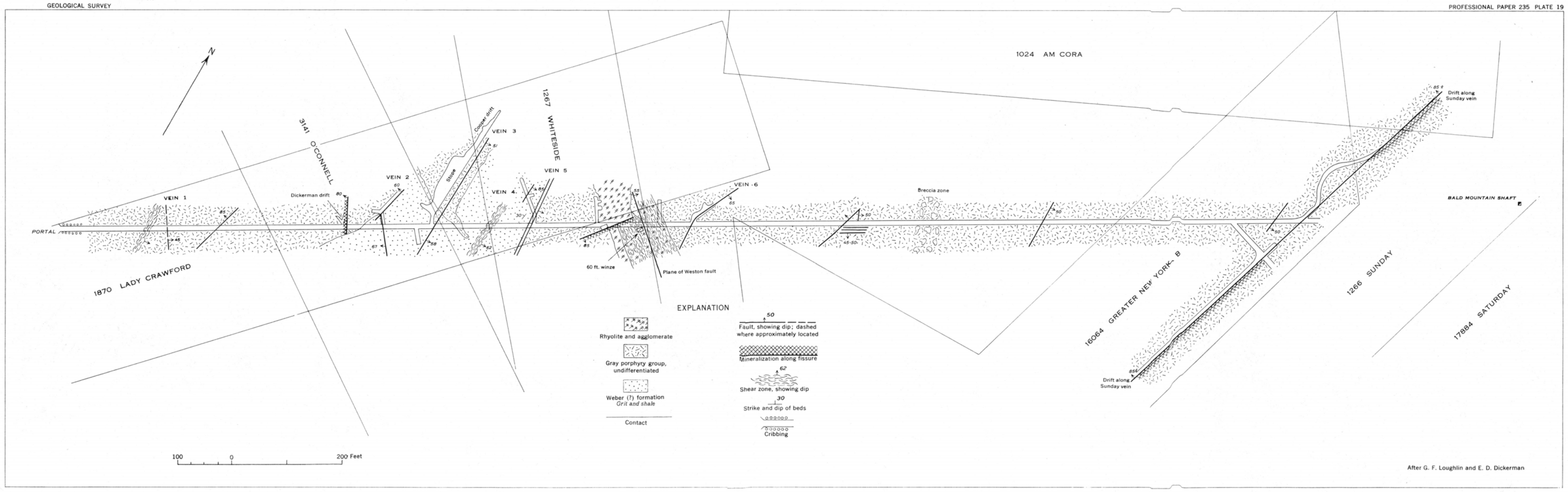
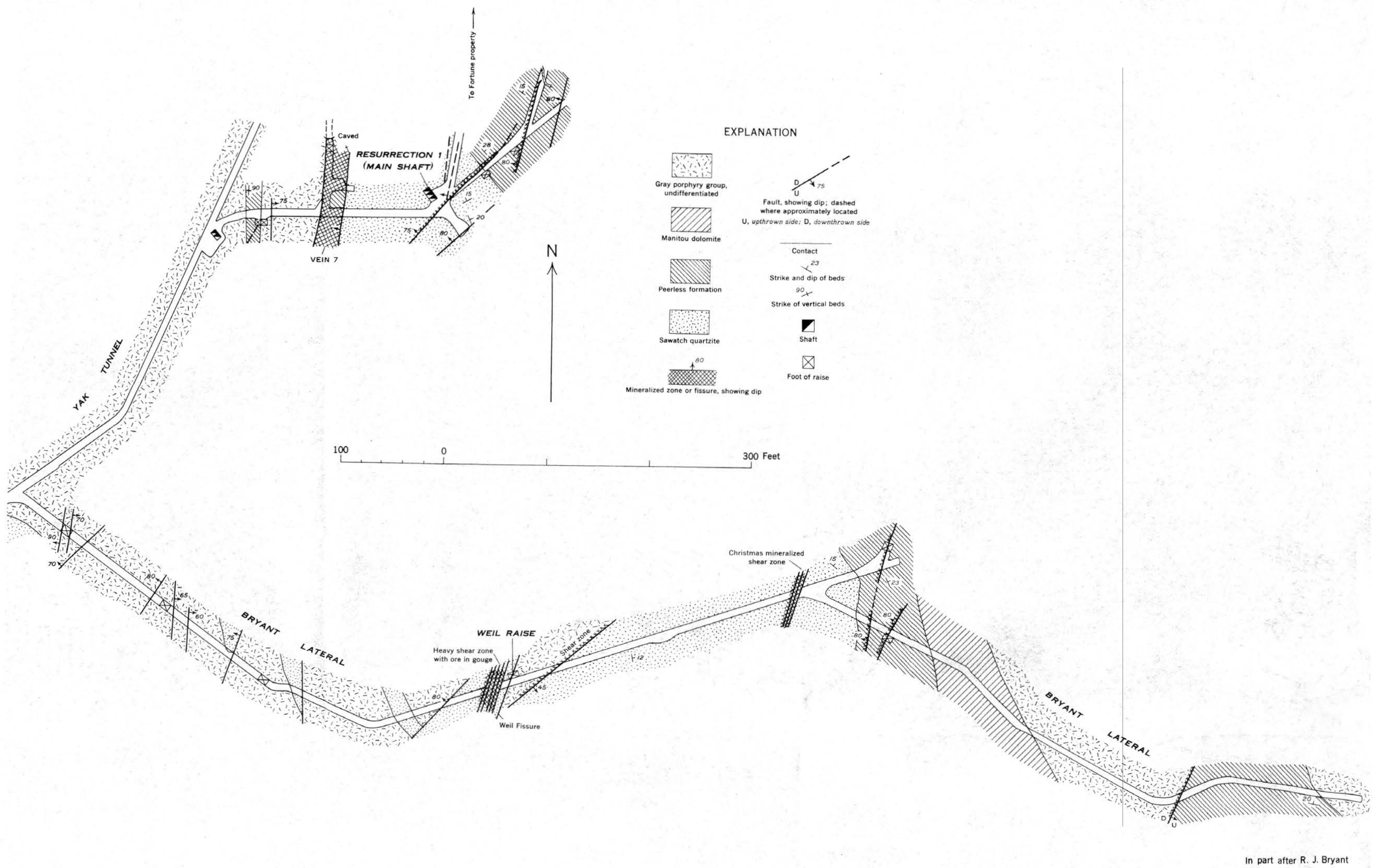
Plate 18.



PLAN AND GEOLOGY OF GARIBALDI TUNNEL AND WORKINGS ON SUNDAY VEIN

998133 O - 53 (In pocket)

Plate 19.



PLAN AND GEOLOGY OF PART OF RESURRECTION MINE, YAK TUNNEL LEVEL

Plate 20.