

Betekhtinite from the St. Cloud silver mine Chloride mining district, New Mexico

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The rare mineral betekhtinite, a sulfide of copper, lead, and iron, occurs in significant amounts in the St. Cloud copper-silver-gold deposit located near Winston in the Chloride mining district, Sierra County, New Mexico. Situated on the eastern slopes of the Black Range approximately 40 miles west of Truth or Consequences, the mine is owned and operated by the St. Cloud Mining Co. Along with the adjoining Atlanta and Mayflower lode mining claims, the St. Cloud was located in 1884. A few tons of hand-sorted, oxidized, copper-silver ore were shipped from near-surface workings on the Atlanta-St. Cloud claims in the 1880's and early 1890's. Drilling by the Goldfield Corp. in 1968 on the St. Cloud-U. S. Treasury vein intercepted ore-grade mineralization at a depth of 450 ft. Subsequent drilling established the presence of two ore bodies, the St. Cloud and the U. S. Treasury.

The St. Cloud ore deposit is a mesothermal, vein-type deposit occurring in a strong northwesterly striking fault structure. Host rocks are the Madera limestone (Pennsylvanian) and andesitic flows and sills (Tertiary). The fault zone and vein structures are 20-60 ft. wide. Ore-grade mineralization is typically 10-20 ft. wide and occurs as shoots within the structure. Mineralization tends to favor those areas where the vein structure has limestone on one wall and andesite on the other. Massive ore often contains mineralization consisting of (in decreasing order of abundance) sphalerite, bornite, betekhtinite, galena, chalcocite, and stromeyerite in a siliceous breccia. Outer portions of the ore body contain some chalcopyrite. Pyrite, although common in the wall rocks, is noticeably less abundant in the ore. Late-stage calcite is common. Oxidation in the upper parts of the deposit created very minor amounts of native copper, cuprite, and copper carbonates.

Betekhtinite was first described in 1955 as a Cu-Pb-Fe sulfide from veins in the Mansfeld "Kupferschiefer" (copper shales) of East Germany. Since then it has been found in Europe, Asia, Africa, South America, and Australia. A GSA abstract mentions the unconfirmed occurrence of betekhtinite at Butte, Montana. In 1982 betekhtinite was identified in concentrates from the St. Cloud mine. We believe that our 1986 paper at the New Mexico Minerals Symposium was the first reported occurrence of the mineral in New Mexico and the second in North America.

Chemically, the New Mexico betekhtinite is a Cu-Pb-Fe sulfide with minor amounts of silver, but electron microprobe analyses indicate that the published formula-- $\text{Cu}_{10}(\text{Pb},\text{Fe})\text{S}_6$ --is in error. In the literature on this mineral, the formula has undergone a number of changes, partly because the silver and iron may be assigned to either the Cu site or the Pb site. Analyses from the present study and from many literature sources seem to best fit an empirical formula of $\text{Cu}_{13}(\text{Pb}, \text{Fe}, \text{Ag})_2\text{S}_9$.

*A portion of this work was performed at Sandia National Laboratories and was supported by the U.S. Department of Energy under contract no. DE-AC04-76DP00789. The authors would like to acknowledge the cooperation and assistance of the St. Cloud Mining Co.

BISMUTH SULFOSALTS OF COLORADO

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Bismuth sulfosalts have been a persistent topic of Colorado mineralogy from the early days of mining to today's modern research. Commonly overlooked due to their generally inconspicuous appearance, often resembling galena or tetrahedrite, and because of their commonly fine-grained intergrowths, the bismuth sulfosalts have often been misidentified. Detailed study using a variety of techniques, including ore microscopy, X-ray diffraction, and electron microprobe analysis are generally necessary to properly identify the bismuth sulfosalts. Of the 57 bismuth sulfosalts (ignoring selenium-dominant sulfosalts) 20 are well documented as occurring in Colorado. Of these, eight were first described from Colorado.

The study of bismuth sulfosalts in Colorado can be broken down into the following three time periods:

1. 1870-1900: The bonanza mining era of Colorado. Deposits of the bismuth sulfosalts were commonly richly argentiferous, however, their pockety distribution in generally narrow veins made most unremunerative. G. A. Koenig, a chemistry professor, collected and described many species, most of which were later found to be mixtures. F. A. Genth, a chemist and mineralogist, described many specimens sent in from miners. W. F. Hillebrand, another chemist and mineralogist, described specimens found in territorial survey work by the U. S. Geological Survey and in samples provided by miners.
2. 1900-1967: Sporadic studies by persons interested in the economic geology (e.g., E. P. Chapman, in the 1930's) or sulfosalt mineralogy (e.g., E. W. Nuffield) of the bismuth sulfosalts.
3. 1968 to the present: Modern research. The discovery of bismuth sulfosalts, similar to those of Colorado, at the cryolite mine at Ivigtut, Greenland spurred S. Karup-Møller, and later with his colleague E. Makovicky, to reexamine Colorado specimens in museum collections. Studies by E. Makovicky, E. E. Foord, and others on recently collected material have disclosed many more occurrences of bismuth sulfosalts species in the State. In this recent work many new species have been discerned, usually on a microscopic scale, and many of the older species have been discredited or redefined. Also, recent works, especially university theses, have revealed widespread occurrence of bismuth sulfosalts in Colorado mining districts.

Occurrences of bismuth sulfosalts in the state are principally quartz veins or sulfide replacement orebodies. The bismuth sulfosalts are often closely associated with chalcopyrite, sometimes with barite, and generally with common sulfides such as galena, sphalerite, and pyrite. Many of the literature reports of bismuthinite may actually represent unrecognized bismuth sulfosalts. Bismuth sulfosalts, especially of copper, are also likely to occur in the Precambrian sulfide deposits in the state, although none have yet been reported.

Unlike the classic hypothermal W-Bi-Mo-Sn veins of the world which occur near granites and contain gangue of glassy white quartz, the bismuth sulfosalt-bearing veins of Colorado typically carry only small amounts of molybdenum and tungsten and have a granular grayish quartz gangue. However, molybdenum and tungsten minerals are often present in separate deposits near bismuth sulfosalt occurrences. Thus the occurrence of bismuth sulfosalts, as well as that of their chemical relatives, the tetradymite family, is a very good indicator of nearby molybdenum or tungsten mineralization.

SPECIMEN MINERALOGY OF THE COLORADO SAN JUAN MOUNTAINS
OURAY AND SAN JUAN COUNTIES, COLORADO

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Introduction

The San Juan Mountains are located in the southwestern quadrant of Colorado. They comprise some of the youngest mountains in the state, and consequently are among the highest and most rugged, with many exceeding 14,000 ft. in height. The center of volcanic activity which formed these mountains between 28 and 22.5 million years ago covered a large part of San Juan, Ouray, and Hinsdale counties. Several ancient calderas succeeded one another and overlaid the earlier ones. The San Juan, the Uncompahgre, the Silverton, and the Lake City calderas were all located in the area bounded by the Red Mountains on the west, by the town of Silverton on the south and Lake City to the northeast.

Fissures were generated by repeated volcanic activity, both as concentric rings around the calderas and as long "cracks" radiating outward from the centers as successive intrusions forced their way to the surface. These fissures were later filled in by enriched mineralized solutions. The major mines of the San Juan Mountains are located along these great vein systems and they exploit the intense mineralization of the veins. We will focus on the mineral occurrences of the western portion of this area.

Mineralogy

For the most part, mineralization of the San Juan vein systems is fairly simple: either silver-sulfide enrichment or gold-quartz-gangue associations. Tungsten-quartz veins are also common. The major valuable metals, obviously, are gold, silver, and tungsten. The most common gangue minerals are quartz, fluorite, calcite, barite, and rhodochrosite. Other minerals of significance include chalcopyrite, sphalerite, pyrite, enargite, and tetrahedrite. There are several uncommon species as well, such as pyroxmangite, anatase, cerussite, scheelite, azurite, and malachite.

Although both gold and silver do occur in Ouray and San Juan counties as native elements, they do not form especially showy specimens -- at least compared to gold from Breckenridge or silver from Creede or Aspen.

The really desirable specimens from a collector's point of view are the well-crystallized gangue minerals: in particular rhodochrosite, fluorite, calcite, and quartz. Chalcopyrite, sphalerite, enargite, huebnerite, and scheelite, along with these other species, have also formed outstanding specimens. A summary of the major mines and their specimen mineralogy follows.

OURAY COUNTY MINES

There are many mines in Ouray County noted for well-crystallized mineral specimens.

Camp Bird Mine

The Camp Bird mine is the best known and largest mine in Ouray County. Discovered by Thomas Walsh, this mine produced many millions of dollars for its various owners. Although the Camp Bird has been in operation for most of a century, the best known and most desirable mineral specimens were mined in the 1960s and 1970s from the replacement ore body. Most recently, some very well-crystallized scheelite specimens have come from the East Camp Bird mine, in the vicinity of the old King Lease, which had been first worked during the 1920s.

- Calcite -- Sprays of scalenohedrons in "fans", generally cream-colored; with quartz and sphalerite.
- Chalcopyrite -- Large, brilliant crystals to 3.5 cm, with sphalerite and calcite; mainly from the 14 Level of the replacement ore body.
- Fluorite -- Pale green or colorless cubes to about 2.5 cm; with quartz and dolomite. Rough, pale green octahedra found with scheelite on the 5 Level of the East Camp Bird mine.
- Galena -- Simple lustrous cubes to 2.5 cm, in association with sphalerite and chalcopyrite.
- Quartz -- Long, slender, transparent crystals to 7 cm in sprays, sometimes with flattened disc-like rhombs of calcite coating the tips; also with sphalerite and pyrite; outstanding examples from the 14 Level.
- Scheelite -- Cinnamon-brown octahedra to 5 cm on granular grey-green fluorite or calcite; from the King Stope, 5 Level, East Camp Bird mine.

Sphalerite -- Large crystals are near-black, but appear emerald green when strongly backlit; in association with chalcopyrite and calcite. Best examples are from the replacement ore body.

There are, of course, a number of other species which occur in the Camp Bird, but they do not form large, well-crystallized examples.

Mountain Monarch Mine

The Mountain Monarch mine is located on the Engineer Pass road, just south of Ouray. Within the last ten years, some very fine rhodochrosite specimens to 5 cm across have come from the Mountain Monarch mine, associated with quartz, tiny chalcopyrites, and minor sulfides. Early specimens were labeled as originating in the "Mickey Breen mine" which is the local name of one of the claims in this complex of sixteen patented and unpatented claims.

Grizzly Bear Mine

Also within the last ten years, a project was begun to drive an access tunnel from the Amphitheater, the large cirque east of Ouray, to the old Grizzly Bear Mine. Known as the Zanett Tunnel, it was never completed. However, a number of fine mineral specimens were recovered during this undertaking. The most notable specimens were rhodochrosite on green quartz colored by chlorite inclusions. Other vugs produced fine pale green fluorite octahedrons to 2 cm on stubby quartz crystals. A watercourse produced large rhodochrosite rhombs to 3 cm, which were unfortunately somewhat etched, on drusy quartz.

Senorita Mine

This mine, located in the Pacquin mining district just north of Ouray, is a silver mine with a very sporadic production history. It has produced, however, some outstanding white tabular barite crystals to 5 cm on edge, implanted on drusy clear quartz. Delicate casts of quartz after calcite are also found.

Portland Mine

Located in the Amphitheater east of Ouray, this mine contains fine lime-green sphalerites, associated with calcite, quartz, and small pyrite crystals. The quartz crystals from this mine are similar to those from the Idarado mine.

Ohio Mine

Outstanding large milk-white quartz crystals to 25 cm in length have come from this small mine in the Amphitheater. Sprays of these large crystals as much as 50 cm across are known. Quartz-coated calcite is also found at this mine.

Longfellow Mine

Located on Red Mountain Pass just north of the dividing line between Ouray and San Juan counties, in the 1950s this mine produced one large pocket of outstanding enargite crystals to 2.5 cm. Also found in this mine are skeletal quartz crystals, massive pyrite, and tetrahedrite. Some nice fluorite crystals of pale lavender or white color have also been found.

Other Ouray County Mines

There are hundreds of other mines in Ouray County. Many of these mines have produced well-crystallized mineral specimens worthy of mention; some of the more important are:

Bachelor mine, north of Ouray, has produced some nice calcite sprays similar to those from the Camp Bird mine.

Black Girl mine, just south of the Senorita mine, has produced fans of orange calcite, some of which resemble "wheat sheaf" stilbite from Nova Scotia, on a black, fine-grained matrix.

Crystal Cave, along Canyon Creek, contains large calcite crystals coated with drusy quartz.

Gertrude mine, at the north end of Ironton Park south of Ouray, has yielded some nice fluorite octahedra to 5 cm, coated by drusy quartz; also with associated calcite.

Ores and Metals mine, on the Hayden Trail, contains small crystals of anatase on clear quartz.

Silver Point mine, south of Ouray, has produced fine casts of quartz after barite or anhydrite, dusted with a light hematite coating.

Thistledown mine, on the Camp Bird Road, has yielded large apple-green fluorite octahedrons on etched quartz.

SAN JUAN COUNTY

San Juan County, with Silverton as its only real town, has literally thousands of mines and prospects, many of which contained well-crystallized mineral specimens.

Sunnyside Mine

The Sunnyside mine and its American Tunnel portal have yielded some of the best mineral specimens in the Colorado San Juans. Most of these specimens have been labeled as coming from the "American Tunnel," and some probably have (the tunnel itself was widened and extended in the early 1960s).

Rhodochrosite -- Large baby-pink rhombs to 6 cm on white drusy quartz; especially produced in the early 1960s.

Fluorite -- Green octahedrons, grey-green, lavender, and pale blue cubes, to 5 cm on drusy quartz.

Selenite -- Large, clear spears to 7 cm, with rhodochrosite rhombs.

Other species with well-crystallized examples from this mine include tetrahedrite, pyroxmangite, and pyrite.

Bandora Mine

This mine, located on South Mineral Creek northwest of Silverton, has recently yielded some exceedingly fine specimens of chalcopyrite, sphalerite and quartz. These have

come from the upper levels of the Little Todd vein in the mine. The chalcopyrite crystals greatly resemble those which came from the Camp Bird mine during the 1970s, as well as those currently coming from Peru. Cerussite also occurs in this mine, a rare species for the San Juans.

Yukon Mine

Located on Cement Creek, this mine has produced some outstanding fluorite crystals, appearing as apple-green octahedrons with lavender cores, and associated with huebnerite and quartz. The huebnerite forms attractive red-orange sprays to 6 cm across.

Osceola Mine

This mine is located in Cunningham Gulch, east of the Animas River several miles north of Silverton. It is one of the oldest mines in the district, having been worked as early as the 1880s. It produced fine specimens of calcite, quartz, galena, and sphalerite, as well as some brilliant small chalcopyrites and occasional barite roses.

Ransom Mine

This mine is located just above the townsite of Eureka. It was in litigation and closed down during the 1960s in a dispute over whether ore from the rich veins of the Sunnyside mine was being pirated at this mine. Recently, the mine has yielded some fine, large, complex, pale green to colorless crystals of fluorite, and large plates of white, stubby quartz crystals very similar to those from the Idarado mine. The fluorites have tiny twinned chalcopyrite crystals included within and are coated by a very thin layer of quartz.

Other San Juan County Mines

There are numerous other mines in San Juan County which are noted for fine specimen material, but only of one or two mineral species. Several of these mines include:

Adams mine, near Ross Basin, produced sprays of fine huebnerite when etched out of quartz.

Brooklyn mine, located near the townsite of Chattanooga on State Highway 550 just north of Silverton, is a gold mine which contained some nice wires of gold on black sphalerite, in association with pale pink rhodochrosite.

Bullion King mine, located just south of Red Mountain Pass, has produced some groups of milky quartz scepters on a matrix of iron-stained, porous, "crusty" massive quartz.

Gold King mine, lying next to the Sunnyside mine, has very recently produced some fine apple-green fluorite cubo-octahedrons, lightly coated by drusy quartz, and associated with huebnerite blades.

Pride-of-the-West mine, located just to the east of the Osceola mine, contained some interesting galena crystals of cubo-octahedral form, lightly coated by drusy quartz.

Ruby mine, a tungsten mine, is noted for plates of small, gemmy huebnerite crystals on quartz, with occasional pale green fluorite cubes.

The Idarado Mine

The Idarado mine, which was perhaps the biggest mine in the Colorado San Juans, covers parts of three counties: Ouray, San Juan, and San Miguel counties. The mine actually represents a consolidation of a large number of older mines which lie on the great fissure veins in the northwest quadrant of the Silverton Caldera. Some of the finest mineral specimens of the Colorado San Juans have come from this mine, especially from the replacement ore body, and in particular from the Argentine and Black Bear veins.

Calcite -- Large scalenohedrons to 10 cm long in plates to a meter across. Those colored pink by manganese are especially noteworthy.

Chalcopyrite -- Brassy crystals similar to those from the Camp Bird mine.

Fluorite -- Grey-green, lavender, and colorless cubes, to 10 cm, in association with quartz, chalcopyrite, and calcite.

Quartz -- Large, barrel-shaped milky crystals in large clusters; also clear slender crystals which resemble those from Hot Springs, Arkansas.

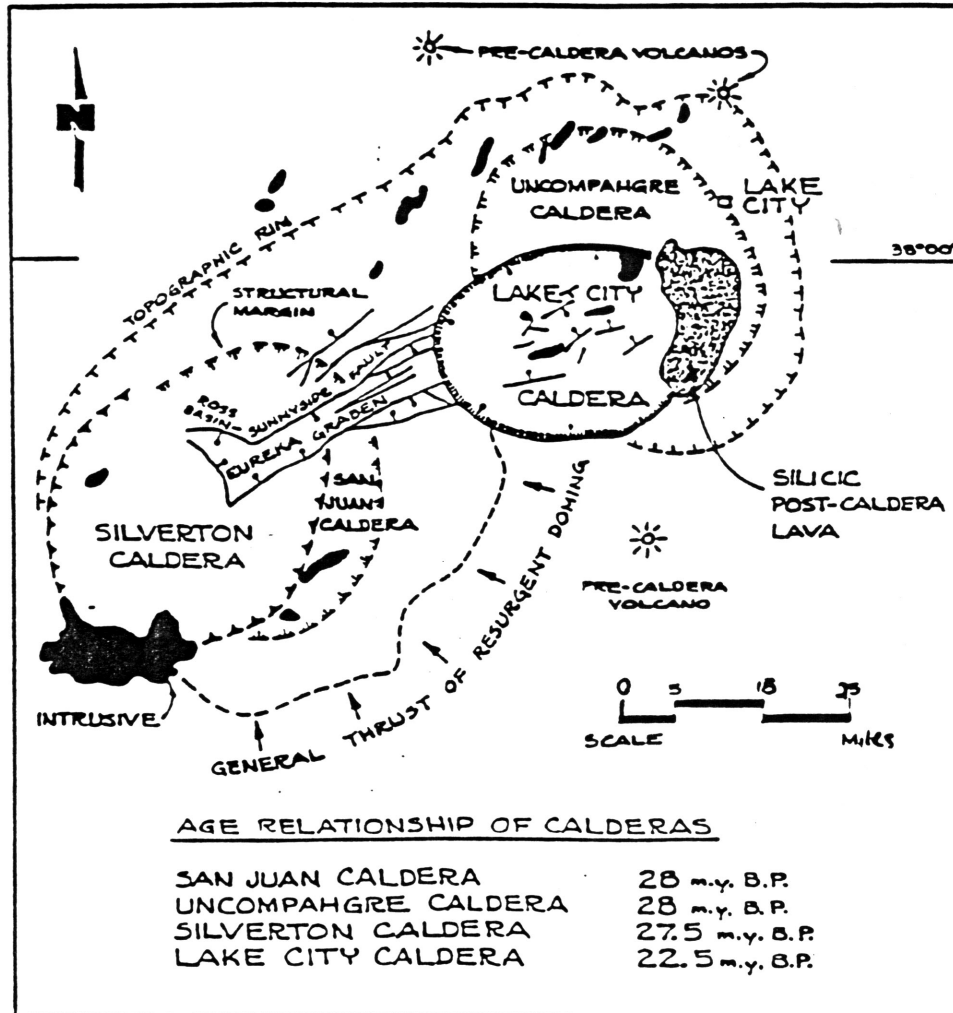
Sphalerite -- Fine, lustrous, black crystals to 6 cm, often with chalcopyrite and quartz. Resembles sphalerite from the replacement ore body of the Camp Bird mine.

Conclusions

The western Colorado San Juans have been a source of some of the finest mineral specimens to come from Colorado. In particular, excellent examples of well-crystallized rhodochrosite, quartz, calcite, barite, sphalerite, chalcopyrite, huebnerite, and enargite have come from a considerable number of mines in this area. Although the species tend to occur in suites, their particular appearance is distinctive to each mine and serves as distinguishing features.

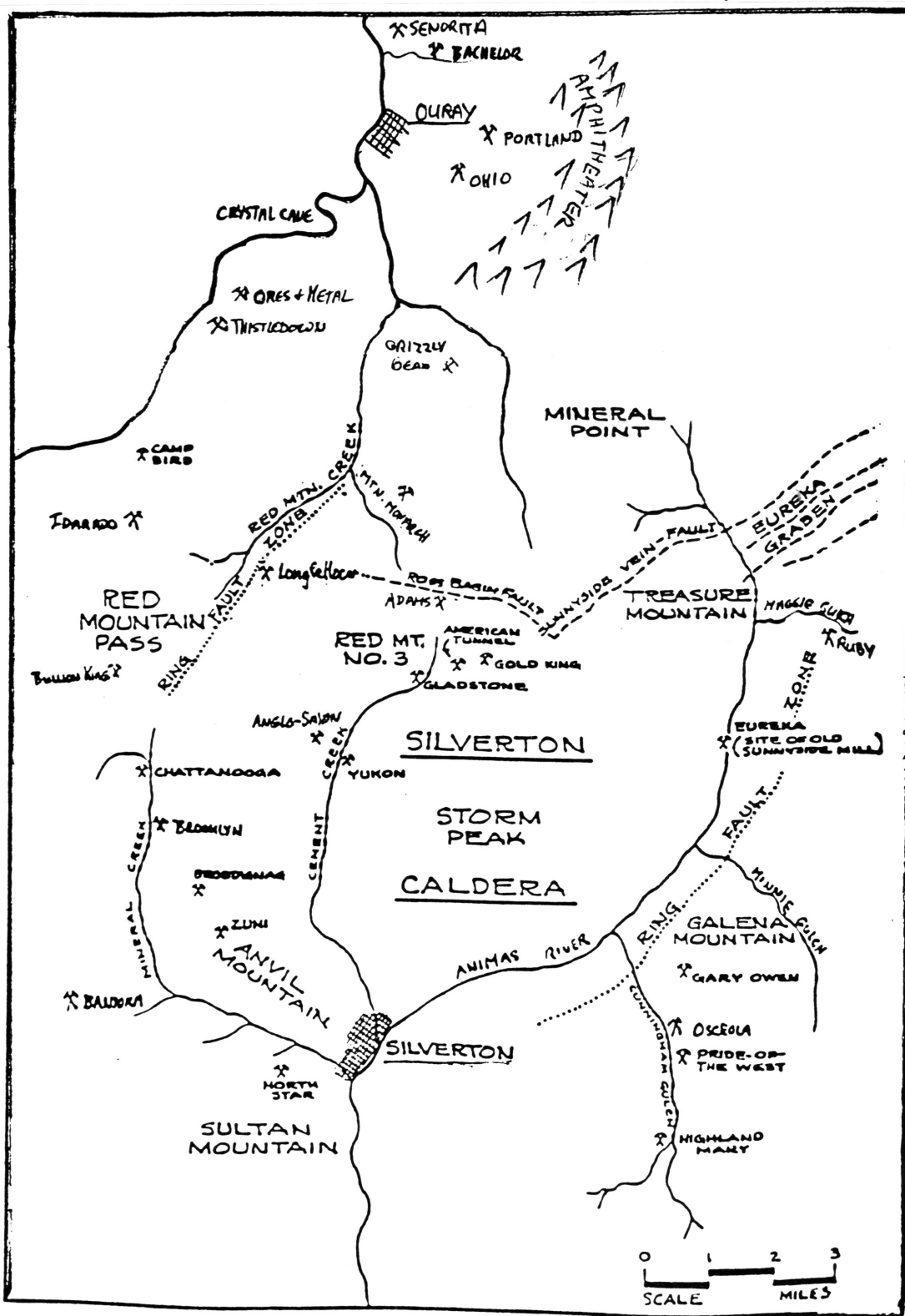
MAP ONE.

CALDERAS OF THE
SAN JUAN MOUNTAINS OF
COLORADO



Adapted from USGS Professional Paper 958 (1976).

MAP TWO. SOME MAJOR MINES IN THE SAN JUAN MOUNTAINS, COLORADO



Adapted from R.W. Holmes and M. Kennedy, Mines and Minerals of the Great American Rift, and W.S. Burbank, Colorado Scientific Society Proceedings, vol. 13, no. 5 (1933).

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MINERALOGY OF THE CREEDE DISTRICT, MINERAL COUNTY, COLORADO

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INTRODUCTION

At least once during a mining district's "life" it is common for either government and/or privately funded scientists to painstakingly "dissect" its geology. At the end of such a study a formal geological report is written and, among other things, the district's mineralogy is discussed. Most of the mineralogical work usually hinges upon a combination of very detailed microscopic study and sophisticated chemical and physical examinations. In order to fully appreciate the mineralogy of the district, one must usually resort to some of the same microscopic techniques that were utilized in the formal study, simply because many of the characteristics of the mineral assemblage are normally too small to be easily seen in any other way. It is extremely rare for readily available hand specimens to clearly show most of the characteristics, mineral habits, paragenetic sequences, assemblages and associations that are studied in a geological/mineralogical investigation. It is also unusual for easily obtainable hand specimens to show evidence for most of the geologic phenomena that controlled the processes of ore deposition within the district. Creede is unique among Colorado's precious metal mining districts in that hand specimens showing many of the prominent features of the district's mineralogy and geology can still be obtained.

Another pertinent matter in the Creede story is the nature of geologic investigation to which the district has been subjected. Emmons and Larsen (1923) first described the Creede district in the typically thorough U.S. Geological Survey style after the standards set by Emmons' father, S. F. Emmons, in his classic monograph on the Leadville District. At the time of this original compilation the complex caldera-dominant volcanic pile that makes up the San Juan Mountains was not at all well understood. Much progress had been made in volcanology by the time of Steven and Ratté's (1960 and 1965) works on Creede, and a suggestion for prospecting led directly to the discovery of ore in the deeper portions of the Bulldog Mountain fault zone. A coherent geologic understanding of the district in its relation to the San Juan volcanic pile was being first formulated during these years. Steven's and Lipman's regional studies in the San Juans (during the late 1960's and continuing through the 1970's) finally put the Creede District into proper perspective as part of a stacked and partially overlapping cluster of at least five calderas in the sprawling discombobulation known as the central San Juan caldera complex. In the mid-1970's a series of papers describing the environment of ore deposition at Creede was published in Economic Geology. Steven and Eaton (1975) described the regional geology; Bethke, Barton, Lanphere, and Steven (1976) described not only the age of mineralization, but also placed the timing of mineralization within the various eruptive sequences; Barton, Bethke and Roedder (1977) described the mineralogical parameters of the district; and Bethke and Rye (1979) described the sources and nature of the mineralizing fluids that formed the ore deposits. Research by U.S. Geological Survey scientists is continuing to this day. Finally, Robinson and Norman (1984) studied the mineralogy of the southern Amethyst vein system within the district. These studies have added up to making Creede one of the better understood districts in the United States.

GEOGRAPHICAL AND HISTORICAL BRIEF

The Creede mining district (Fig. 1) lies near the confluence of Willow Creek with the Rio Grande River. The town of Creede is located along Willow Creek below the junction of its East and West branches, and upstream from its juncture with the Rio Grande. The entire district has been part of Mineral County since it was separated from Hinsdale County in 1893 (Emmons and Larsen, 1923).

John C. McKenzie made the original mineral discoveries in the area in 1876 with his discovery of the Alpha mine at Sunnyside, three miles southwest of Creede. In 1878 McKenzie located the Bachelor mine on Bachelor Mountain, just west of West Willow Creek. Neither of these discoveries caused any excitement as Colorado was just beginning to reverberate from the fantastic Leadville discoveries. In 1889 Nicholas C. Creede (real name-William Harvey) located the Holy Moses mine on East Willow Creek. It was this discovery, more than any other, that led to the sudden boom of the Creede camp (though not yet named), when a large shipment of ore was made late in that year. One of the interested parties was none other than David Moffat who quickly engaged Nicholas Creede's services as a "contract" prospector. Moffat eventually became a major investor in the district as well as a principal stockholder in several of the mines. Moffat's interest in the district assured that the fledgling camp's boom would be heard loud and far (Mumey, 1949; Feitz, 1969; Wolle, 1949).

In addition to the Alpha, Holy Moses, and the Bachelor mine (which was purchased by the principals of the The Holy Moses Mining Co.) other claims were soon discovered; the best known and most profitable were all located along the Amethyst vein system (which runs roughly parallel to West Willow Creek). From the part of the vein near Creede and running north the original claims were: Bachelor, Copper Vein, Commodore, New York, Del Monte, Last Chance, Amethyst, Happy Thought, White Star, and Park Regent. The Holy Moses mine was located on the Solomon-Holy Moses vein system (roughly paralleling East Willow Creek). The claims located on this vein system were the Solomon, Ridge, Holy Moses, and Phoenix. Up until the development of Homestake Mining's Bulldog Mountain Project (*aka* Bulldog mine) the Amethyst, Commodore, Bachelor, and Last Chance accounted for over 90% of the district's silver production (Emmons and Larsen, 1923; Meeves and Darnell, 1968).

Following the initial discoveries, the camp boomed into one of the last of the "rip-roaring" western mining towns whose legends have far outlived both fact and time. The arrival of the Denver and Rio Grande Railroad's extension line from nearby Wagon Wheel Gap paid for itself in four months (Feitz, 1969). During the boom (which ran from 1890 through 1893) two passenger trains each way serviced Creede each and every day. The assortment of unsavory characters that they brought made Creede the last stand for a western rogues gallery that was unsurpassed in both color and deed. From Soapy Smith (con artist supreme) and Bob Ford (killer of Jesse James) to Bat Masterson (former peace officer turned saloon owner) the notorious parade kept the place alive twenty-four hours a day (Mumey, 1949; Feitz, 1969; Hauck, 1979.)

Production in Creede's early days was mainly from the rich oxidized zone, reaching a peak in 1893 of almost 4.9 million ounces. In October of that year Congress repealed the Sherman Silver Purchase Act, thus removing the governmental subsidy that had held up silver prices for several years. While there is no doubt that the repeal helped to send the silver mining camps of the American west into decline, the downward trend in silver prices had begun many years earlier. Prices had dropped from an annual average of \$1.34 per ounce in 1871 to \$.87 in 1892. The entire national economy was on shaky ground, from the over-extended railroads to the over-producing silver mines, so when the British closed their mints in India in June, 1893, the price of silver dropped from \$.82 to \$.62 per ounce. The actual ending of price supports only caused the market to bottom out at a penny down from that previous record low, and that did not occur until March, 1894. The depression that

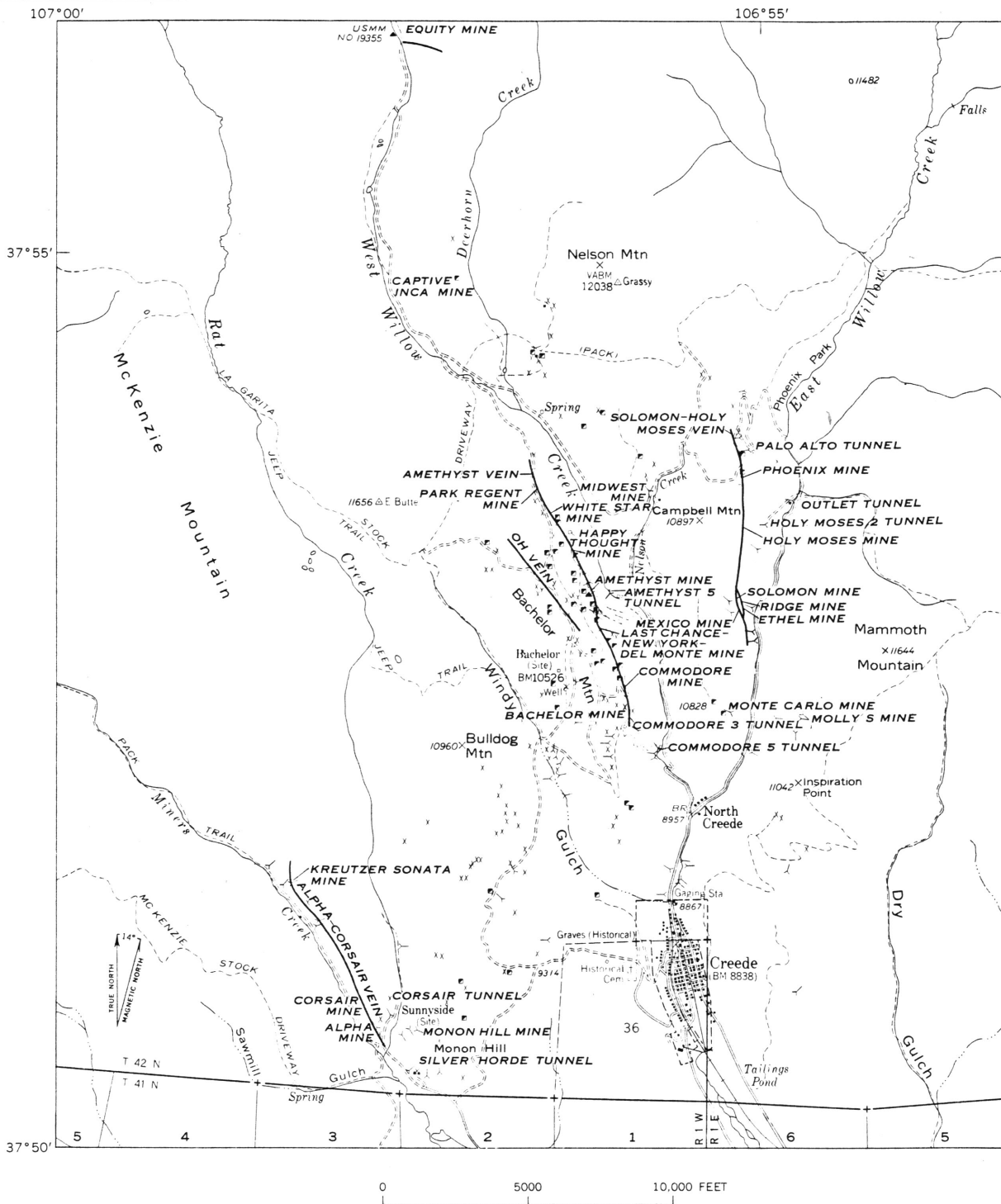


FIGURE 2.—Productive veins and principal mines in the Creede district, Colorado.

Fig. 1 Mines of the Creede district (from Steven and Ratté, 1965, U.S.G.S. Prof. Paper 487, p. 4).

followed, however, was real enough throughout the American West, and as silver mining took a nose dive--Creede's boom days came to an end (Blair, 1980; Henderson, 1926; Mumey, 1949).

By the early 1900's the mines were into the sulfide zone, and production of any remaining rich oxidized ore was sporadic at best through 1916. The sulfide ores required beneficiation, so during the following years the district saw numerous milling operations established. Among the best known were the Amethyst, the Solomon, and the Ridge, with each dressing ores from their respective mines, and the Humphreys which was built mainly to handle the ores from Creede United Mines, operator of the Happy Thought, White Star, and Park Regent mines on the northern end of the Amethyst vein system (Emmons and Larsen, 1923).

Around the turn of the century several access tunnels were driven to tap deeper portions of the Amethyst vein system, serve as haulage ways, and drain the mines along the vein system. The Nelson Tunnel Co. had driven a deep drainage adit in the 1890's. The tunnel did not encounter any significant ore bodies so the idea of simply using it as a haulage way began to have more appeal. This tunnel was lengthened twice, as part of two separate projects--the Wooster Tunnel and the Humphreys Tunnel. The combined efforts became known simply as the Nelson Tunnel. It extended over two miles along the vein system from the portal at the southern end to the Park Regent workings at the northern end, with its track continuing on beyond the portal to the Humphreys Mill. The Nelson Tunnel was only being utilized as a drainage way by the 1960's (Meeves and Darnell, 1968). At the same time as these projects were being undertaken, the Commodore Mining Co. drove its own tunnel approximately 45 feet above the Nelson Tunnel into its own workings (Emmons and Larsen, 1923). Not long after this work had been completed, the Panic of 1907 drove silver prices down approximately 22% from \$.68 to \$.53 per ounce, troy. The camp never really did recover from this setback, even though the World War I metals boom provided a brief respite from hard times (Hauck, 1979).

In 1917 the Creede Exploration Co., a subsidiary of the American Smelting and Refining Company (ASARCO), consolidated several properties along the Amethyst vein system, but not much ore was discovered and the company did not make any contribution to the further development of the district. After World War I the mines were operated mainly by lessors, the most enduring of whom was Herman Emperius (spelled Imperious in Larsen, 1929), first in partnership with B. T. Poxson (spelled Poxin in Feitz, 1969) as the Poxson and Emperius Leasing Co.--1934 to 1938, and then by himself in the Emperius Mining Co. from 1938 on. Other leasing operations on the Amethyst vein system included the Sloan Lease (Amethyst), Dean Lease (Commodore), Withrow Leasing Co. (Commodore), Morgan and Sloan (Last Chance), Amethyst Leasing Co. (Amethyst), and Hollister and Futterer (Del Norte, New York, & Equity) (Emmons and Larsen, 1923; Larsen, 1929; Meeves and Darnell, 1968; Steven and Ratté, 1965). These leasing operations saw Creede through the 1930's, but when silver hit an all time low of \$.25 per ounce during the Great Depression (from 1930 through 1933) the district shut down all operations. Finally the price was fixed at 65.65 cents per ounce (by presidential decree) and mining was resumed in 1934 (Steven and Ratté, 1965).

Through the remainder of the 1930's several of these leasing companies began to consolidate their holdings and acquire the properties that they had been leasing. Emperius' efforts were by far the most successful, and his holdings eventually included most of the important properties along the Amethyst vein system. During these years the Emperius Mining Co. produced ore from the southern and middle portions of the Amethyst vein system's hanging wall. The company made several important discoveries in the hanging wall sections of the Last Chance-New York-Del Monte group, which were developed as the P and E workings. Then in 1938 (or 1939?) the OH vein was discovered extending northwestward from the Amethyst vein system. Most of the district's production during the 1940's and 1950's came from this vein (Steven and Ratté, 1965; Meeves and Darnell, 1968). Production was from the oxidized zone of the vein during the early years, and showed correspondingly high silver values, but after 1946 the operations produced mainly from primary sulfides (or only partly oxidized ore), with high base metal values. In 1940, Emperius

Mining Company took over milling operations at the flotation mill which had been originally built by Creede Mills, Inc., in 1937. Emperius' operations were carried on by lease arrangement at first, but the company purchased the mill in 1945 and renamed it the Emperius Mill. Milling operations were interrupted for nine months when a fire destroyed the mill in August 1955 (Steven and Ratté, 1965).

By the 1960's Emperius Mining Co. controlled 50 patented claims along the middle and southern portions of the Amethyst vein system. Creede Mines, Inc., controlled many claims along the northern portion of the Amethyst vein system, while Colorado Imperial Mining Co. held 103 claims on East Willow Creek along the Solomon-Holy Moses vein (Meeves and Darnell, 1968). Yet the most significant exploration work to be done in the district during these years was not a project of either company, but instead was the result of U.S. Geological Survey research.

The late 1950's and early 60's saw the beginning of yet another round of study by the U.S. Geological Survey. Steven and Ratté (1960) recognized that the Bulldog Mountain fault zone represented an antithetic fault system developed as part of the complex Creede graben. They also speculated that the Bulldog system intersected the Amethyst fault (vein) system at depth, and therefore should have received the same influx of mineralizing solutions that was responsible for mineralization of the Amethyst vein ore bodies. As a direct result of their recommendations an exploration project led to the discovery of an ore body in the deeper portions of the Bulldog Mountain fault system, an area that had been unsuccessfully prospected in its upper (and barren) portions in the district's early days (Meeves and Darnell, 1968). This discovery is one of the better examples of good geologic work bearing fruit. Majority ownership in Bulldog Mountain, Inc. (operator of the Bulldog mine) is Homestake Mining.

The 1980's also saw another significant discovery in the Bulldog Mountain area, as other vein systems that could be projected to intersect known ore-bearing vein systems were explored as part of extensive core drilling projects. These ore bodies are currently being developed as a joint project between the various companies holding interested claims.

GEOLOGY

The Creede district's vein systems developed through mineralization along portions of a complex graben system that formed as subsidence features during caldera collapse. The geology of the San Juan volcanic pile, of which Creede is a part, has been adequately described elsewhere, especially in Steven and Lipman (1976); Lipman (1975); Lipman, Steven and Mehnert (1970); Luedke (1968); Ratté and Steven (1964 and 1967); Steven, et al., (1974); Steven, Luedke and Lipman (1974); and Steven and Ratté (1965 and 1973). It is not the purpose of this presentation to go into a detailed geologic description of the district; instead we will deal with that part of the geology that concerns the mineralogy of the ore deposits. (Note: all of the geological information is taken from the above-named sources. It is much too complicated to credit each idea to a single source, so for the purposes of this extended abstract, the author simply credits all of the above-named sources. Additionally, the mineralogical information is drawn from the series of papers published in Economic Geology and already mentioned in the introduction. To simplify matters, again, the ideas here are from these sources, and are not easy to separate out as they are so interdependent.)

During the volcanic evolution of the Creede district there were at least five episodes of volcanic eruptions that resulted in caldera collapse structures that partially overlap each other. These calderas (listed in order of formation) were the La Garita, Mammoth Mountain, Bachelor, San Luis, and Creede. Shortly following development of the Creede caldera, a hydrothermal convection cell developed that circulated mineralizing fluids through the central graben fault system (developed during resurgent doming) of the Bachelor caldera. The waters in this cell circulated up from the postulated, buried stock, toward the northern end of what was to become the Amethyst vein system,

through the length of the vein system, and back down toward the heat source of the buried stock. There were probably several points which replenished the convection cell with an influx of meteoric waters during the life of the cell.

The Creede district's convection cell model of ore deposition has led to a more unusual style of mineralization than is usually associated with the standard "in, deposition through, and then out" hydrothermal system. Construction of a table of paragenetic sequences for the entire district is meaningless, as the circulation led to different equilibrating conditions at each point within the vein system. For instance, as the waters rose at the north end of the system they might be saturated with respect to the lead and sulfur ions that could combine to deposit galena. As these waters traveled through the vein system they would deposit galena until either equilibrium was reached with respect to galena, lead and sulfur, or perhaps the waters would actually reach a point of undersaturation with respect to galena and thus dissolve some formerly deposited galena crystals.

As might be expected, this system of mineralization has led to some very curious specimens, for each mineral and group of ions would be subject to similar disequilibrium conditions in the system. Each mineral and set of ions, however, might or might not be independent with respect to the conditions that controlled deposition of all the other minerals. The ore textures show alternating deposition and resorption features of several generations, often with superposition on other minerals showing one or more such episodes themselves.

In addition to simple deposition and resorption features, the ores also show textures that reflect the rate of crystal growth, another characteristic that is dependent on the degree of saturation for a given set of ions in the mineralizing fluids. It is fairly common to find a skeletal crystal (indicating rapid growth from highly oversaturated solutions) that also shows both etching (indicative of undersaturation) and small epitaxial overgrowths (indicating a second period of growth). It is also common to find crusts of one mineral with impressions on the "underside" left by now completely resorbed crystals of another mineral. Sometimes the "crust" is left as a layer over a partially resorbed mineral.

Because of the nature of the open spaces available for mineral precipitation--openings in a fault breccia--the textures often show up in strange combinations that are partially repetitious, partially overlapping, and occasionally oriented on a directional basis that was obviously controlled by direction of flow. Additionally, the breccia is often not completely filled, so that the minerals had open spaces in which to grow as euhedral crystals.

Robinson and Norman (1984) worked out the paragenesis of the southern portions of the Amethyst vein system, but the scheme is quite complicated as might be expected, and includes two major stages of mineralization, with the second stage subdivided into three substages. Also, the deposit was subjected to oxidation, with some areas of secondary sulfide enrichment, but a scheme of paragenesis is again difficult to establish except on a localized basis because of the non-uniform nature of mineral deposition throughout the district. The early bonanza ores were from the oxidized zone in the veins, but few specimens seem to have survived the years. The more recent discoveries in the OH vein and in the Bulldog Mountain fault system have been associated with a zone of secondary sulfide enrichment. The nearly ubiquitous association of wire silver with partially corroded acanthite (paramorph after argentite) crystals leads one to speculate on a period of slight "reheating" to trigger the silver's growth. Perhaps the continuing "rise" and intrusion of a pluton into the near subsurface led to a rise in temperature during the later stages of mineral deposition?

MINERAL DESCRIPTIONS

ACANTHITE (silver sulfide) found as cubic crystals, pseudomorphic after argentite, up to 10 mm on an edge. Often found slightly to moderately altered with wire silver "growing out" of a crystal face. Most, if not all, *wire* silver develops as a result of heating acanthite (Edwards, 1960; Ramdohr, 1980).

ANGLESITE (lead sulfate) reported in Emmons and Larsen (1923) as the most common alteration product of galena. Not often seen in today's ores, but it may turn out that some of the stalactites composed of what are obviously secondary minerals are primarily anglesite.

ARGENTITE (silver sulfide) paramorphed by acanthite.

BARITE (barium sulfate) large blades of white barite up to 15 cm by 10 cm have been found in the OH vein. Barite is a very common mineral in the district, and is often found in banded ore with quartz, silver, and several sulfides and sulfosalts. Specimens of quartz molds around resorbed barite crystals have been found. Most of these molds are 10 to 12 mm by 6 to 7mm in their maximum dimension.

CALCITE (calcium carbonate) reported by Emmons and Larsen (1923), but it is a fairly scarce mineral in the ore deposits, occurring only in small crystals.

CERUSSITE (lead carbonate) groups of "jackstraw" crystals were very common in the early oxidized bonanza ores. They have also been found in the oxidized portions of the Bulldog fault system, and some of these crystals have been observed in twinned growths. Some "jackstraw" cerussite is found with crystals to 6 to 8 cm, but most is in the 1.5 to 3 cm range. One specimen from the old mining days has been observed with hollow crystals that have openings of 1 to 1-1/2 mm.

CHALCANTHITE (hydrous copper sulfate) reported by Emmons and Larsen (1923), and Meeves and Darnell (1968). Occurrence should probably be verified as it may well be ktenasite that has actually been observed.

CHALCOPYRITE (copper, iron sulfide) pseudo-tetrahedral, sphenoidal crystals of chalcopyrite are one of the more common sulfide minerals found in the district. Some crystals reach nearly 15 mm in length, but most are 5 to 7 mm. Often the crystals are coated with a thin oxidized layer of ktenasite.

CHAMOSITE, variety THURINGITE (chlorite group) (hydrous iron, aluminum silicate) a common gangue mineral in the Amethyst vein system. Sometimes the mineral is found replacing the fragments of volcanic rock that make up the fault breccia.

CHLORARGYRITE (silver chloride) Nicholas Creede's discovery of the Holy Moses mine was reported to have been punctuated by the exclamation: "Holy Moses, look at the chloride of silver!!" Although the mineral was very important in the early bonanza ores, it was seldom preserved as a specimen for the simple reason that, as a general rule, it is a grossly unattractive mineral.

CHRYSOCOLLA (hydrous copper silicate) reported by Emmons and Larsen (1923), but not a commonly-seen mineral today.

COPPER (native element) small compound crystal growths of native copper have been found in the Bulldog mine in what is obviously secondary mineralization. The crystals are flattened and elongated octahedrons that closely resemble the "spear point" habit seen in material from Ray, Arizona.

CUPRITE, variety CHALCOTRICHITE (copper oxide) a small quantity of the reddish, fibrous variety of this mineral species was found in the oxidized ore at the Bulldog mine.

FLUORITE (calcium fluoride) a relatively rare mineral at Creede. The author has observed clear octahedrons up to 3 mm on an edge (OH vein, Bachelor mine), and light purple octahedrons of a comparable size (Commodore mine). Specimens with "impressions" of a resorbed octahedral mineral have been found in quartz. While the resorbed mineral could have been pyrite or galena, it seems just as likely that it could have been fluorite.

GALENA (lead sulfide) found as cubic crystals, sometimes of very large size (up to 10 cm on an edge), with the cubic faces occasionally modified by octahedral faces. More rare are octahedral crystals, occasionally found up to 4 cm on an edge, but more often in the 5 to 15 mm range. Some spinel law twins have been observed. Most galena in the district takes on at least a slightly skeletal habit, and/or may be slightly etched or even partially resorbed. At least one specimen (Commodore mine) has been seen that has been almost totally resorbed with only one corner of a cube extending downward toward the former center of the crystal in a triangular cross section (exactly like the Elmwood mine, Tennessee fluorite specimens).

Some specimens (especially from the Bulldog mine) are quite spectacularly skeletal and twinned, while others show several generations of growth and resorption. Another unusual specimen (OH vein, Bachelor mine) is slightly skeletal, with elongated impressions where the galena was in contact with a now resorbed bladed mineral during its final stages of growth. In some "grooves" or impressions, very small blebs of acanthite are growing in a linear orientation. Epitaxial overgrowths of chalcopyrite are occasionally found on galena crystals (Bachelor mine).

Stalactites of mixed sulfides with a generous sprinkling of galena cubes (to 3 mm on an edge) were found in the OH vein, Bachelor mine. Specimens made up of 5 to 7 mm cubes in parallel growth have also been found in the district.

GOLD (native element) reported in the values from production of the ores, but not as a distinct mineral species. The author has seen one gold specimen with less than a well documented pedigree giving Creede as a location and prefers to consider the specimen mislabeled.

GOSLARITE (hydrous zinc sulfate) reported as a post-mining efflorescent material by Emmons and Larsen (1923). Micro sprays of goslarite have been collected on the Commodore dumps.

GYPSUM (hydrous calcium sulfate) reported by Meeves and Darnell (1968), occasionally seen in micromount material.

HEMATITE (iron oxide) definitely not found in great quantities at Creede, but the mineral is widely enough dispersed as a fine dusting of reddish brown "powder" on other crystals, that it can serve to identify a specimen as being from Creede.

JAROSITE (potassium, iron sulfate hydroxide) reported in outcrop samples by Emmons and Larsen (1923). This species has not been reported since then, but it is usually skipped over in most mining districts.

KAOLINITE (hydrous aluminum silicate) fairly abundant as an alteration product of plagioclase in rock fragments of the breccias.

KTENASITE (hydrous copper, zinc sulfate hydroxide) usually found as thin, blue-green crusts coating chalcopyrite crystals, or as small blebs mixed in with partially oxidized sulfides. It is possible that the chalcantite identified by some workers might have been misidentified ktenasite.

"Limonite" (mixture of various hydrous iron oxides) not of particularly common occurrence at Creede except in outcrop.

MALACHITE (copper carbonate hydroxide) reported by Emmons and Larsen (1923), but not in abundance. It is only rarely seen today, usually as thin crusts and blebs. Much of what is called malachite is probably ktenasite.

MARCASITE (iron sulfide) is not reported as being particularly abundant by Emmons and Larsen (1923), but the botryoidal iron sulfide noted by Barton, Bethke, and Roedder (1977) may very well have been deposited as marcasite and then altered to pyrite. The botryoidal iron sulfide is very unstable as a general rule, altering readily to melanterite. An interesting observation is the association of botryoidal iron sulfide with pyrargyrite--this ruby silver mineral is almost never found without it in the ores from the Bulldog mine.

MELANTERITE (hydrous iron sulfate) Emmons and Larsen reported this to be a common mineral found coating the walls of the drifts. The collector is much more likely to find it coating his specimens, as many Creede pieces appear to be somewhat unstable even when no pyrite or marcasite is visible. Specimens that show some formation of melanterite should be isolated from other specimens in order to prevent a chain reaction.

ORTHOCLASE, variety ADULARIA (potassium, aluminum silicate) reported by Emmons and Larsen (1923) in thin veinlets found in the wall-rock of the Amethyst mine. Barton, Bethke, and Roedder report K-spar to be widespread in the OH vein, but not found in large quantities.

POLYBASITE (silver, copper, antimony sulfosalt) not reported by Emmons and Larsen (1923), but their "stephanite" may very well be a misidentification of polybasite. Most specimens are massive and seen in the banded ore of the Bulldog mine. A few micro-crystals 1 mm across have been seen in small vugs.

PYRARGYRITE (silver antimony sulfosalt) not reported by Emmons and Larsen (1923), but seen in the zone of secondary sulfide enrichment in the material from the Bulldog mine. Almost always associated with botryoidal iron sulfide, usually in 1 to 3 mm crystals. Some specimens have crystals up to 5 mm, and one has a single 25 mm crystal, but these are quite rare.

PYRITE (iron sulfide) is not nearly as common a sulfide as either sphalerite or galena. Perfectly formed "floater" crystals showing the pyritohedral form are occasionally seen up to 15 mm across. Octahedral pyrite is also seen, but is not as common as that showing the pyritohedral form. Rarely, combinations of octahedrons and pyritohedrons are observed. Cubic forms are seen as modifications on pyritohedrons, but are only rarely seen as complete crystals. In addition to well-formed crystals of pyrite, botryoidal iron sulfide is found throughout the OH vein. It may well be that this material is pyrite after marcasite.

PYROMORPHITE (lead chloro-phosphate) reported by Emmons and Larsen (1923), but not observed by the author. Small crystals of mimetite have been observed in ores from the Bulldog mine. See mimetite.

PYROSTILPNITE (silver antimony sulfosalt) the monoclinic silver, antimony sulfosalt has been found in a few specimens from the Bulldog mine. The long slender crystals are coated with an epitaxial overgrowth of polybasite and have a minor association of pyrite. They are approximately 7 mm long, and are often grouped in subparallel clusters of 5 to 7 crystals.

QUARTZ (silicon oxide) found as the clear, milky, and amethystine varieties throughout the district. In addition, several types and colors of chalcedony are found in the deposits. The most notable occurrence of quartz is the amethyst, for which the Amethyst vein system is named. Eighty to

140 mm-thick bands of amethyst were prized specimens found on the mine dumps in the 1950's. These specimens were actually coarsely drusy plates of pale amethyst. The crystals only rarely reached more than 1 cm of freestanding separation, even though the total length of the crystals (easily seen in cross section) was up to 6 cm. Amethyst was also a common cement holding the breccias together, and has been found in association with most of the other minerals of the district. Isolated crystals (on matrix) up to 4 or 5 cm are not common, but are sometimes seen.

RHODOCHROSITE (manganese carbonate) relatively rare at Creede, rhodochrosite is found in two habits. The first is small scalenohedral crystals of 4 to 6 mm length, usually with a secondary rhodochrosite overgrowth that gives them a dirty tan/pink appearance. The second is as crusts and botryoidal growths, sometimes partly resorbed. These are reniform, partly radiating crusts, 5 to 10 mm thick, that are almost, but not quite, botryoidal. The true botryoidal growths are much smaller, never more than 2 or 3 mm across, and are often intergrown with blades of barite.

SIDERITE (iron carbonate) reported by Emmons and Larsen (1923), but not extremely common. Often found in association with fluorite. Sometimes seen as tiny "saddle crystals" not over 2 mm across.

SILVER (native element) found in a remarkable number of habits and associations throughout the district. Massive native silver was found as bands in the rich "banded ore" of the Bulldog mine. The silver was deposited as a distinct band (up to 15 cm wide) along with galena, polybasite, acanthite, quartz, and barite.

Silver wires, usually associated with and often growing directly from acanthite, have been found throughout the district--almost exclusively in the zone of secondary sulfide enrichment. This association is certainly one of the better examples evidencing the most common origin of wire silver. The wires are commonly 1 mm in diameter and range up to 40 to 50 mm in length and are often tangled in complex "birds-nest" growths. The district has produced some truly exceptional specimens. One famous specimen is a single wire, approximately 5 mm at its greatest diameter, and over a meter long!! Another spectacular specimen consists of a "rope" of silver 200 mm long by 20 mm in diameter!!

Another habit is approximately half way between wire and arborescent or compound "spear-like" growths. The strands are remarkably straight, unlike the wire habit. They are usually no more than 2 mm in diameter, and 20 mm in length, and are found in complexly intertwined clusters that are no more than 25 to 30 mm across.

Arborescent growths are comparatively rare, but were considered one of the truly spectacular types of specimens from the Bulldog mine. They were usually no more than 20 mm in length, and 10 mm across. A series of very closely spaced but quite distinctly formed "branches" are found to be "growing" (in parallel growth?) out of a "trunk". The delicacy seen in these specimens is absolutely incredible--they rival the finest Batopilas herring-bone growths in their beauty and intricacy.

Creede has also produced specimens with fine (although small) euhedral crystals of silver. Most are somewhat elongated and not over a few millimeters in size, but they are often found perched on amethyst!

The last major habit to be encountered is that of "leaf" silver. Some "leaves" are up to 100 mm across, and only 1/2 mm thick, but most are 20 to 30 mm across. They are all so thin that they seem to shimmer like aspen leaves when the specimen is jarred. Some "leaves" take on an appearance of having been shredded, as they are more "ribbon-like", and are found in complex intergrowths, usually in clusters not over 40 to 60 mm across.

SMITHSONITE (zinc carbonate) reported by Emmons and Larsen (1923), but not a common mineral in the district.

SPHALERITE (zinc, iron sulfide) one of the most common sulfide minerals in the district. Specimens usually show fairly complex crystals, some with spinel law twinning, and others with minor polysynthetic twinning. The iron content varies greatly from specimen to specimen, and also

from core to rim within single crystals. The iron content variations within single crystals were used to establish the "pulses" of the circulating waters within the convection cell. Sphalerite crystals vary in color according to the amount of iron content, with some showing a bright yellow green color (low iron), and others showing a deep blackish brown color (high iron). Partial resorption of sphalerite crystals leaves an irregular fluted texture, not unlike that produced in partially dissolved limestone.

STEPHANITE (silver antimony sulfosalt) reported by Emmons and Larsen (1923), but not since then. It is certainly possible that all of this material is actually polybasite.

STIBNITE (antimony sulfide) has been reported as a rare mineral by Barton, Bethke, and Roedder (1977), but has not been observed by the author. Apparently this mineral was found only in a certain section of the OH vein, and was rare even at this location.

TETRAHEDRITE/TENNANTITE (copper, iron, zinc, antimony/arsenic sulfosalt) euhedral crystals are quite rare at Creede, which is probably the reason that it was not reported by early workers. As a massive mineral (especially in the banded ore of the Bulldog mine) it is fairly widespread, though never in large concentrations.

"Wad" (mixture of hydrous manganese oxides) fairly abundant in the oxidized ores of the early days.

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Mineralogy of the Patch Mine, Gilpin County, and the Alice Mine, Clear Creek County, Colorado

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The Patch and Alice mines, located in the Front Range of Colorado, are combined here because of their similar geologic features - they are both stockwork ore deposits that have been developed by open-pit mining. These mines have similar gangue minerals, but show differences in sulfide mineralization, and have produced excellent mineral specimens.

Location and History

The Patch mine (often referred to locally as "the Glory Hole") is located on Quartz Hill, approximately 1 mile southwest of Central City in Gilpin County. The Patch mine was located by W.M. Muchow in 1929, who consolidated numerous older mining claims (such as the San Juan, Rhoderick Dhu, Little Pittsburgh, Gardner, and Climax mines, among others) on Quartz Hill; these mines were subsequently developed by open-pit methods. A Chicago-based company known as the Chain O' Mines operated the Patch mine on a large scale until 1937; work has proceeded intermittently since then. In addition to an extensive open pit, the orebody is developed by three tunnels: the LaCrosse tunnel, which enters from the north at the 300-foot level, the Quartz Hill tunnel entering from the east at the 700-foot level, and the Argo (formerly Newhouse) tunnel that enters from the south at the 1,650-foot level. A milling plant (located southeast of the glory hole) with a capacity of more than 5,000 tons per day was reportedly operating on a limited basis during the early 1950's.

The Alice mine is located about 10 miles northwest of Idaho Springs, in Clear Creek County, and is accessible from Fall River Road. This property was first located and developed as a placer deposit; more than \$60,000 in gold was reported to have been produced from it by the use of hydraulic mining methods in the early 1880's. Free-milling oxidized ore that was uncovered during the placer operations was subsequently processed by a stamp mill located on the property. The mine operated until 1915, but lay idle for a period thereafter when attempts to treat the unoxidized ore proved unsuccessful. The increase in the price of gold in 1933 led to the re-opening of the mine; considerable work was done between 1935 and 1938, resulting in a large open pit and irregular underground workings. A 200 ton-per-day mill was built in 1936; ore was transported from the glory hole to the mill through a 250-foot-long tunnel. Approximately 350 to 400 ounces gold per month and 6 tons per day of concentrates (containing about 0.8 ounce gold per ton) were produced from the mine during this period of operation.

Geology

The mines are located in an area of the Front Range that is composed mostly of Precambrian rocks (granite, schist, and gneiss) formerly known as the Idaho Springs Formation. Both mines are

stockwork ore deposits; each consists of a pipe or chimney-like body of fractured porphyry of irregular shape that intruded the Precambrian gneiss and schist. The porphyries are cut by a network of branching and interconnecting small veinlets in such a fashion that the entire ore body must be mined - in this case, by glory hole or open-pit operations. The Alice mine differs from the Patch mine in that most of the fracture openings are narrow and the breccia fragments are not substantially displaced relative to one another, as they are in areas of the Patch mine. Furthermore, mineralization in the Alice mine has been mostly by metasomatic replacement, whereas mineralization in the Patch mine has been accomplished mainly by fissure filling.

The Patch mine is located within an irregularly fractured and brecciated body of rock (principally microcline-bearing granite gneiss with bostonite porphyry occurring at several places) that is approximately 750 feet long in an east-west direction and 400 feet wide on a north-south axis, dipping steeply to the north. Several principal veins intersect the upper part of the Patch mine; these being the California-Gardner and Rhoderick Dhu. On the Argo tunnel level, the principal veins are the Kansas-Burroughs group. The breccia extends to the Argo tunnel level (1,600 feet below surface), but the degree of mineralization is sharply diminished. Substantial movement of the breccia fragments is noted in some places, evidenced by considerable rounding and mixing of different fragment types. Brecciation (and mineralization) reached a maximum along several parallel northeast-trending zones, but the magnitude of alteration does not necessarily correlate with the extent of this brecciation. The most recent account of the origin of the Patch mine (Sims and others, 1963) postulated an upward punch of magma, preceded and accompanied by considerable gas that resulted in an explosion when the gas reached near enough to the surface to overcome lithostatic pressure; brecciation was followed by alteration and mineralization. Two types of ore mineralization are evident at this mine: (1) pyrite, chalcopryite, and minor tetrahedrite; and (2) sphalerite, with subordinate galena, chalcopryite, and pyrite. There is little mingling of these two ore types. Ore in the southern part of the Patch mine is mostly pyrite and chalcopryite with minor sphalerite, whereas ore in the northern part is predominately sphalerite with lesser amounts of pyrite, galena, and chalcopryite. Gangue minerals associated with both ore types are primarily quartz and siderite with minor barite. Ore shipped from the San Juan workings in the Patch mine between 1888 and 1909 had an average gold content of about 2.09 ounces per ton, and an average silver content of about 6.81 ounces per ton; the copper ranged from less than 1.5 to 9%. Assay values at the Argo tunnel level are substantially less than they are in the upper workings, being approximately 0.071 ounce per ton for gold and 0.489 ounce per ton for silver. Most ore shipped since 1900 has been of comparatively low grade.

The Alice mine is a stockwork of Tertiary age that is composed of two types of porphyry: a coarser, quartz-monzonite porphyry, and an alaskite porphyry (probably derived from the same magmatic source as the monzonite porphyry but at a later time). The mineralized area is about 300 feet long and 150 to 200 feet wide. Mineralization resulted from metasomatic alteration along networks of interconnecting fractures, which are most prominent in the coarser monzonite porphyry. Alteration of the porphyry is most intense at intersecting fractures where nests of ore minerals, often as much as 3 inches across and less commonly as much as a foot in diameter, have been formed. The grade of the ore was directly related to the degree of supergene copper sulfide present; specimens rich in secondary sulfide assayed more than an ounce of gold per ton, but the primary pyritic ores below the enriched zone assayed only 0.03 ounce or less per ton. Ore sent to the mill averaged from 0.13 to 0.22 ounce of gold per ton and from less than 1 to 1.21 ounces silver per ton; the copper content ranged from approximately 0.05 to 0.38%. The primary ore is pyrite and subordinate chalcopryite, and the gangue is chiefly quartz and siderite with minor barite.

Mineralogy

Patch mine

Barite: Sharp, cream-colored crystals to 3/4 inch; also as rosettes of intergrown crystals to 1 inch.

Chalcopyrite: Distorted and etched crystals to 1 inch, luster fair to poor; uncommon.

Galena: Sharp cubes, with corners often modified by the octahedron; also as predominately octahedral crystals. Luster varies from dull to brilliant. Cubes to 2 inches on edge; a single modified octahedron approximately 3 inches on edge was reported (Keith Williams, oral communication, 1988). Crystals often exhibit rounded edges and corners, giving a "melted" appearance, which is apparently caused by re-solution.

Gold: Wire gold has been found in aggregates exceeding an inch. Very rare.

Greenockite: Locally found as a greenish-yellow coating on earlier-formed minerals including sphalerite, pyrite, and siderite. Analysis shows that this coating is actually a thin layer of iron-free sphalerite containing submicroscopic inclusions of cadmium sulfide; X-ray diffraction confirms the presence of greenockite, and possibly a trace of hawleyite.

Pyrrhotite: Occurs as pseudomorphs of pyrite after pyrrhotite; typically as hexagonal, curved, and distorted crystals to approximately two inches in length. All specimens examined by X-ray diffraction have been found to be composed of fine-grained pyrite.

Pyrite: Lustrous cubic crystals ranging in size to 1 inch on edge; corners often modified by the octahedron. Crystals vary from sharp cubes to heavily striated and distorted crystals.

Quartz: Crystals to 3 inches in length; typically as stout, "barrel-shaped" crystals ranging from 1/4 to 3/4 inch in length. Smaller crystals are glassy clear and colorless; larger crystals usually are milky gray to white due to inclusions. Scepters to about 2 inches in length are present but uncommon. A few quartz crystals have a faint amethystine color.

Siderite: Crystals seldom exceed 1/8 inch in length; they typically form rosettes composed of curved crystals. Color varies from cream to tan in unweathered specimens to brown due to an iron oxide coating.

Sphalerite: Occurs as sharp, lustrous tetrahedral crystals to 1 inch in length; intergrown groups of tetrahedra exceeding 2 inches have been found. Individual crystals are black (variety marmatite) and usually less than 3/8 inch on edge.

Tennantite-Tetrahedrite: Reported from the Patch mine by Bastin and Hill (1917), but not observed as euhedral crystals.

Alice mine

Allanite: Acicular inclusions in quartz were noted to be allanite (Eugene Foord, U.S. Geological

Survey, oral communication, 1982); this also has been confirmed by the authors (using scanning electron microscopy) on additional specimens. The inclusions vary in color from brown to off-white; the brown needles appear to be mostly allanite, whereas the paler color material appears to be an alteration product, possibly sericite.

Arsenopyrite: Noted by Lovering and Goddard (1950), but not confirmed since then.

Barite: Occurs as transparent to opaque, cream to tan crystals that are typically aggregates of tightly intergrown crystals, but occasionally forms euhedral, tabular crystals. This last habit was noted as a cluster of 1/4 inch crystals (overall cluster approximately 1-1/4 inches) on siderite.

Bismuth sulfosalts: Gray, metallic sulfides, often associated with chalcopyrite, have been found to consist of an intergrowth of Bi-Ag-S (with subordinate Cu) and Cu-Pb-Bi-S mineral phases. Preliminary X-ray diffraction and qualitative microprobe and scanning electron microscope analyses indicate that euhedral, gray, columnar crystals (noted to 1 inch in length) are aikinite (the Cu-Pb-Bi-S phase), and the more massive-appearing material (showing a bladed morphology in polished section, which is the Bi-Ag-S phase) is matildite that contains a small amount of intergrown aikenite. The relative absence of lead (galena) in the Alice mine presumably permitted the development of these uncommon sulfosalt minerals, which are not often seen in other precious metal deposits in Colorado.

Bornite: Reported by Lovering and Goddard (1950); material having the appearance of bornite has been found by the authors to be covellite.

Chalcanthite: Noted as thin, bluish-green, botryoidal layers coating mine walls.

Chalcocite: Appears as thin, "sooty-black" coatings on earlier sulfide minerals, usually chalcopyrite.

Chalcopyrite: Chalcopyrite can occur as sharp, lustrous, sphenoidal crystals to 2 inches in size; typically it forms somewhat distorted or intergrown crystals seldom exceeding 1/2 inch, with a poor luster.

Chlorite: Greenish inclusions within quartz crystals have been identified as a chlorite-group mineral (Eugene Foord, U.S. Geological Survey, oral communication, 1983); this has been confirmed by the authors on additional samples.

Covellite: The bright blue to bluish-black, iridescent tarnish noted on some chalcopyrite crystals has been identified by X-ray diffraction as covellite.

Gold: Noted as microcrystals or as leaf gold, usually found on pyrite or chalcopyrite. Crystals seldom exceed 3 millimeters.

Muscovite: Rarely noted as micro rosettes of light gray crystals with a pearly luster.

Pyrite: Occurs as simple cubes to 2 inches on edge (often with corners modified by the octahedron) or as "stepped" cubes exceeding 3 inches on edge. Crystals often have a distinctive eight-sided striation pattern on the cube faces; these patterns are progressively offset giving a "spiral staircase" appearance. Individual crystals are typically 1/2 inch on edge; they seldom exceed 1 inch on edge. Occasionally noted as highly modified octahedrons.

Quartz: Tapered crystals to 2 inches occur, but more typically they are less than 1/2 inch in length and are transparent to translucent. Scepters (to approximately 1 to 1/8 inch) are occasionally found,

and rarely these have a faint amethyst tint. Inclusions of sulfide minerals, chlorite and allanite are common.

Siderite: Crystals are typically less than 1/4 inch, but have rarely been noted to 1 inch. Groups of intergrown crystals to 4 inches or more occur. Their color ranges from cream to tan, but crystals are invariably coated by a thin layer of a brown iron oxide. Microprobe analysis shows the siderite to be a manganoan variety, with a Fe:Mn ratio of about 5:1.

Sphalerite: Rarely noted as translucent to transparent yellow-green crystal fragments, or as small tetrahedral microcrystals that are less than 1/8 inch.

Paragenetic Sequence

A tentative paragenetic sequence for the principal minerals occurring at the Patch and Alice mines is as follows:

Patch mine:

(1) quartz > sphalerite ≥ galena > pyrrhotite > pyrite > siderite

(2) quartz > pyrite ≥ sphalerite > siderite

Alice mine:

quartz > chalcopyrite = bismuth sulfosalts ≥ pyrite > gold > siderite > barite

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MINERALOGY OF THE BESSIE G MINE
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INTRODUCTION

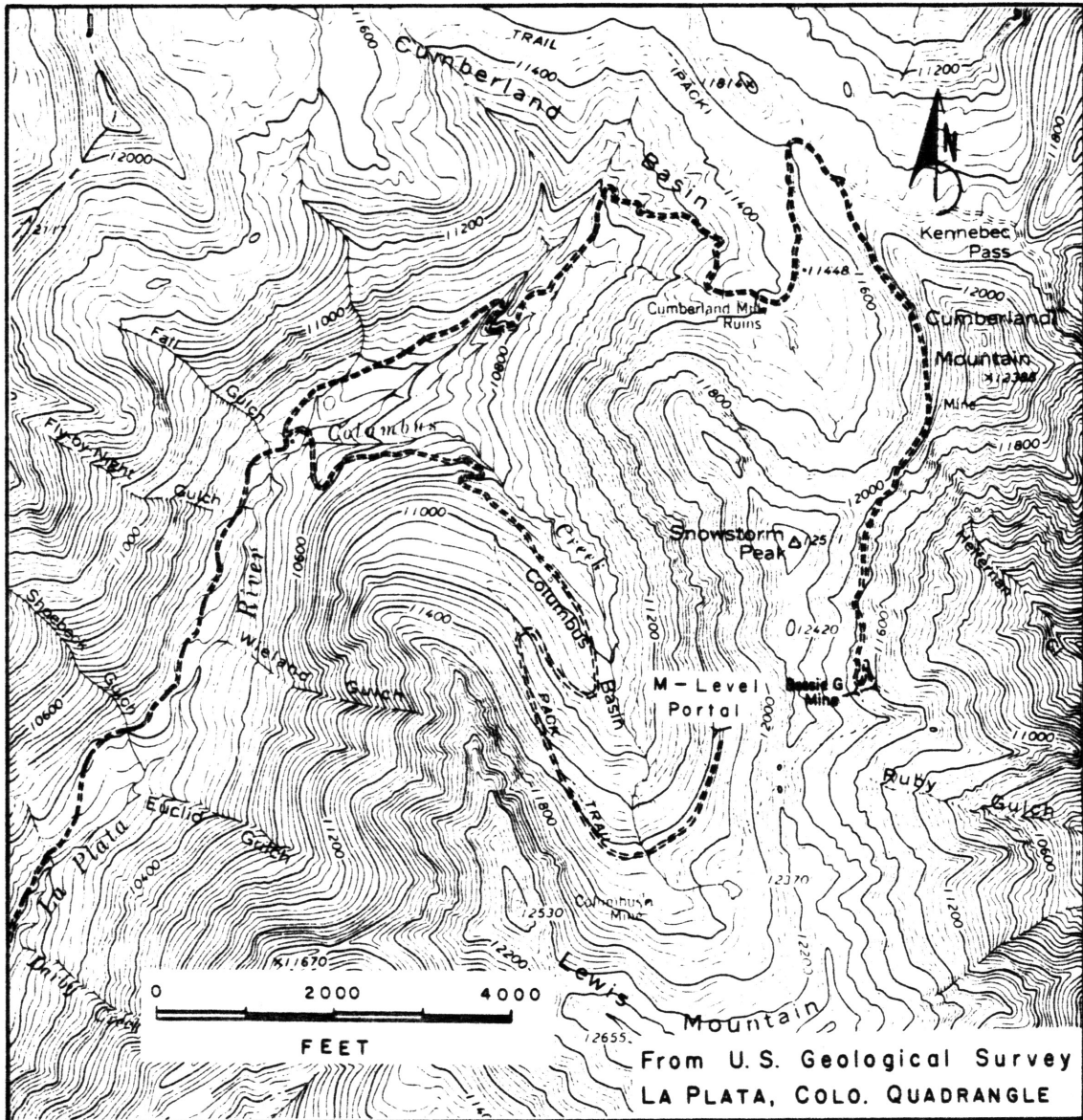
Gold mining activity during the past two years at the Bessie G mine has created a renewed interest in the minerals occurring at this site. The amount of ore and rock mined in this brief period has almost equaled that mined during the previous nearly one hundred year operation of the mine. This property, located in the northeast portion of the La Plata District, La Plata County, Colorado, continues to produce native gold and an assemblage of gold, silver, and mercury tellurides.

This short paper is an effort to focus on new and updated information on the full suite of minerals occurring at the Bessie G mine and combine this more recent data with the mineralogy of the La Plata District earlier presented by F.W. Galbraith (1949) as it applies to the Bessie G mine. In preparing this paper this writer has relied upon earlier data presented by Edwin B. Eckel, J.S. Williams, and F.W. Galbraith in their classic work entitled *Geology and Ore Deposits of the La Plata District, Colorado*. This U.S. Geological Survey Professional Paper 219, published in 1949, continues to be the major general reference for the La Plata District.

Galbraith (1949) made an extensive study of the tellurides of the La Plata District. His conclusion is that the tellurides occurring at the Bessie G mine are all "contemporaneous intergrowths" of hypogene origin. In other words, the various telluride minerals occurring at the Bessie G mine were all deposited during a single period from ascending hot water solutions. The tellurides occur as small masses, patches, and blebs of intergrown telluride mineralization, usually in quartz veins and often with native gold.

It is difficult to identify the various telluride species in a hand specimen by visual means, including observation through a 20 to 45 power binocular microscope. The appearance of all these telluride minerals is very similar in most respects. Their appearance generally grades from a metallic iron-black to a metallic tin-white and when closely intergrown present only subtle recognizable differences. Because of the intergrown characteristic of the tellurides at this occurrence most specimens showing telluride mineralization may contain more than one of the telluride species consisting of calaverite, coloradoite, hessite, krennerite, petzite, and sylvanite.

Visiting the Bessie G mine over the course of the last 25 years or so, a few specimens have been found on the dumps where the telluride minerals exhibit some degree of euhedral crystallization. Although rare in well crystallized form krennerite has been observed in several specimens and its identity confirmed by the U.S.G.S. Denver branch. Also observed in crystal form is one specimen of sylvanite, a few micro crystals of petzite, and coloradoite. The remaining telluride species of calaverite and hessite have not been observed by this writer in euhedral crystal form.

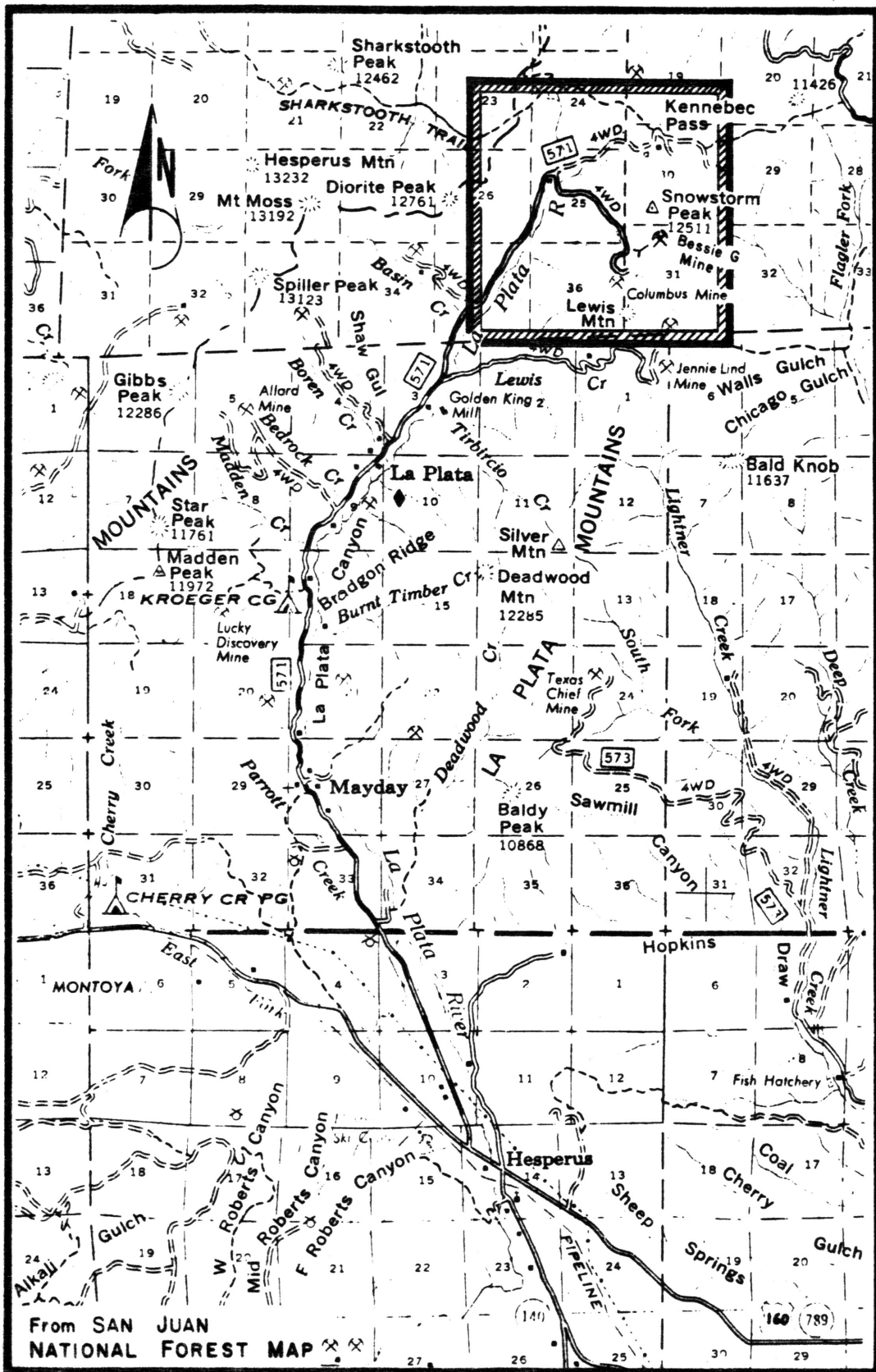


BESSIE G MINE LOCATION MAP

LOCATION

The Bessie G mine is situated in the northeastern portion of the La Plata Mountains approximately 12 miles northwest of Durango, Colorado.

The present main adit of the Bessie G mine, this being the west adit of M-level, is located on the west face of the ridge connecting Snowstorm Peak with Lewis Mountain at an approximate elevation of 11,650 feet. The mine workings can be described as being in the NW 1/4 of Section 31, Township 36 North, Range 10 West. This location is in the northeast portion of the La Plata Mining District, sometimes also known as the California Mining District, La Plata County, Colorado.



From SAN JUAN NATIONAL FOREST MAP

BESSIE G MINE VICINITY MAP

Access by road is by way of Forest Service Road #571 north from U.S. Highway 160 at Hesperus, Colorado. Forest Service Road #571 is asphalt surfaced for an estimated 4 miles to the settlement of Mayday. Thereafter the road surface is graveled for approximately 7 miles to the haul road turnoff to the east leading into Columbus Basin. The haul road leading up Columbus Basin is a series of steep grades and switchbacks for approximately two miles. This haul road up through Columbus Basin was constructed in 1984 to provide a greatly improved access and the ability to work the mine for a longer season at this high elevation.

Prior to 1984 the only access and only adits were located on the east side of Snowstorm Peak. The former route continued northeasterly on Forest Service Road #571 from the Columbus Basin road junction to Kennebec Pass, then southeasterly through Windy Gap and south to the east adits of the mine, a distance of approximately 4 miles from the Columbus Basin turnoff. The portion of this route south along the east face of Snowstorm Peak is very steep and narrow and is not recommended for motor vehicles. The dumps below the east adit contain several thousand tons of waste rock from the days when the ore was principally hand sorted.

HISTORY

The Bessie G location was first named the Egyptian Queen claim when discovered and staked in 1879. Nine years later, in 1888, it was patented by Grace Fox and renamed the Bessie G. The mine has changed ownership many times and has been worked by numerous owners or lessees on a relatively small scale until around 1950. Up to that time the only access to the mine was by burro. All equipment had to be packed in, and all ore had to be packed out.

About 1950, Don DeLuche purchased the Bessie G from miner Bert Thompson. In 1955, DeLuche built the first road to the mine. DeLuche later, in 1970, incorporated and founded Sierra Resources which still controls the claim. Exxon Minerals Corporation acquired a lease on the property in 1982. A new portal was completed in 1984 which provided a tunnel completely through the south ridge of Snowstorm Peak to Columbus Basin. What had started as a new lower level, known as M-Level, to explore for ore by Noranda Exploration Company in the 1970's was driven completely through the mountain for a total distance of approximately 1,800 feet. This new west portal now provides better access and the ability to work the mine, and ship ore, for a longer annual season.

On Sunday evening, November 17, 1985, Jack Ritter, then the sub-lessee of the mine, and Lester Morlang were attempting to construct a snow shed at the east M-Level portal when they were buried under tons of snow that came thundering down the slope of Snowstorm Peak. Lester Morlang dug for 22 hours and thru 30 feet of snow to reach the surface and be confronted by a raging blizzard.

It was not until Monday evening that the La Plata County sheriff's office became aware that the two miners were possibly buried by an avalanche. At day-break on Tuesday rescue efforts got under way. The rescue team waded thru the 1,800 foot tunnel to the east portal to find Ritter's frozen body beside his loader and continued to shovel snow looking for a second body.

Lester Morlang had sat in his snow shelter all Monday night trying to stay warm with an outside wind-chill factor of 50 degrees below zero. When he awakened Tuesday morning, he literally rolled the quarter-mile downslope to tree line. Later Tuesday morning Morlang was rescued by helicopter and flown to Durango for medical treatment.

During 1986 and 1987, the Bessie G has been subleased to Goldstar Mining Company, a subsidiary of Energy Fuels Nuclear, Inc.. Goldstar has mined approximately 15,000 tons of ore, nearly all of which has been milled. Prior to this brief period of activity, during the years from 1879 thru 1985, about 16,500 tons were mined at the Bessie G, of which only 872 tons of principally hand sorted ore was milled, for an average grade of 11.36 ounces of gold per ton. Ore mined by Goldstar is of a much lower grade since all of the mined rock is sent to the mill.

Goldstar is not actively mining the Bessie G in 1988, but is conducting surface geological studies on their claims in the immediate area during this season.

GEOLOGY

The La Plata District occupies the center of a structural dome formed by the intrusion of lacoliths during the Late Cretaceous or Tertiary geologic time periods. In the central portion of this dome the overlying sedimentary units have been uplifted approximately 9,000 feet above the surrounding Colorado Plateau. The eroded remnants of this uplift form the present day La Plata Mountains.

These intrusions of lacolithic origin are irregularly shaped and occur as dikes, sills, and stocks. The rocks in the district belong to two distinct intrusive phases. The oldest are generally porphyritic and include monzonite, diorite, and syenite. The more recent igneous rocks consist predominantly of non-porphyritic stocks of diorite and syenite.

The emplacement of the earlier porphyritic intrusions, which are the only ones exposed in or near the Bessie G mine, resulted in normal faulting during doming. These faults have radial to concentric orientation. Later activity reflecting the intrusion of the non-porphyritic rocks created new radial faults and fissures. These younger faults and fissures contain most of the gold and telluride mineralization in the district. The telluride deposits, such as at the Bessie G, appear only at or near the periphery of this area of intrusive activity.

Silicified red beds of the Dolores and Cutler formations cut by irregular dikes and sills of diorite and porphyry compose the country rock in the area of the Bessie G mine.

The Bessie G vein system consists of a zone or system of mineralized faults and fractures. The faults can usually be traced for no more than a few hundred yards. In the Bessie G vein system some mineralized faults die out completely along their strike, or splay out in a series of minor fractures, or are even transferred along cross fractures to parallel members of the system.

Mineralization is inconsistent throughout the vein system. Evidence indicates that when a fracture within the system became sealed off, the mineralizing fluids and gases moved to other fractures in the zone via a secondary set of cross fractures. It has been observed that the more mineralized ore shoots occur in the upper portion of what had been open space within the vein system, in the proximity to where it has been sealed off.

MINERALOGY

Ankerite - $Ca(Fe^{+2}, Mg, Mn)(CO_3)_2$ - Ankerite has been observed as yellow-brown rhombic like crystal groups on quartz.

Arsenopyrite - $FeAsS$ - Eckel (1949) reports that arsenopyrite is locally abundant at the Bessie G mine where it is disseminated as masses and grains within the vein quartz.

Azurite - $Cu_3(CO_3)_2(OH)_2$ - Blue stains of azurite were noted as a coating on quartz in a drill core sample by Norris (1987).

Barite - $BaSO_4$ - Barite occurs as white to clear thin tabular crystals in quartz pockets. Some of the barite often exhibits a stair step crystal growth development.

Bornite - Cu_5FeS_4 - Bornite has been observed as an alteration product on the surface of chalcopyrite crystals.

Calaverite - $AuTe_2$ - Galbraith (1949) notes that calaverite is a minor constituent of ores from the Bessie G mine where it occurs as small masses intergrown with krennerite, petzite, hessite, and coloradoite.

Calcite - $CaCO_3$ - Rhombohedral calcite crystals occur implanted on quartz.

Chalcopyrite - $CuFeS_2$ - Chalcopyrite most commonly occurs as disseminated masses and grains within the vein quartz. Chalcopyrite has also been observed in crystals of micro size associated with rich native gold, tetrahedrite, and the telluride minerals. The surface of some chalcopyrite crystals has been altered to bornite and covellite.

Cinnabar - HgS - One specimen of cinnabar has been observed in which the cinnabar, as bright red massive material, is associated with tetrahedrite on quartz matrix. Cinnabar has also been observed as a bright red dusting on quartz crystals.

Coloradoite - $HgTe$ - Coloradoite has been found occurring as black massive material and subhedral crystals where the crystal surface of one specimen has the appearance of being "melted". Galbraith (1949) reports coloradoite as forming contemporaneous intergrowths with other tellurides, all of hypogene origin. Coloradoite is noted by Saunders (1986) to be the most abundant telluride mineral occurring at the Bessie G mine where it occurs as intergrowths with other tellurides, tetrahedrite, and gold. The physical description of coloradoite provided in Dana's System of Mineralogy,

Seventh Edition, Volume 1, Page 118 (1944) is most appropriate for material from the Bessie G. The massive coloradoite does not show cleavage; is brittle with an uneven to subconchoidal fracture; its luster is metallic and color is iron-black. One of the most apparent physical features of coloradoite is the appearance of the subconchoidal fracture when viewed thru the binocular microscope.

Covellite - CuS - Covellite occurs as a deep blue surface alteration of chalcopyrite crystals.

Dickite - $Al_2Si_2O_5(OH)_4$ - White pulverulent masses of microscopic platy crystals of dickite were observed occasionally in quartz cavities. Galbraith (1949) reports that it is the last mineral to form in the telluride bearing veins.

Dolomite - $CaMg(CO_3)_2$ - White curved rhombic crystals of dolomite occur in pockets of vein quartz.

Fluorite - CaF_2 - Clear cubic crystals, up to 3 millimeters in size, rarely occur on quartz.

Galena - PbS - One small cleavage surface of galena on quartz was observed by Norris (1987).

Goethite - $\alpha\text{-Fe}^{+3}O(OH)$ - Pyrite crystals of octahedral habit with the surface altered to iron oxide were observed. Iron oxide surface staining of quartz crystals is common.

Gold - Au - Gold is found as small irregular masses and patches intergrown with the telluride minerals on quartz. It has been observed occurring with tetrahedrite and chalcopyrite. Gold has been observed on several specimens in wire form; one specimen was in the shape of a ram's horn of less than one millimeter in diameter.

Hessite - Ag_2Te - Hessite is said, by Galbraith (1949), to occur in considerable quantity in the ore of the Bessie G mine. Galbraith notes that "It is intimately associated with the other tellurides in contemporaneous hypogene intergrowths".

Krennerite - $AuTe_2$ - Krennerite occurs as a tin-white material with perfect cleavage. Well formed lath shaped orthorhombic crystals of krennerite showing vertical striations and of lamellar structure have been observed in open spaces within quartz veins. Some krennerite crystals exhibit old breaks that have been re-healed. Krennerite is associated with other tellurides and gold.

Marcasite - FeS_2 - Marcasite is present on quartz matrix where it exhibits a radiating structure. Norris (1987) reports that marcasite commonly occurs as fibrous crystal rims around pyrite. Some of the fibrous crystals appear to actually be pseudomorphs of pyrite after marcasite.

Muscovite Variety Sericite - $KAl_2(Si_3Al)O_{10}(OH,F)_2$ - Fine grained sericite as an alteration product of feldspar in the porphyritic rocks is occasionally present on quartz.

Petzite - Ag_3AuTe_2 - Petzite occurs as iron-black metallic crystals of less than 0.5 millimeter size perched on gold. Petzite is reported to be a minor constituent of the ores from the Bessie G by Galbraith (1949). In the same manner as with the other Bessie G tellurides, petzite is intimately associated with the telluride minerals as a contemporaneous intergrowth.

Pyrite - FeS_2 - Euhedral crystals of cubic, pyritohedral, and octahedral form occur in the open space of quartz gangue. Occasionally the surface of the pyrite is altered to goethite. Pyrite is common as grains within the quartz vein material, and is the most abundant sulfide occurring at the Bessie G mine.

Quartz - SiO_2 - The vein material containing the ore minerals consists entirely of quartz. Often this vein material is colored green by the inclusion of roscoelite grains. Short quartz crystals are common in the usual hexagonal prism terminated with a hexagonal pyramid form. Pseudo-cubic crystals are often observed.

Roscoelite - $K(V,Al,Mg)_2AlSi_3O_{10}(OH)_2$ - Much of the vein quartz is colored dull green by microscopic inclusions of the vanadium bearing mica, roscoelite. This green quartz is considered an indicator of the presence of high-grade telluride ore.

Sphalerite - $(Zn,Fe)S$ - Dark brown sphalerite crystals and crystal groups are associated with gold, chalcopyrite, tetrahedrite, and tellurides in quartz cavities.

Sylvanite - $(Au,Ag)_2Te_4$ - Poorly developed crystals of sylvanite were observed as a tin-white mineral completely enclosed in quartz.

Tetrahedrite - $(Cu,Fe)_{12}Sb_4S_{13}$ - Tetrahedrite in massive black patches on quartz and occasionally as crystallized material is a rather common association with gold and the telluride minerals. Its appearance can be easily mistaken for the telluride minerals, but its dark red streak distinguishes it from the tellurides.

CONCLUSIONS

The Bessie G mine still contains substantial ore reserves and, undoubtedly, future mining, whether by Goldstar Mining Company or other operators, will result in the continued production of gold and telluride ores. The assessment of the Bessie G by Eckel (1949) continues to be appropriate at the present time. Eckel noted "The conditions are favorable for finding small, high-grade pockets though not for finding large bodies of ore."

The reader should be reminded that the Bessie G mine is located on a patented claim which is private property. There is presently a locked gate on the haul road within Columbus Basin at a point approximately one mile below the M-Level adit with an attached sign noting that the route is a private road.

ACKNOWLEDGMENTS

This writer expresses thanks and appreciation to the following individuals who provided support and assistance in the preparation of this paper: **Joe Norris**, Senior Project Geologist with Energy Fuels Nuclear, Inc. who provided data on the geology and history of the Bessie G mine and specimen material for study; **Bill Casadevall**, Senior Geologist with Energy Fuels Nuclear, Inc. for providing specimen material for study and photography; my wife, **Carrie Hampson**, for finding and collecting specimen material and searching this material through the binocular microscope for micro crystals; **Peter Modreski** of the U.S. Geological Survey for identification of several telluride specimens with the scanning electron microscope, as well as the review of and suggestions helpful in the preparation of this manuscript; **Dorothy Kruse** and **Tracy Duncan** for word processing and placing the draft in final form; and **Douglas Conger** for preparation of the location maps. This writer also thanks the management of **Energy Fuels Nuclear, Inc.** for review of the manuscript and permission to publish this paper.

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MINERALOGY OF THE CAMP BIRD MINE
OURAY COUNTY, COLORADO

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The Camp Bird mine, located 6 miles southwest of Ouray, was discovered by Thomas F. Walsh in 1896. Under Walsh's management, the Camp Bird mine was developed into one of the most profitable and famous mines in Colorado and made Walsh a millionaire many times over.

Rocks in the Camp Bird mine area consist of Paleozoic and Mesozoic sediments that have been partially eroded. The Tertiary Telluride Conglomerate was deposited on the peneplained surface and is the host rock for the Pb-Cu-Zn replacement ore bodies. Later volcanic eruptions from a series of central-vent volcanoes deposited rhyodacitic ash and lava flows on the Telluride Conglomerate and formed the Tertiary San Juan Tuff and Silverton Volcanic Series.

All of the gold production of the Camp Bird mine has come from the Camp Bird vein, which strikes east-west and dips 70° south. Early day production was mainly Au-Ag-Cu ores, but as mining progressed deeper the gold values diminished and changed to Ag-Pb-Cu-Zn ores.

Three stages of mineralization make up the compound Camp Bird vein. The first stage of vein formation was the quartz-sulfide component which consists of quartz, galena, chalcopyrite, sphalerite, and rarely tetrahedrite. Accessory minerals include pyrite, calcite, chlorite, rhodonite, rhodochrosite, fluorite, ankerite, and scheelite. The second stage of vein formation was the gold-quartz breccia component which consists of quartz, gold, minor petzite and locally small amounts of sulfides. In the deeper levels of the mine appreciable specularite hematite is associated with the gold stage. The third and last stage of vein formation was the bull quartz stage, which is barren of ore minerals and usually forms massive veins which sometimes show cockscomb structure. Vugs are numerous and contain milky white quartz crystals up to 4 inches long.

During the 1970's most of the ore mined was from Pb-Cu-Zn replacement ore bodies along the Orphan and Gordon veins at the base of the Telluride Conglomerate. Galena, chalcopyrite and sphalerite were the primary ore minerals and replaced the matrix, pebbles and cobbles that made up the conglomerate. Accessory minerals include quartz, epidote, calcite, pyrite, barite, fluorite, and rhodochrosite.

Over the years, the Camp Bird mine has produced hundreds of fine mineral specimens. Exceptional specimens of native gold and quartz crystal groups have come from the Camp Bird vein, while exceptional crystal groups of galena, sphalerite, and chalcopyrite associated with quartz, epidote, and calcite have been recovered from the replacement ore bodies. In June, 1987, a vug was discovered in the Camp Bird vein that produced the finest scheelite crystals ever found in Colorado.

GOLD IN WYOMING

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Available information indicates that gold, with some exceptions, is found throughout much of the geologic record in Wyoming. Gold anomalies, occurrences, and deposits are described in many rock units in Wyoming, ranging from Archean to Tertiary age, as well as in modern placers.

The Archean craton of Wyoming includes a vast region of granite-gneiss with interspersed metamorphosed plutonic, volcanic, and sedimentary terranes known as greenstone belts and high-grade supracrustal successions. These volcano-sedimentary belts host the oldest known gold deposits in Wyoming. These include shear zone and vein deposits that predominately conform to regional foliation. At South Pass in the southern Wind River Mountains, auriferous shears are principally hosted by metagreywacke, and less frequently by mafic amphibolite, graphitic schist, and ultramafic schist (Hausel, 1987, 1988a). Traces of gold have also been detected in banded iron formation at South Pass, as well as in a few other Wyoming greenstone belts, but these are incompletely explored.

Paleoplacers are reported at several locations in the State including along the flanks of the South Pass greenstone belt. Along the southern and northeastern margins of South Pass, extensive auriferous Eocene and Oligocene conglomerates eroded from the metamorphic terrane, have periodically been placered for gold. The gold is relatively coarse, occurs in an arkosic matrix with pebbles, cobbles, and boulders eroded from the granite-greenstone belt. The Oregon Buttes paleoplacer to the south, contains an estimated 28.5 million ounces of gold in the Eocene Wasatch Formation conglomerate (Love and others, 1978). Boulders include granite, granodiorite, with lesser amphibolite and minor metagreywacke -- a lithologic assemblage typically found along the margin of the granite-greenstone belt or along the edge of an intrusive granite dome.

The Twin Creek paleoplacer to the northeast, contains an unknown amount of gold in the Oligocene White River Formation conglomerate. Pebbles, cobbles, and boulders of granodiorite, greenstone, amphibolite, and banded iron formation are interspersed in the matrix (Antweiler and others, 1980). This lithologic assemblage is typical of rocks found within the older units of the greenstone belt.

In the north-central Sierra Madre and Medicine Bow Mountains of southeastern Wyoming, thick successions of 2.5 to 2.0 Ga miogeosynclinal metasedimentary rock unconformably rest on the Archean basement. These rocks include basal, radioactive, quartz pebble metaconglomerates, which locally contain pyrite and uraninite. Analogies have been drawn between these rocks and the richest gold

deposits in the world in the Witwatersrand Basin of South Africa (Karlstrom and Houston, 1979). Unfortunately the Wyoming metaconglomerates have not been systematically explored for gold even though a few random samples have yielded anomalies.

Other paleoplacers include Cretaceous titaniferous sandstones in the Mesa-verde Formation. Some of these paleo-beach placers contain 1.3 ppm gold in addition to other heavy minerals (Houston, 1969). These deposits occur at several places in the Bighorn, Green River, Laramie, and Wind River Basins.

The basins of Wyoming also include many enigmatic gold anomalies. Stream sediment samples collected in the basins have yielded as much as 6.55 ppm gold (Albert, 1986). Visible gold has also been identified in rock, drill core, and sediment samples taken at a number of localities in the basins (Hausel, 1988b).

In northeastern Wyoming, Tertiary (38.0 to 50.0 Ma) alkalic igneous complexes in the Bear Lodge, Mineral Hill, and Black Buttes districts of the Black Hills contain gold and silver associated with potassium fenitized trachytes. Mineralization occurs in feldspathic breccia, veins, replacement deposits and jasperoids. The low-grade disseminated gold deposits in the Bear Lodge Mountains are associated with significant low-grade rare earths and thorium.

Modern placers have been mined at many locations in the State. In the Mineral Hill district of the Black Hills, gold and tin placers drain the Tertiary complex. The Douglas Creek district in the Medicine Bow Mountains contains extensive gold and minor platinum placers which cut through mineralized veins and shear zones in Proterozoic and Archean metamorphic rocks. Placers in the South Pass greenstone belt have been relatively productive. Recent mining in South Pass has yielded average gold values of 0.01 to 0.1 ounce per cubic yard with accessory amounts of tungsten and traces of tin. Significant quantities of gold were recovered from dredging operations along the Wind River in the Wind River Basin in the early 1900s. The gold in the Wind River Basin occurs in gravels and terrace deposits along the Wind River, Little Wind River, and Popo Agie River. In places, the gold-bearing gravel extends several hundred feet from the stream banks into the adjacent upland gravels.

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REPORTS OF PLATINUM-METALS IN COLORADO

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The platinum-group elements are a set of six metals which show a marked tendency to be associated geochemically. The platinum-group elements are iridium, osmium, palladium, platinum, rhodium, and ruthenium.

In compiling the reported mineralogy of the State for the update of Eckel's 'Minerals of Colorado-a 100 Year Record', I was impressed by the large number of platinum-group metals reported in the State (Table 1). However, virtually no detailed mineralogical work has been done on these elements in Colorado. The only specific minerals reported are platinum and iridosmium. Most reports are only of chemical elements detected in assaying.

The extensive panning for gold throughout the State in the past 150 years and the comparatively low number of resulting finds of platinum-group metals, especially as compared with California, indicate little potential for such deposits in the State. The coincident report of precious metals with platinum-group metals, especially if of high assays which are not later substantiated, is often the hallmark of fraudulent mining promotions. Accordingly, any wide compilation such as this should be read with skepticism.

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TABLE 1. PLATINUM-METAL REPORTS IN COLORADO

Boulder, Denver and Douglas Counties:

Cherry and Boulder Creeks, along the Front Range
Ir in black sands (Randall: notes newspaper reports)

Boulder County: Caribou district:

Pt (Randall: newspaper report)

Chaffee County: near Buena Vista:

\$12.90/ton Pt assay of black-sand concentrates (27 lbs black
sand/cubic yard) (Day and Richards, 1906, p. 1193)

Clear Creek County: Georgetown district, Centennial mine:

Hearsay report of \$3/ton Pt+Ir assay of a small patch of tetrahedrite
ore on the 600' level. (Spurr, Garrey, and Ball, 1908, p. 276)

Clear Creek County: Clear Creek:

Pt in black sands (Anonymous, 1917)

Gunnison County: Iron Hill carbonatite:

Listed as a platinum-group metal locality. (Blair, Page and Johnson,
1977). Evidently in error for the Iron Hill placer in Park County.

Hinsdale County: White Cross district:

Pt in a lode near the district. (Randall)

La Plata County: La Plata district: Copper Hill mine:

Chalcopyrite ore contains small amounts of Pt and Pd in about equal
proportions which vary directly with the amount of Cu. Polished
sections failed to show residence of platinum-group metals, which is
possibly in chalcopyrite. (Eckel, 1938; Schwartz, Varnes, and Eckel,
1949)

Lake County: Granite district: B. and M., General Logan, and other mines:

Pt in ores (Randall: from newspaper report)

Ouray County: Ouray district:

Pt (1.18%), iridosmium (4.51%) in a gold assay button. (Day and
Richards, 1906, p. 1226)

Park County: Alma district:

Pt in a lode in Mosquito Gulch (Randall: from newspaper report in 1878)

Park County: Iron Hill placer at Como:

Pt 'mechanically combined with magnetite', in auriferous sands. (Anonymous, 1917)

Pitkin County: Aspen district:

\$1.50/ton Pt assay of galena from a fissure vein in a tunnel. (Day and Richards, 1906, p. 1193)

Saguache County: Liberty district:

\$1.80/ton Pt assay of concentrates (unknown concentration factor). (Day and Richards, 1906, p. 1193)

San Miguel County: Naturita Canyon, near Norwood:

Pt in a bed of sandstone known to be rich in Au. (Anonymous, 1911)

San Miguel County: Telluride district:

\$2.70/ton Pt assay of concentrates (1 lb/3 cubic yds of gravel). (Day and Richards, 1906, p. 1195)

Summit County: Breckenridge district:

\$231.50/ton Pt+Au assay of concentrates (10 lbs/cub.yd). (Day and Richards, 1906, p. 1195).

Summit County: Breckenridge district: mine on Gibson Hill:

Ir in ore (Randall)

Summit County: Breckenridge district, small placers along American Gulch, east side of Farncomb Hill:

Hard, steel-gray particles in placer material which contained native gold. The particles were found to be a mixture of platinum and an Ir-Os alloy (74% Ir, 26% Os). The platinum was chemically free of other elements. (Roland Schmidt, communication to Bulletin 1114 update committee, 1983)

THE GOLD KING MINE, SILVERTON CALDERA, SOUTHWEST COLORADO

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Abstract

The Tertiary (27.5 m.y.) Silverton caldera is a non resurgent trap door collapse structure, which contains a hinge zone in its northern part. Significant precious and base metal deposits occur along ring faults, hinge zone fractures, and NE-faults of the apical Eureka Graben (27.5-22.5 m.y.), which extends northeastward to the Lake City caldera (22.5 m.y.).

The Gold King deposit, in the north center of the caldera, follows steeply SE- and NW-dipping, NE-trending subsidiary fractures of the Eureka Graben and NW-trending hinge zone faults. The electrum (95/5 weight% Au/Ag) - petzite - sylvanite - altaite - tetrahedrite - bismuthinite, ± pyrite, ± chalcopyrite, ± bornite assemblage at Gold King occurs in so-called "flat veins". These structures are between 0.3 to 1 meter wide, and strike NE with a 30-45° dip to the NW and NNW. They yield high grade gold ore assaying up to 2,488 g gold and 1,088 g silver per ton. Primary fluid inclusions indicate temperatures from 270° to 290°C for the deposition of milky quartz hosting the precious metal minerals at an elevation of 3,605 meters. The adjacent Sunnyside deposit yields base and precious metals at 3,596 meters. Other neighboring mines, at least 60 meters lower in elevation, contain base metals only.

Predominantly meteoric-derived hydrothermal solutions ascended through alloclastically fractured, ferruginous Precambrian formations and overlying Tertiary caldera fill, 10 to 15 m.y. after the Silverton caldera collapse. Due to the southward dipping caldera roof, solutions were funnelled northward into hinge zone fractures and the Eureka Graben fault system. Epithermal, precious metal deposition was due to the breakdown of reduced Au-bisulfide complexes during boiling, increasing oxygenation, and mixing with fresh meteoric water.

MULTISPECTRAL REMOTE SENSING OF PRECIOUS METAL DEPOSITS

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EXTENDED ABSTRACT

INTRODUCTION

Multispectral remote sensing is a new, yet powerful tool for precious metals exploration. Remote sensing instruments available to the exploration geologist include satellite sensors such as the Landsat Multispectral Scanner (MSS) and Thematic Mapper (TM) and airborne instruments like the Geophysical and Environmental Research imaging spectrometer (GERIS) and the Thermal Infrared Multispectral Scanner (TIMS). Field reflectance spectrometers are used to measure spectral properties quickly on the ground to confirm remote sensing interpretations.

The fundamental physical properties of minerals allow detection and mapping of mineralogy associated with hydrothermally altered rocks (Hunt, 1979; Lee and Raines, 1984). Color images are computer generated to enhance the spectral properties of minerals, rocks, and soils. The image format of these data allow rapid mapping of the spatial distribution and variability of alteration mineralogy. Broad-band systems such as the MSS, TM, and TIMS allow definition of broad alteration mineral groups such as iron oxides, clays or carbonates, and silica-rich areas (Podwysocky and others, 1983; Watson and others, 1988), while the higher spatial and spectral resolution imaging spectrometer system makes identification of individual minerals (alunite, kaolinite, illite, hematite, goethite, etc.) and mineral assemblages possible (Goetz and others, 1985; Kruse, 1987, 1988). Further work with the remote sensing data, field, and laboratory reflectance spectra, and conventional field mapping is required to verify the link between airborne and satellite-based spectral measurements and the ground mineralogy.

CRIPPLE CREEK, COLORADO

Remote sensing studies are in progress at the Cripple Creek mining district, Teller County, Colorado. The Cripple Creek mining district is located 21 miles southwest of Colorado Springs. The mineralization is hosted by a silica-undersaturated alkalic intrusive complex (Thompson, 1986). The texture, structure and composition of the intrusive rocks suggest a diatreme-like origin showing several root centers and episodes of activity (Wobus and others, 1976). Lode gold mineralization

is hosted by upper Oligocene age phonolitic breccia pipes which have produced over 21 million ounces of gold since discovery in 1891. The objective of the work at Cripple Creek is to identify and map lithological variation related to emplacement of the intrusive rocks and subtle lithological variation caused by hydrothermal alteration. Landsat Thematic Mapper (TM) data were processed for the Cripple Creek district and despite heavy vegetation and soil cover, areas containing hydrothermally altered rocks were identified. TM images were produced using standard image processing techniques. Band ratio images of TM band 5 divided by TM band 7 were useful for identifying clay alteration and TM band 5 divided by TM band 1 was useful for outlining iron staining related to hydrothermal alteration. Principal components images were used to search for clusters of data that correspond to mappable geologic units. Hydrothermal alteration shows up well in these images because of the spectral differences between altered and unaltered rocks. An experimental system called the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) was flown over the Cripple Creek district during 1987. Although the quality of the first data set was poor, color composite images show alteration sites more clearly than the TM images because of the higher spatial and spectral resolution of the AVIRIS instrument. Additional AVIRIS data will be acquired for the Cripple Creek district during 1988. It is expected that AVIRIS data will contribute to a better understanding of the volcanic center and the processes that localized the gold deposits by making possible the identification of specific minerals.

CUPRITE, NEVADA

High spectral resolution remote sensing studies are in progress for the Cuprite district south of Goldfield, Nevada. The Cuprite site, although not economically mineralized, is an excellent area to test remote sensing technology for precious metals exploration because of good rock exposures and the presence of several alteration minerals commonly found in gold deposits. Cuprite has been used for many remote sensing studies over the years and an extensive image database exists for the district (Kahle and Goetz, 1983). The new Geophysical and Environmental Research 64 channel imaging spectrometer (GERIS) was flown over Cuprite during 1987. First results from the data are exciting (Kruse and Calvin, 1988). The minerals kaolinite, alunite, and buddingtonite have been directly identified using the imaging spectrometer data and their spatial distribution has been mapped. Identification and mapping of the ammonium feldspar buddingtonite using this system is especially significant for precious metals exploration because this mineral is often associated with hot springs type gold deposits.

PREBLE, NEVADA

The Preble disseminated gold deposit in the southern Osgood Mountains of north-central Nevada is being studied using field and laboratory spectral measurements and X-ray diffraction (Hauff and Kruse, 1988). Hydrothermal alteration has extensively modified the Middle Cambrian Preble Formation. Gold is recovered from the most intensely altered rocks. X-ray diffraction studies of several deposits demonstrate that illite species reflect lateral and vertical zonation around gold ore bodies. Illites change structure with temperature and may act as geothermometers indicating temperatures of ore deposition and proximity to hypogene and supergene fluids. Changes in the illite reflectance spectra are observed as the illites progress from the lower temperature, less ordered 1M variety through the higher temperature 2M type. Distinctive absorption features near 1.90 and 2.20 μm and between 2.3-2.5 μm differentiate interlayer water, structural water (OH-) and some octahedral layer characteristics. Preliminary work at Preble indicates that illites vary regularly around the ore body. Reflectance spectra for the Preble illites indicate that this distribution can be mapped using a field portable spectrometer. Field and laboratory studies during 1988 will refine the method.

SUMMARY

Reflectance spectroscopy and multispectral remote sensing are proven tools for locating and mapping altered rocks. Broad band systems such as Landsat provide an operational capability that can be used by the exploration geologist to identify areas for more detailed study. High spatial and spectral resolution imaging spectrometers can be flown for specific sites of interest to perform detailed mapping of alteration mineralogy. Field and laboratory reflectance spectroscopy should be used to verify aircraft measurements. The final exploration decisions should be made based on the integration of the field and laboratory spectral measurements, satellite and aircraft data, and all other available geologic and geochemical information.

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GEOLOGY, MINERALOGY, AND ZONING OF THE BUFFALO BOY VEIN DEPOSIT
SAN JUAN COUNTY, COLORADO

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The Buffalo Boy Mine, located 10 km east of Silverton, Colorado, has produced rich silver-gold ore from a vein cutting Tertiary volcanic rocks of the San Juan Volcanic Field (Figure 1). The main portal of the mine is located at an elevation of 3230 m and workings are developed both above (40 m) and below (120 m) the main level (Figure 2). Numerous prospect pits and several adits along the vein help trace its course. The vein has a northerly strike, dips steeply to the east, and can be followed on the surface for more than 3 km. The strike of the vein is intermediate between the directions of concentric and radial fracturing which resulted from doming and collapse of both the Silverton and San Juan calderas. The mine lies outside of the ring fracture of the Silverton caldera but inside of the larger San Juan caldera (Figure 3). The vein occupies a fault which shows only minor displacement.

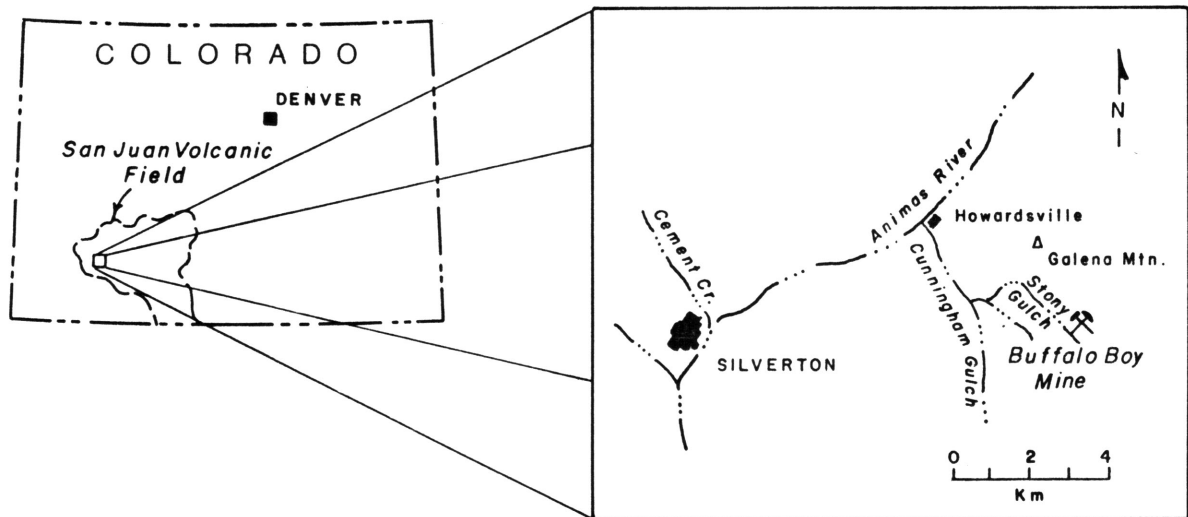


FIGURE 1: Location map of the Buffalo Boy Mine in relation to the San Juan Volcanic Field and Silverton.

Rock Units

In the area of the mine there are five mappable rock units: Precambrian schist, two quartz monzonite intrusives, ash flows of the Eureka member of the Sapinero Mesa Tuff, and ash flows and volcanoclastic facies of the Burns Formation. The Burns Formation, which consists of latite, and quartz latite, forms the host rock for the presently exploited parts of the Buffalo Boy Vein.

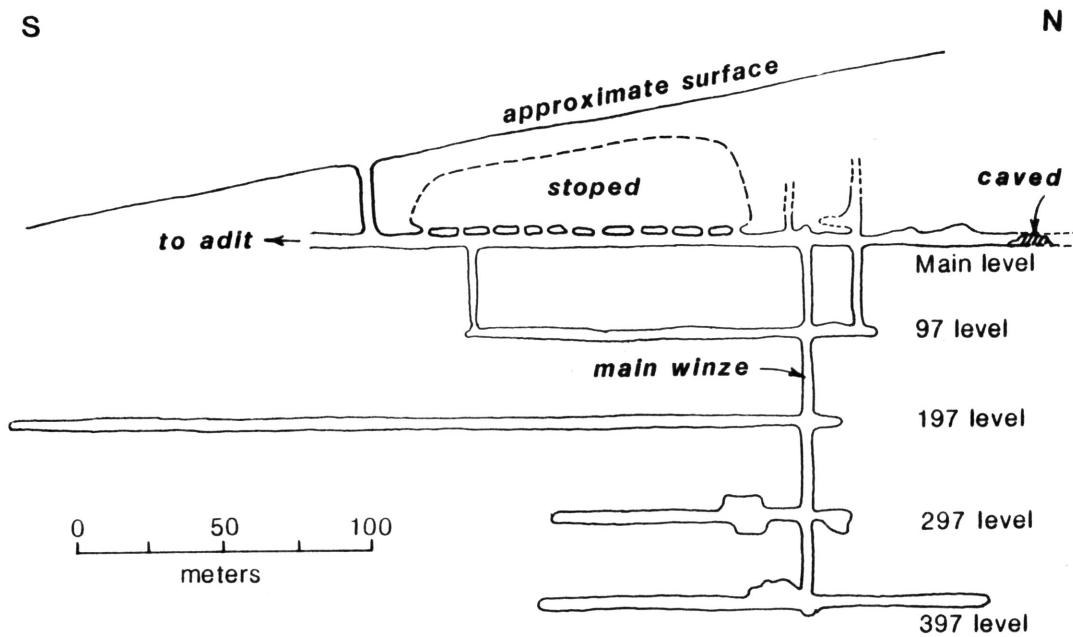


FIGURE 2: Longitudinal section of the Buffalo Boy Mine looking west

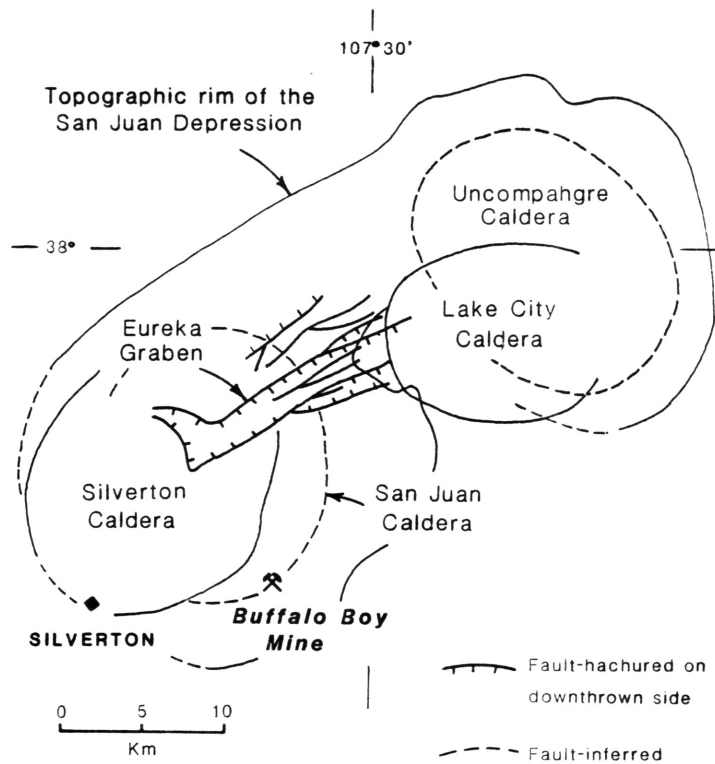


FIGURE 3: Sketch map of the Western San Juan Caldera complex with the Buffalo Boy Mine (after Steven and Lipman, 1976).

Nature of the Vein

The Buffalo Boy vein is an epithermal, complex-sulfide, base- and precious-metal deposit. Massive to banded and brecciated quartz fills the vein. Wall-rock solution and replacement is locally important, although open-space textures predominate. The Buffalo Boy vein is the largest of a series of north-trending veins in the area and lies at the edge of the intensely-veined area on Galena Mountain described by Ransome (1901). The vein reaches a maximum width of greater than 4 m although the typical width ranges from 1 to 2.5 m. The mineralogy and concentration of sulfides as well as ore grade varies locally. High-grade ore may occur in ore shoots as large as 2 m thick, 15 m long, and 25 m high or as thin veinlets within the less spectacular quartz-vein material.

Wall Rock Alteration

Crosscuts reveal numerous quartz veinlets parallel to and up to 6 m away from the main vein. These veinlets contain pyrite but little precious metal. Wall rock immediately adjacent to the main vein is silicified. This wall rock may contain high precious-metal values in areas of high-grade vein mineralization (Figure 4).

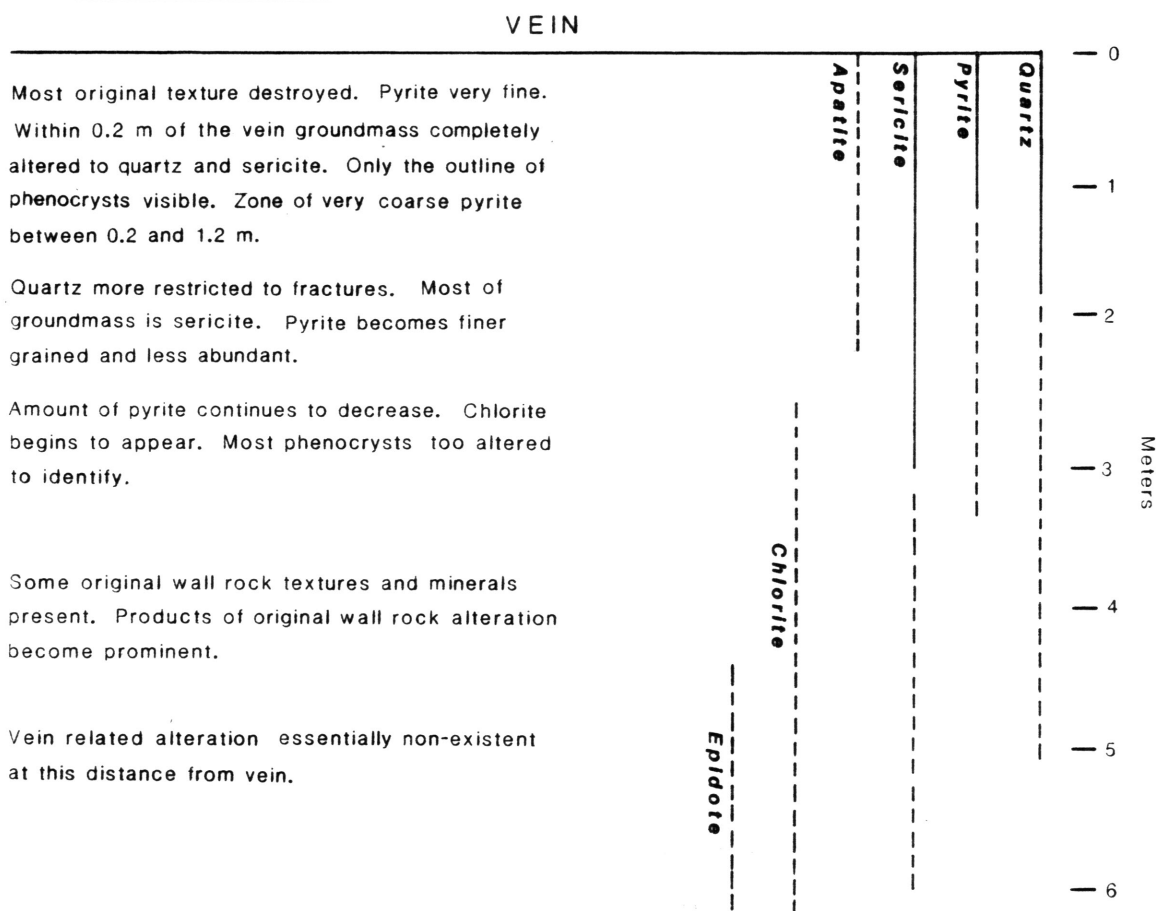


FIGURE 4: Wall rock alteration adjacent to the Buffalo Boy vein. The scale applies to the specific area studied but varies depending on local intensities of alteration.

Mineral Zoning

The Buffalo Boy vein shows vertical mineral zoning within the workings (Figure 2). The deposit changes from leached outcrop to gold and pyrite to a complex assemblage of sulfide minerals with increasing depth. In the exposed workings, three parts of a four part zoning sequence can be identified (Table 1). Zones 1, 2, and 3 have been identified in the mine and zone 4 is postulated from comparison to other deposits in the area. Zones overlap and base-metal minerals occur throughout the mine.

TABLE 1: Mineral-zoning sequence of the Buffalo Boy vein.

<u>Zone</u>	<u>Mineral assemblage</u>
1) surface	jasper, calcite, and marcasite
2) above main level	gold and pyrite
3) below main level	polybasite, pyrargyrite, proustite, acanthite, gold, pyrite, galena, sphalerite, and chalcopyrite.
4) at depth?	galena, sphalerite, tetrahedrite, chalcopyrite, and acanthite

Vein Mineralogy

The Buffalo Boy vein hosts a relatively complex suite of sulfide and sulfosalt minerals in a confined working area. The complex vein mineralogy can be attributed to multiple episodes of mineralization and strongly telescoped zoning (Table 2).

TABLE 2: Ore and gangue minerals identified in the Buffalo Boy Mine.

Ore Minerals

Argentite-acanthite	Ag ₂ S
Chalcopyrite	CuFeS ₂
Colusite	Cu ₃ (As, Sn, V, Fe, Te)S ₄
Electrum	(Au, Ag)
Galena	PbS
Gold	Au
Marcasite	FeS ₂
Pearceite	Ag ₁₆ As ₂ S ₁₁
Polybasite	Ag ₁₆ Sb ₂ S ₁₁
Proustite	Ag ₃ AsS ₃
Pyrargyrite	Ag ₃ SbS ₃
Pyrite	FeS ₂
Silver	Ag
Sphalerite	ZnS
Tennantite	(Cu, Fe, Ag) ₁₂ As ₄ S ₁₃
Tetrahedrite	(Cu, Fe, Ag) ₁₂ Sb ₄ S ₁₃

Gangue Minerals

		<u>Trace or tentatively identified minerals</u>	
Aragonite	CaCO ₃	Bornite	Cu ₅ FeS ₄
Barite	BaSO ₄	Miargyrite	AgSbS ₂
Calcite	CaCO ₃	Stephanite	Ag ₅ SbS ₄
Quartz	SiO ₂	Stromeyerite	AgCuS

Gangue Mineralogy

The gangue mineralogy of the Buffalo Boy Mine is relatively simple compared to that reported for other mines in the area (Ransome, 1901; Hulin, 1929; Burbank, 1933; Kelly, 1946; Varnes, 1963; Blood, 1968; Burbank and Luedke, 1969; and Casadevall, 1973). Quartz is the dominant mineral present in the vein. Euhedral crystals of quartz typically shorter than 2 cm occur in vugs. The sulfide content of the vein material varies from trace to approximately 75%.

Minor amethyst occurs on the 397 level, and white, gray and clear quartz occur throughout the mine. Calcite is present on the surface and in minor amounts throughout the mine. Calcite is most abundant on the 397 level while minor aragonite is found in the deeper parts of the mine.

Sulfide Mineralogy

Unlike the gangue mineralogy, the sulfide assemblage of the Buffalo Boy is relatively complex compared to the other mines in the area. The ore minerals (Table 2) comprise a typical but rich epithermal suite. X-ray fluorescence analysis of several high-grade ore samples from different parts of the mine shows most of the expected elements. The presence of tellurium, uranium, thorium, and molybdenum suggests that other interesting minerals may also be present in the ore.

Pyrite is the most abundant sulfide, and it occurs throughout the mine. Deposited early in the paragenetic sequence, it tends to be coarse and euhedral, and sometimes hosts exsolved gold within the grains. The abundance of pyrite is a poor indicator of ore grade. Where it occurs as coarse, shiny, anhedral crystals it is an indicator of high-grade ore and is usually accompanied by sulfosalt minerals including the ruby silvers.

Polybasite is the most abundant sulfosalt mineral and pyrargyrite predominates over proustite in the ore. In assays antimony is much more abundant than arsenic which is consistent with the observed mineralogy. Polybasite, proustite, and pyrargyrite formed late in the sequence and replace nearly all other minerals. They can occur as veinlets, disseminated grains, or intergrown masses replacing other sulfides and quartz. Because proustite and pyrargyrite form a solid solution series above 300°C (Toulmin, 1963), their occurrence as separate phases indicates a crystallization temperature below 300°C. Keighin and Honea's (1969) work indicates that pyrargyrite does not form below 192°C and this places a lower limit on the temperature of formation of the ore of 192°C.

Rare subhedral crystals of acanthite appear to have a cubic form which implies crystallization above 175°C (Keighin and Honea, 1969; and Roy and others, 1959). This along with the proustite-pyrargyrite association places a firm floor on the formation temperature of the main ore stage between 175°C and 192°C.

Paragenesis

The paragenesis of the Buffalo Boy ore indicates early, high temperatures followed by gradual cooling. The sequence has been divided into four stages (Figure 5). Base-metal minerals occur early with most of the important precious-metal minerals. Late in the development of the deposit, acanthite, native silver, and marcasite suggest cooler

conditions. The mineral textures appear to indicate hypogene deposition although the late minerals, especially marcasite and native silver, may have formed, in part, from supergene alteration.

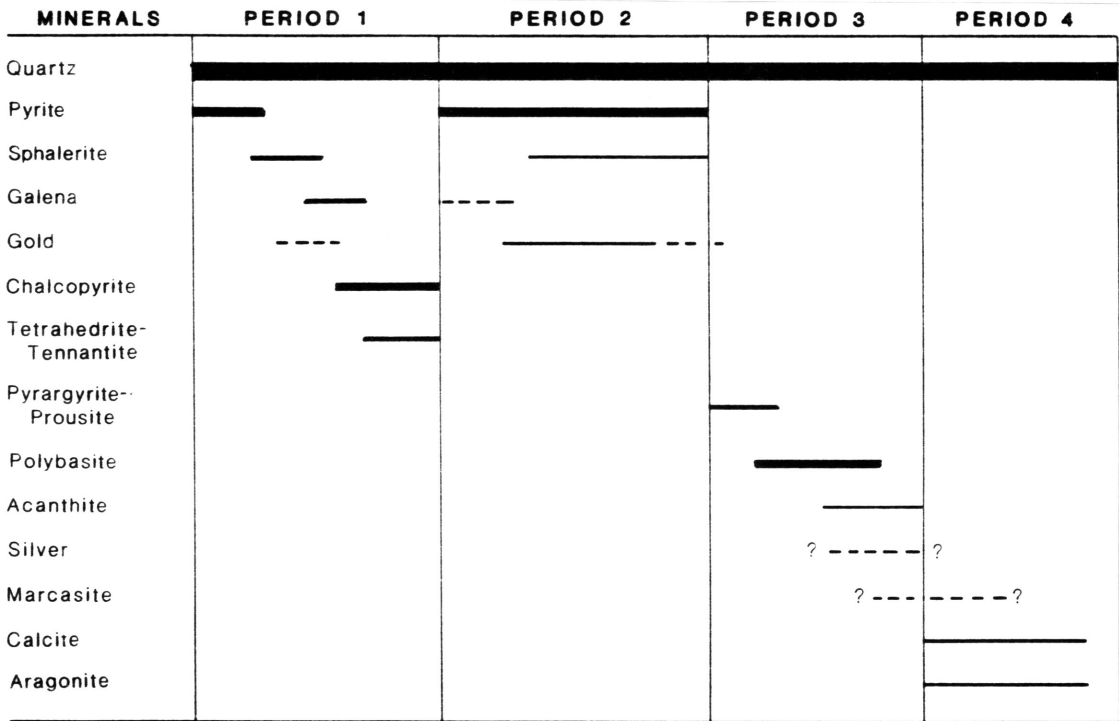


FIGURE 5: Paragenetic diagram for the Buffalo Boy Mine. Width of the lines indicates relative abundance of the minerals.

The precious-metal-rich sulfosalt assemblage of minerals remains the dominant assemblage at the 397 level of the mine. Zone four, base-metal-rich ore is expected to predominate at some unknown depth below the current workings. The deposit remains open at depth as well as along strike in both directions from the developed workings.

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**PARAGENESIS OF THE MINERALIZATION EVENT AT ASPEN, COLORADO,
BASED ON STRUCTURAL, TEXTURAL, AND MINERALOGICAL STUDIES
OF THE OREBODIES IN THE SMUGGLER MINE**

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INTRODUCTION

The Aspen district, located 170 km southwest of Denver, has produced over 100 million ounces of silver with accessory lead, zinc, and copper from a group of large manto-type orebodies in the Leadville Limestone. The Aspen ores are notably rich in silver, with a district-wide average grade (including both oxidized and sulfide ore) of 44.2 ounces per ton (OPT) Ag, 5.9% Pb, 2.1% Zn, and 16.4% Ba (calculated from data in Spurr, 1898). Locally, however, silver concentrations as high as 19,000 OPT have been measured (Spurr, 1898). As might be expected, the silver-rich ores have an abundance of silver minerals, including silver sulfosalts, silver sulfides, and native silver. The native silver is a product of supergene enrichment of the primary sulfide and sulfosalt minerals, and is both widespread and locally abundant. In 1894 for example, a 770 kg boulder of silver was recovered from the Smuggler mine, along with several others weighing between 225 and 450 kg. For complete discussions of the geology of the Aspen District, see Spurr (1898) and Bryant (1979).

Previous mineralogic work

The mineralogy and basic paragenesis of the Aspen ores was documented by Spurr (1898), Bastin (1925) and Bastin (1950). Bastin's work was based primarily on samples obtained from private collections; the mine workings at that time did not expose high-grade ore. In the early 1980's the Smuggler Mine was reopened, and from 1983-1986 we had an opportunity to complete comprehensive textural, structural, mineralogic, and geochemical studies on the ore exposed there (see Stegen, 1988, for details). As part of those studies, some important paragenetic relations not recognized by Spurr (1898) and Bastin (1925) were identified.

Purpose

The purpose of this report is to summarize the paragenesis of the mineralization event(s) at Aspen. We have found the work of Spurr (1898) and Bastin (1925) to be exceedingly accurate (although in some ways incomplete), and it has been possible to incorporate all of their observations into our paragenetic sequence. Although most of the samples described by the authors are from the Smuggler Mine, several samples from other areas of the district were also examined.

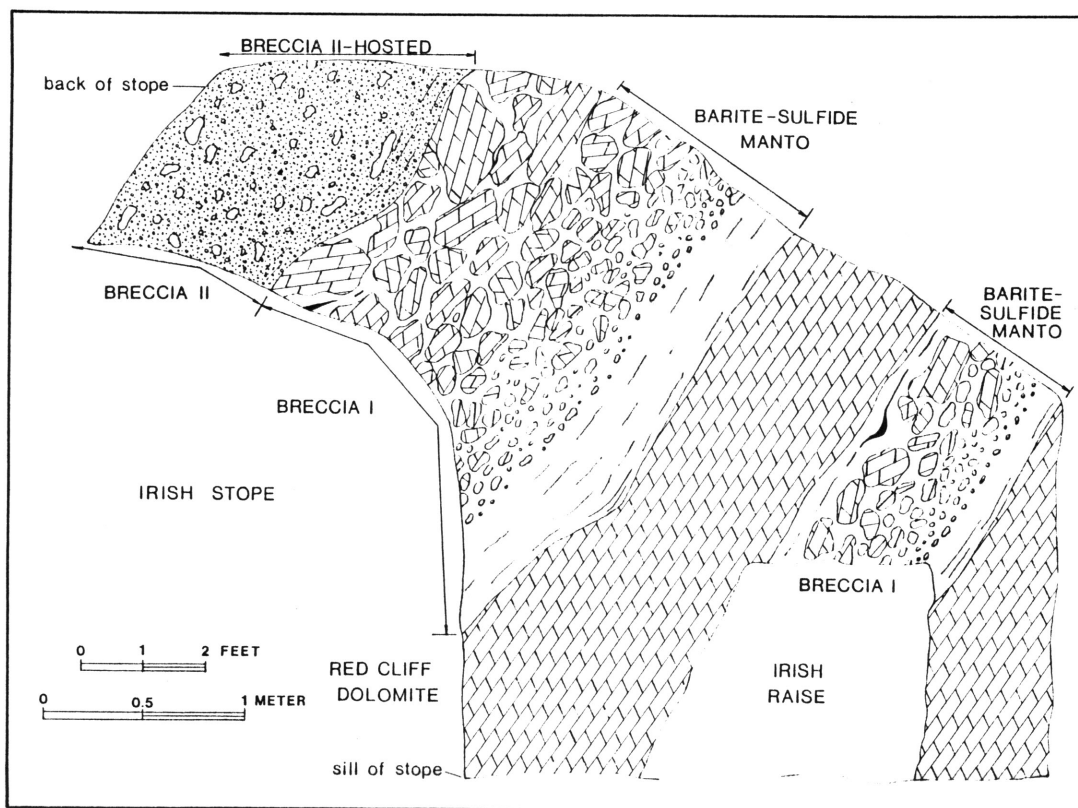


Figure 1. Rib sketch of the Irish Raise area in the Smuggler Mine, showing the relationship of manto ore to breccia masses in the Leadville Limestone.

Methods

Samples were taken principally from stopes within the Smuggler Mine. From these samples, 105 singly polished thin and thick sections, doubly polished thin sections and polished slabs were prepared. Ore petrology was identified using reflected and transmitted light microscopes, x-ray diffraction, and VHN determinations.

Orebodies

Most of the mantos in the Smuggler Mine are hosted by dolostone breccias in the Leadville Limestone (Fig. 1). In addition, however, substantial mantos are also present in the Belden Formation. The manto deposits consist predominantly of mixed sulfides, sulfosalts, and native silver in a barite-rich (30-70%) gangue (Fig. 2a). Locally, massive sulfide ore is present, as is barren barite. The hydrothermal minerals are present in two main textural settings; as open-space filling between breccia fragments, and as replacement of a discontinuous bed of stratified dolomite sand located in the basal part of the breccia. Contacts with enclosing wallrocks are sharp. The orebodies range in thickness from 1 to 5 meters.

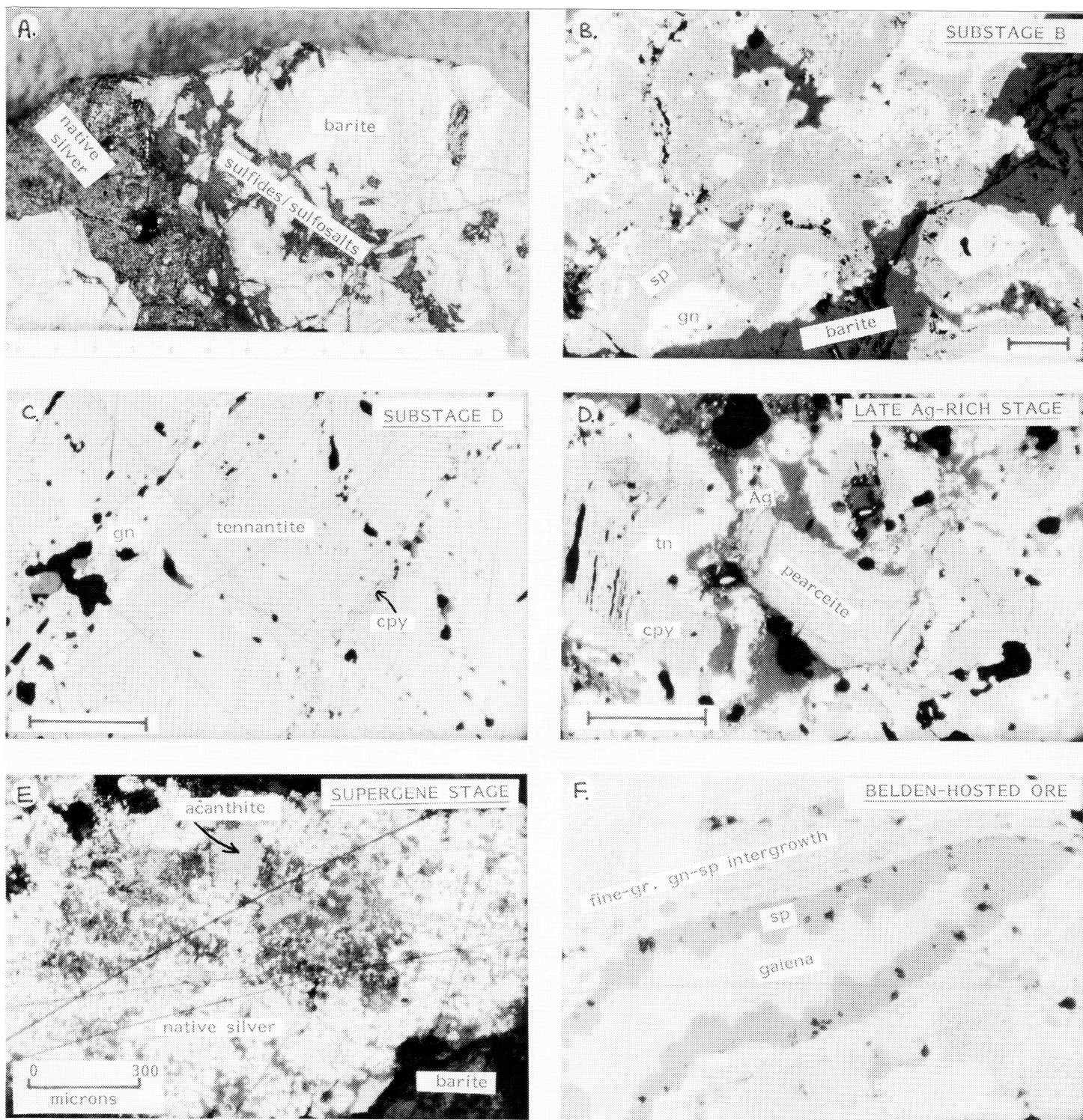


Figure 2. A). Baritic manto ore from the Smuggler Mine (scale is in cm). Figures B-F are photomicrographs of manto ores from the Smuggler Mine; scale bar in all cases is 300 microns. B). Substage B sphalerite and galena with barite. C). Substage D galena, chalcopyrite, and sphalerite replacing tennantite. D). Substage D chalcopyrite with tennantite. Pearceite replaces tennantite and chalcopyrite but is veined by native silver. E). Silver with acanthite in barite. F). Open-space sphalerite lining galena-sphalerite mass. Later galena event infilled void. Width of field is 0.35 mm.

PARAGENESIS, MINERALOGY

The mineralization event can be subdivided into three general periods on the basis of mineralogical, textural, and structural criteria:

- 1). An early hydrothermal event that was responsible for most of the ore deposition. This was followed by a major brecciation episode.
- 2). A post-brecciation hydrothermal event.
- 3). Supergene enrichment of the primary sulfide/sulfosalt ore.

This paragenetic sequence is summarized in Figure 3. All of the mineralization effects at Aspen are low-pyrite (<1%) and low-gold (<5 ppb).

Main ore-forming event

The main ore-forming event can be subdivided into three principal stages (Fig. 3):

- 1). An early gangue stage dominated by the open space growth of barite within the breccia;

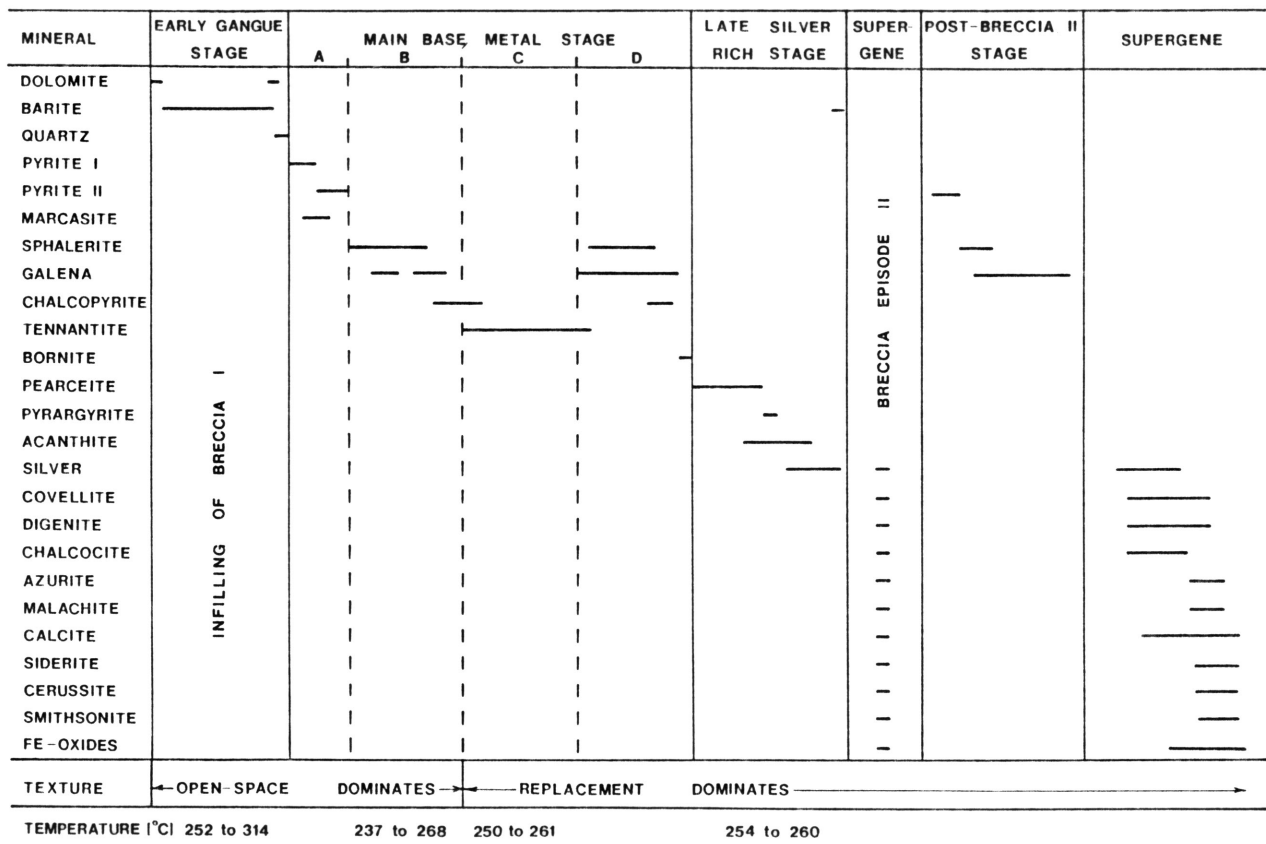


Figure 3. Generalized paragenetic sequence, textural relationships, and fluid inclusion temperatures for manto ores of the Aspen District.

- 2). A main base metal stage characterized by colloform growth on barite by base-metal sulfides followed by replacement and veining by tennantite ((Cu,Ag)₁₂As₄S₁₃; the arsenian counterpart of tetrahedrite), sphalerite, and galena;
- 3). A late silver-rich stage with replacement of base-metal sulfides by pearceite ((Ag,Cu)₁₆As₂S₁₁; the arsenian counterpart of polybasite), acanthite (Ag₂S), and native silver.

Early gangue stage. Barite is most commonly found as tabular to radiating, growth-zoned crystals attached to breccia fragments. It also occurs as coarse-grained aggregates that replaced breccia matrix and stratified dolomite sand. The bulk of the barite preceded sulfide deposition and was coated, veined, and replaced by the later ore minerals. A volumetrically minor, post-sulfide barite stage was seen on a local scale.

Main base-metal stage. This stage was separated into four substages. Substage A is volumetrically the smallest and is composed of pyrite and marcasite. Both minerals have a wide range of forms but are principally seen as discrete anhedral grains disseminated in barite and also as clusters or aggregates of crystals that coated barite crystal faces. Substage B is characterized by open space growth of sphalerite, galena, and chalcopyrite on barite, pyrite, and marcasite masses. Colloform or botryoidal morphologies of these sulfide minerals are abundant. Sphalerite is light greenish-brown in color and often exhibits well-developed growth zoned crystals when viewed in transmitted light; it has not been possible to correlate these growth bands through the district. Other sphalerite and galena morphologies seen range from semi-linear bands of anhedral to euhedral grains to irregular-shaped masses. The substage C mineralogy is composed of tennantite, the most abundant metallic mineral in the mantos. This substage marks a change from open space growth textures seen in substages A and B to a replacement-dominated texture found throughout the remaining paragenesis. Tennantite has poorly developed crystal outlines and is usually massive. It also forms complex atoll textures with, and veins early chalcopyrite. Tennantite is extensively replaced by substage D sphalerite, galena, and chalcopyrite (Fig. 2c). These substage D sulfide minerals are volumetrically much larger and more extensive than their substage B varieties. Substage D sphalerite and galena range from small veinlets in tennantite to expansive areas of massive ore. The bulk of the lead and zinc produced from the district is from this substage.

Late silver-rich stage. Pearceite, acanthite, and native silver occur collectively in amounts subordinate to tennantite. Pearceite is the most abundant silver mineral. It forms coarse-grained anhedral aggregates when replacing tennantite (Fig. 2d) and fine-grained masses when replacing galena. In rare sites, pearceite was observed as large, euhedral crystals that interlock to form masses as much as 1 cm in diameter. Acanthite forms rounded to irregular-shaped islands in native silver (Fig. 2e) and coarse-grained masses and blebs replacing tennantite. The coarse-grained type contains faintly visible lamellar twinning which suggests that this mineral originally formed as its dimorph argentite and was inverted with lowering temperature (below 179 C) to acanthite (Randohr, 1969). Native silver occurs district-wide and was mined to a depth of about 360 m. In polished section, silver is usually found as veinlets and irregular-shaped patches replacing sulfides. It has a strong spatial association with pearceite and acanthite, and less

commonly tennantite. Native silver is ubiquitous, consisting of irregular patches that replaced prior sulfides and barite. Late supergene oxidation carbonate and oxide minerals are usually associated.

Post-brecciation hydrothermal event

The silver-rich baritic mantos described above (which replace an earlier breccia) are cut by a younger breccia mass, and that breccia is also mineralized (Fig. 1). This type of ore was not described by Spurr (1898), and preliminary work by the authors indicates that it is not present on Aspen Mountain. The ore in the younger breccia consists of varying proportions of galena, sphalerite, pyrite, and pitchblende. The sulfide minerals occur as replacement of the breccia matrix. No replacement of breccia fragments was found. Mineralized rock varies from massive ore to sparse, fine-grained disseminations. In the Smuggler mine, massive ore was mined principally along intersections of the brecciated strata with Laramide-aged faults. In these stopes, fragments of barite-sulfide ore derived from the older silver-rich mantos were cemented by masses of galena, sphalerite, and supergene silver. In stopes distal to these faults, the breccia is generally weakly to non-mineralized.

The mineralogy of the younger breccia-hosted deposits is simple (Fig. 3). Galena is the dominant sulfide with sphalerite and pyrite occurring as accessory minerals. When replacement of the matrix is complete, galena forms anhedral masses. Sphalerite and pyrite are seen as irregular-shaped masses and blebs replaced by galena. As the degree of replacement decreases, the primary bedding characteristics of the matrix are easily identified.

Supergene enrichment stage

Much of the native silver in the Aspen District developed during this episode, which was not studied in the current work. For details, see Spurr (1898) and Bastin (1925).

Manto ores in the Belden Formation

Manto ore in the Belden Formation has previously not been described from the Aspen District. In the Smuggler Mine, however, limestone in the Belden is locally replaced by massive sulfide. These mantos are mineralogically somewhat different than those in the Leadville Limestone, and it is not possible to unambiguously place these ores in the paragenetic sequence developed from studying the Leadville. In particular, these ores have a comparatively low silver-content. For this reason, a separate paragenetic diagram has been constructed for the Belden-hosted mantos (Fig. 4).

Mineralogy of the mantos contained in the Belden Formation consists of pyrite, marcasite, sphalerite, and galena. The mantos are tabular-shaped, up to 1.5 m thick, and extend laterally 60 to 140 meters. The host rock consists of carbonaceous shale interbedded with limestone. Pyrite in the Belden-hosted mantos forms subhedral to euhedral grains that are growth zoned and replaced by sphalerite and galena. Marcasite is an accessory mineral and is seen as discrete isolated crystals and aggregates of several crystals. Marcasite is extensively replaced by galena and sphalerite. Galena volumetrically dominates over sphalerite, but both are abundant. Most commonly galena and sphalerite

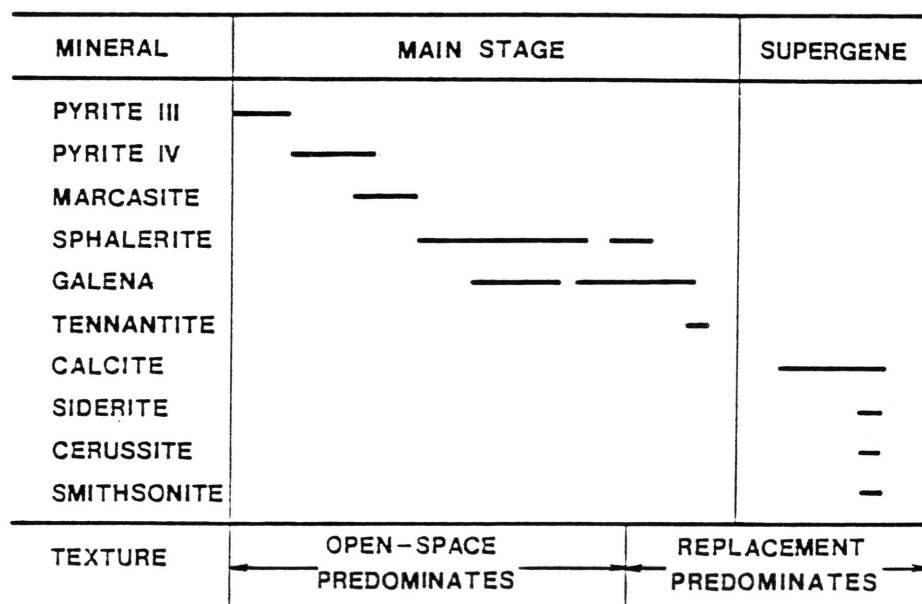


Figure 4. Generalized paragenetic diagram for mantos hosted in the Belden Formation, Smuggler Mine.

are seen replacing shale but they also occur as colloform or botryoidal growths (Fig. 2f). Sphalerite occurs as islands and patches within massive galena and as semi-linear bands oriented along colloform growth boundaries. Galena is always massive.

Acknowledgements

This work constitutes a portion of the senior author's M.S. thesis at Colorado State University. We thank Stefan Albouy of Smuggler Consolidated Mines Corp. for assistance, access, and encouragement. Robert Cobban of the Denver Museum of Natural History provided select samples of Smuggler ores.

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THE PRESENCE OF RECTORITE IN HYDROTHERMALLY ALTERED PORPHYRY ASSOCIATED WITH GOLD-RICH MANTOS, BUCKEYE GULCH, CENTRAL COLORADO

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Introduction

In 1984 a possible orebody containing considerable gold and silver was discovered in Buckeye Gulch, approximately 8 km NNW of Leadville, Colorado. The precious metals occur in a sulfide replacement mass within the Leadville Dolomite. Porphyry in the area of this occurrence has been affected by intense hydrothermal alteration. Most of the altered samples show assemblages similar to those described from many other hydrothermal ore deposits, including those at the nearby Leadville and Gilman mining districts. In addition, a few samples show complex or unusual clay assemblages, including some containing the mineral rectorite. Rectorite occurs in samples with as many as five other discrete clay minerals.

The purpose of this paper is to document the unusual alteration assemblages in Buckeye Gulch, and to interpret their significance.

Local Geology

Buckeye Gulch is located near the northwestern edge of the Colorado Mineral Belt. Cambrian through Mississippian sedimentary rocks in this general area have an aggregate stratigraphic thickness of about 200 m, and are overlain by 3000+ m of coarse clastic Pennsylvanian sedimentary rocks. The sedimentary section in Buckeye Gulch has been expanded by the emplacement of about 10-12 sills of quartz monzonite porphyry, which can be grouped into three major units (Lincoln Porphyry, Pando Porphyry, Sacramento Porphyry), and two minor units that have not yet been named.

GEOLOGY OF THE BUCKEYE GULCH ALTERATION ZONE

General Character

Within Buckeye Gulch a large hydrothermal alteration zone is exposed in outcrop (Fig. 1). Recent core drilling by Noranda/Tenneco and Canyon Resources Corporation has established that this alteration zone extends at least 650 m into the subsurface. The alteration zone is known to be associated with carbonate-replacement deposits in the Leadville Dolomite, but the size, distribution, and overall metal content of those deposits has not yet been determined (Beaty et al., 1987; Pohl and Beaty, 1988). The hydrothermal alteration in Buckeye Gulch is in many ways similar to that in the nearby mining districts at Leadville (Emmons et al., 1927) and at Gilman (Lovering et al., 1978).

The distribution of feldspar-destructive alteration in the Buckeye Gulch area is shown on Figure 1. Within this area, which is about 3 km in diameter, the rocks consist almost exclusively of Lincoln Porphyry and

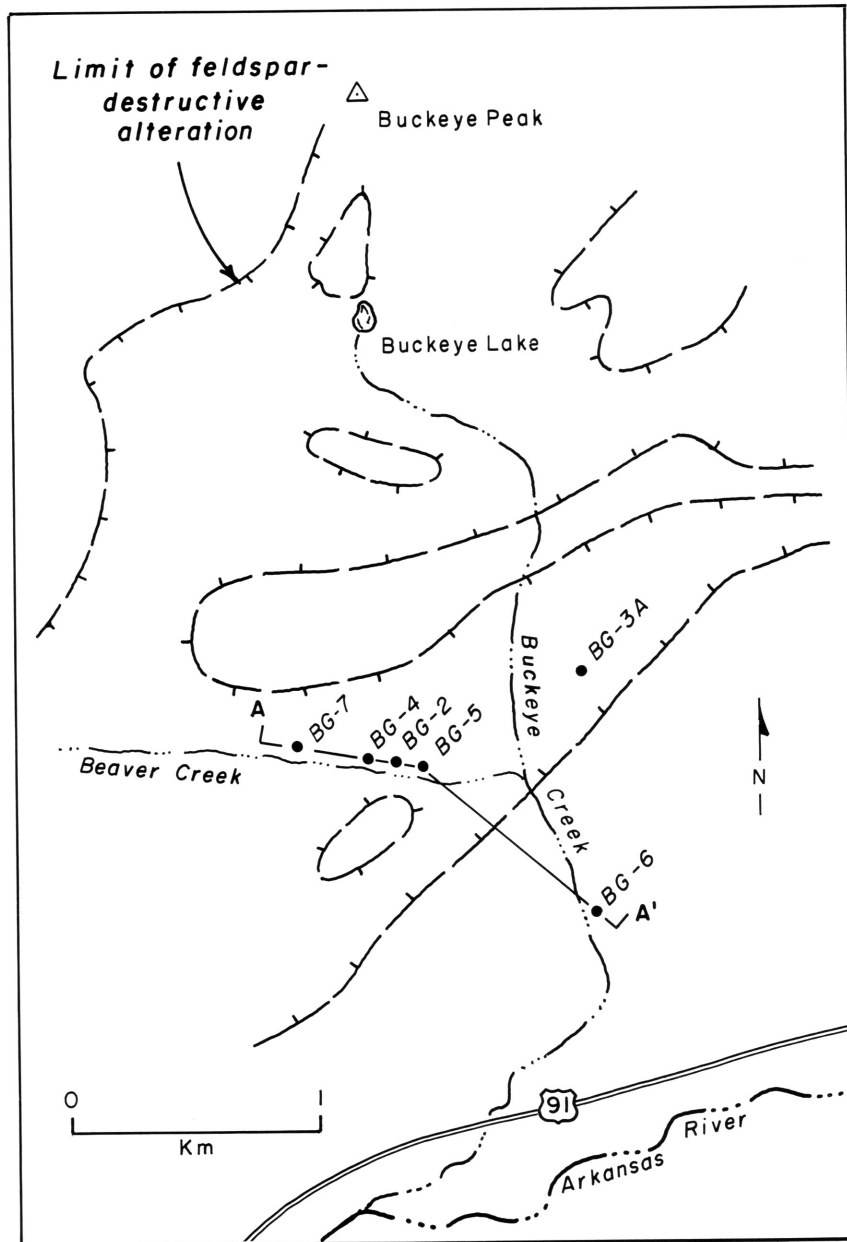


Figure 1. Map of feldspar-destructive alteration in the Buckeye Gulch area. Figure 2 is a cross section along line A-A'. Samples studied in detail are from the drill cores shown.

clastic sedimentary rocks of the Minturn Formation. Hydrothermal alteration is best expressed in the porphyry, but much of the Minturn consists of arkose, which can also be used to define the alteration zone. In addition to destruction of feldspar, the rocks within this alteration zone are characterized by limonite-stained fracture surfaces and sparse quartz-pyrite veins.

In order to define the general mineralogic characteristics of this alteration zone, whole-rock X-ray diffraction analysis was completed on approximately 200 samples of porphyry. Because of the complexities involving possible sedimentary clay minerals in the Minturn Formation, this formation was excluded from the X-ray study. The X-ray diffraction data show that feldspar is variably preserved, that quartz is ubiquitous, that all of the altered rocks contain dolomite and/or calcite, and that the principal clay minerals are kaolinite and sericite. In addition, pyrite is widespread in the alteration assemblage.

The porphyry samples from the surface show variation in alteration assemblages, ranging from sericite-rich to kaolinite-rich. Most of the surficial rocks are kaolinite-rich. In general, the sericite-rich samples are located in the center of the alteration zone. However, there may also be some localized zoning about veins, which produces some mixed assemblages when considered at large scale.

In the subsurface, the abundance of sericite progressively increases with depth, the abundance of kaolinite progressively decreases with depth, and in the center of the system there is no relict feldspar (Fig. 2).

Stability of original igneous minerals

With one exception, all of the igneous units in Buckeye Gulch are composed of quartz monzonite porphyry, with a primary mineralogy of quartz, plagioclase, orthoclase, biotite, magnetite, and several trace minerals. Suites of samples that are variably altered show a systematic sequence of destruction of these minerals. In the most weakly altered samples, plagioclase is altered to clay minerals, and the other components of the rock are unaltered. The plagioclase phenocrysts are more readily altered than the plagioclase in the groundmass. With increasing intensity, the orthoclase phenocrysts are altered to clay minerals, but biotite remains stable. With further increasing alteration, biotite is altered to sericite (or less commonly, to chlorite) + sphene, and magnetite is variably pseudomorphed by pyrite. Quartz is stable throughout this alteration sequence, and igneous quartz phenocrysts locally show quartz overgrowths.

CLAY PETROLOGY

In addition to whole-rock X-ray diffraction analysis, several samples were disaggregated ultrasonically and the <20 μ m and <1 μ m size fractions were separated, mounted, and examined by X-ray diffraction. In addition, chips of each sample were examined by scanning electron microscopy (SEM) and energy dispersive X-ray fluorescence spectrometry (EDS). The fine fractions in several samples exhibit an extremely complex phyllosilicate assemblage containing up to six separate clay minerals. The clay minerals include rectorite, smectite, sericite, kaolinite, chlorite, and remnant biotite.

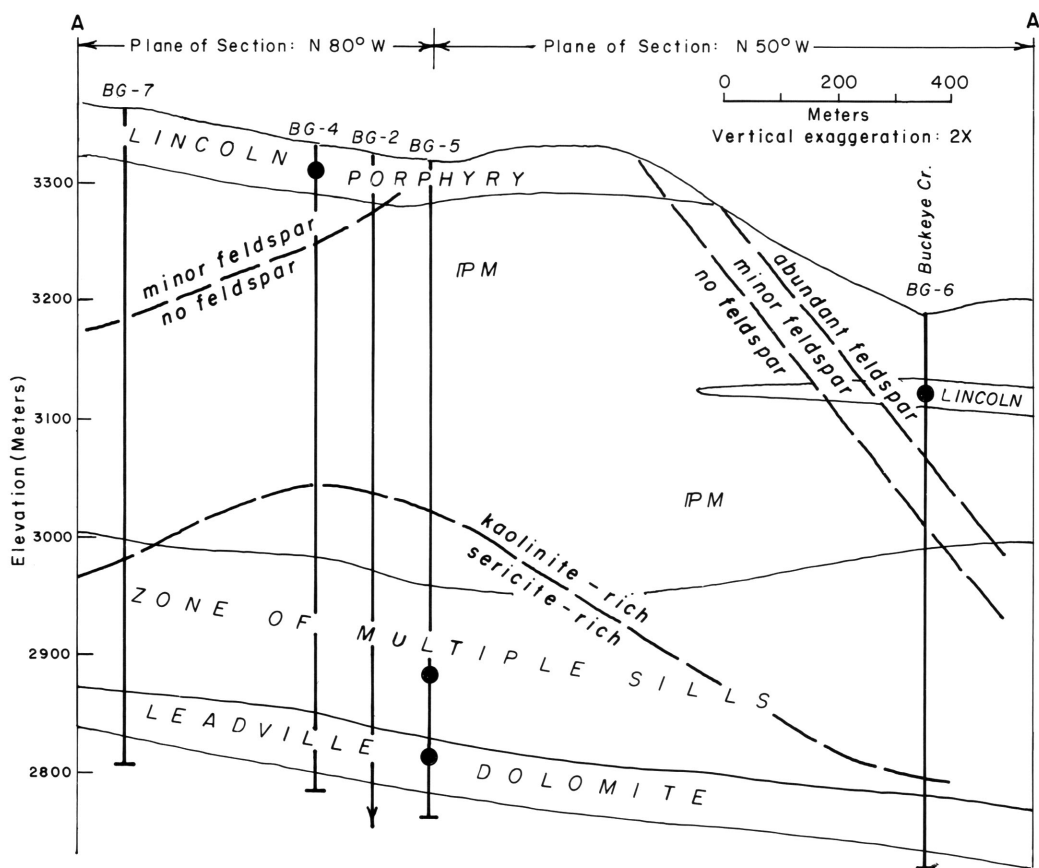


Figure 2. Cross section through part of the Buckeye Gulch alteration zone (see Fig. 1 for line of section). A few small faults have been omitted for clarity. Sample BG-5-531 m is from a porphyry sill within the Leadville Dolomite that is too small to plot at this scale.

Rectorite is a specific type of interstratified mica/smectite; the name is reserved for mica/smectite having equal proportions of mica and smectite layers in regular alternation. Although the mica/smectite in these rocks is technically not all rectorite, the proportion of mica layers is tightly constrained between 55-75 percent. There are no large variations in mica proportions and the mica/smectite either exhibits maximum ordering or is absent; no random mica/smectite was observed. Rectorite is identified with X-ray diffraction by the presence of a superlattice peak representing a basal spacing of about 27Å, with integrally spaced higher order reflections (Figure 3). Qualitative EDS data indicate that the rectorite contains potassium (in the mica interlayers), thus making it a K-rectorite. Texturally, rectorite occurs as cellular or meniscus-like growths on the surfaces of K-feldspar grains, but with no apparent alteration of the feldspar (Figure 4). This delicate texture suggests that the rectorite grew into open pore spaces, rather than developing by alteration of a matrix mineral. The occurrence of K-rectorite is limited to the least altered zones near the surface and occurs only in the Lincoln Porphyry.

Discrete smectite appears locally throughout the system. It is a discrete phase containing no interstratified mica layers. The smectite is abundant in the shallowest samples, but was also identified in a carbonate-hosted sill in the deepest sample. The smectite is chemically distinct from the K-rectorite, containing more iron and magnesium and no potassium.

Sericite occurs in many of the samples, especially the deeper and more severely altered rocks, and is seen as discrete, cornflake-like plates. Unlike the micaceous minerals found in other hydrothermal deposits, these micas exhibit no detectable expandability (X-ray diffraction peaks do not change in position or intensity). The sericite is chemically distinctive, containing abundant potassium but little iron and no detectable magnesium. Although sericite may occur in the same hand specimen as the K-rectorite and smectite, it is texturally separate and shows no obvious genetic relationship to other clays.

Much of the alteration enveloping the sericitic core of the system is rich in kaolinite, which increases in abundance away from the alteration core. The quartz monzonite porphyry contains abundant primary biotite and much of this biotite persists on the periphery of the system. Chlorite is also present in scattered samples and is sometimes associated with biotite.

DISCUSSION

In general, the zonation of hydrothermal alteration at Buckeye Gulch is similar to the zonation in some other hydrothermally altered porphyry systems; it consists of a sericitic core in the zone of most intense alteration with a zone of kaolinite-rich argillic alteration. The pattern of feldspar destruction mimics the kaolinite abundance zonation. The sericitic zone is not well exposed at the surface, where less severely altered rock is widely exposed.

An unusual feature of the low grade alteration is the presence of the K-rectorite. Although ordered mica/smectite has been commonly reported in shales and bentonites in diagenetic environments, it has been described much

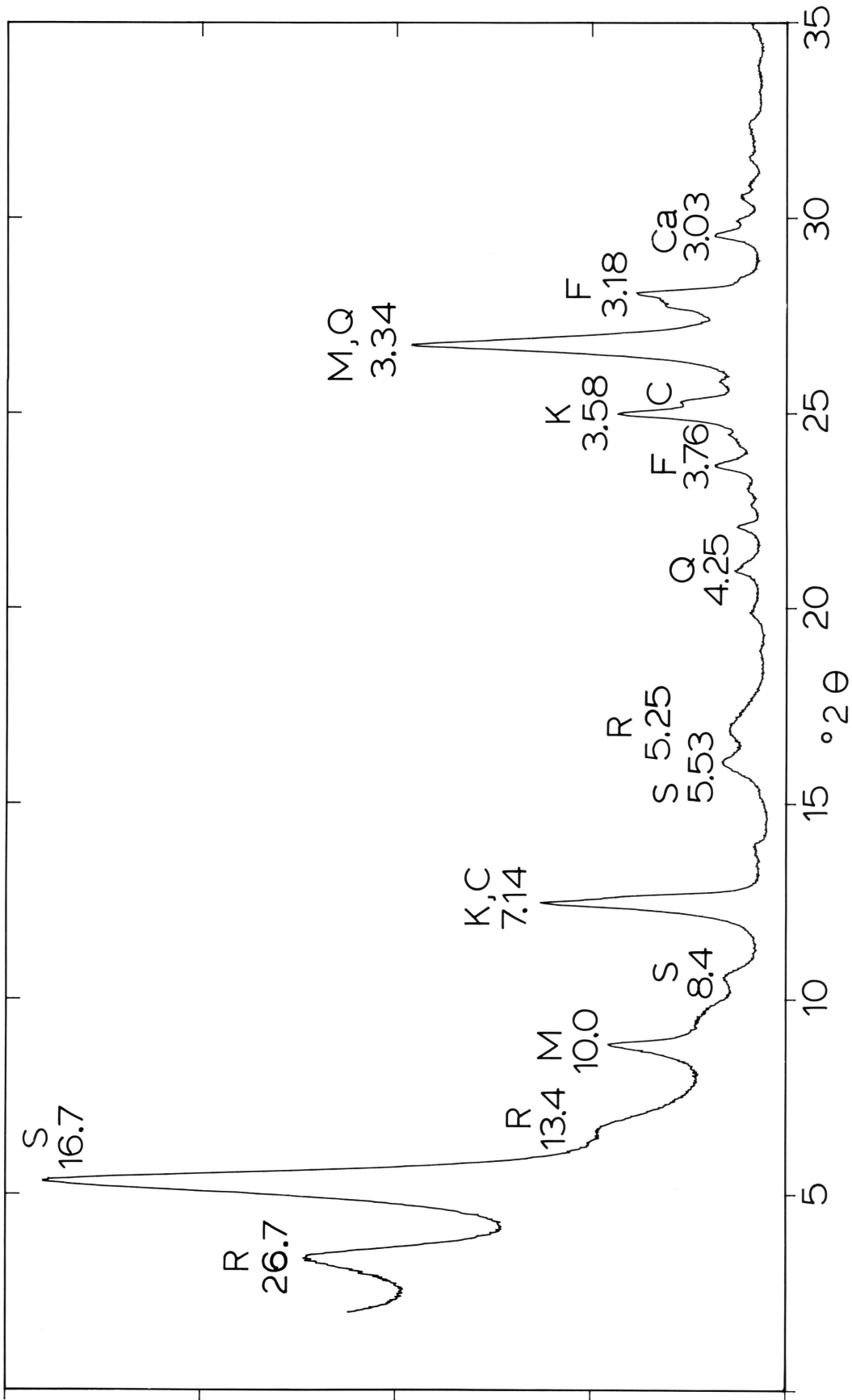


Figure 3. X-ray diffraction pattern for the < 1 μm fraction of sample BG-4-25 showing complex alteration mineral assemblage. Sample is oriented and saturated with ethylene glycol. R = ordered mica/smectite (70% mica layers), S = smectite, M = mica (includes both sericite and biotite), K = kaolinite, C = chlorite, Q = quartz, F = feldspar, Ca = calcite. Peak positions are in angstroms (Cu $K\alpha$ radiation).

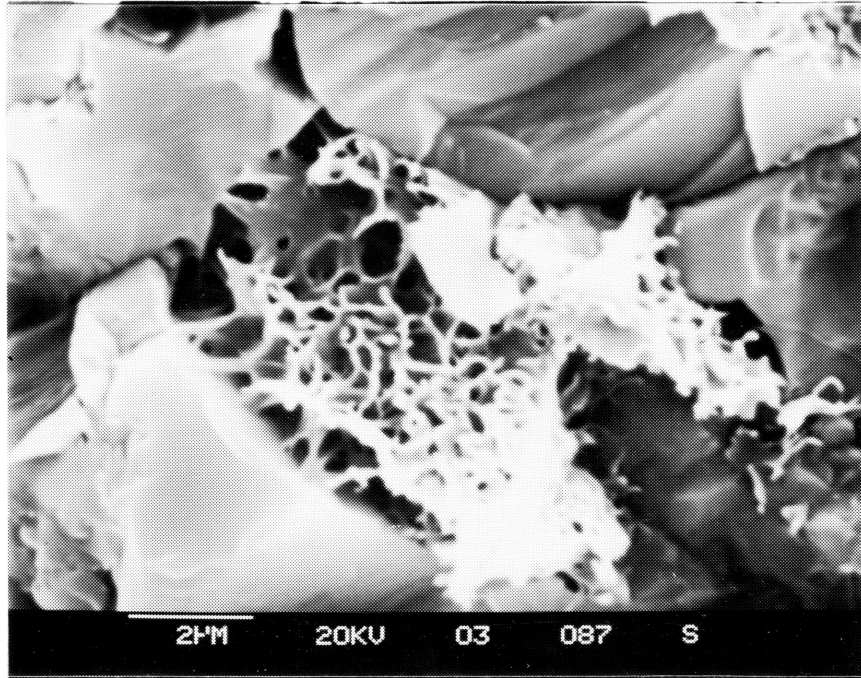


Figure 4. Scanning electron micrograph of K-rectorite on potassium feldspar in altered Pando Porphyry (sample BG-4-25). Bar at bottom of photo is 2 μm .

less frequently in hydrothermal systems (Inoue and Utada, 1983; Vergo, 1984). Its origin and relationship to other alteration minerals has not been well defined. In the present situation, the K-rectorite appears to be a product of hydrothermal alteration at temperatures somewhat below that which produced the sericitic assemblage. The close textural association between K-rectorite and K-feldspar suggests that it forms during the incipient alteration of the feldspar and may represent a metastable intermediate phase in the alteration process; as the alteration of the feldspar continues, the K-rectorite may disappear. Thus its occurrence is restricted to the low grade outer alteration zone. In this respect, it is similar in occurrence to some propylitic minerals.

The K-rectorite and sericite are chemically and structurally similar, consisting of aluminous mica layers with different Al-for-Si substitutions. The primary difference is in the crystallographic continuity and extent of the structure along the c^* direction. In K-rectorite, each 2:1 layer is a discrete unit, separated by expandable layers which behave like smectite. However, in sericite the structure is many layers thick, producing traditional characteristics of a mica. Texturally, the two minerals are distinct and they occur in different zones of the alteration system. Thus we can infer that their mode of nucleation and crystal growth must differ significantly, probably as a function of temperature and fluid chemistry. The higher temperature and higher potassium content near the center of the hydrothermal system permit the nucleation of mica layers that can be nourished from the potassium-bearing solution and grow into multilayer structures. On the periphery of the system, the mica layers nucleated, but were unable to grow in crystallographic continuity, thus producing the K-rectorite. The very high surface area of the K-rectorite renders it unstable with respect to other phases and it disappears as alteration becomes more intense, being replaced by the kaolinite-rich assemblage.

The ubiquity of smectite in this system is also similar to other hydrothermal or geothermal systems. Because aluminous smectite is commonly considered to be strictly a low-temperature phase in potassium-bearing systems, its occurrence with high-temperature minerals in this system must arise from crystallization during late, low-temperature alteration. Otherwise it would be eradicated during the subsequent high-temperature alteration that produced the sericite and associated minerals.

As discussed above, the geology of the Buckeye Gulch hydrothermal system is generally similar to that of nearby Leadville and Gilman. For comparison to the Buckeye Gulch data, we have completed similar detailed X-ray diffraction studies on the altered porphyry at Gilman; unfortunately, comparable data from Leadville are not available. The Pando Porphyry at Gilman was sampled in a number of drill cores which are located both above and peripheral to the sulfide deposit. All samples contain the assemblage sericite, kaolinite, and quartz, with variable dolomite and pyrite. Smectite is locally present, but none of the samples examined from Gilman contains K-rectorite. It is uncertain whether this difference is related to the fundamental physico-chemical difference between the two hydrothermal systems, to different sampling patterns, or even to the absence of the Lincoln Porphyry at Gilman.

In summary, the hydrothermal alteration at Buckeye Gulch has produced a

series of alteration zones ranging from the most intense, sericite dominated central zone surrounded by a kaolinite rich argillic envelope in which feldspars are gradually destroyed. The outermost zone observed in this system contains the unusual mineral K-rectorite which probably forms as a metastable alteration phase associated with K-feldspar. We encourage other researchers to look for K-rectorite in hydrothermally altered rocks so that the origin and stability of this petrologically useful mineral may be better understood.

Acknowledgements

Permission to study these samples and publish these results was granted by Noranda Exploration and Tenneco Minerals. Denise Saunders and Tommy Thompson helped interpret some of the early alteration data. The support of Canyon Resources to one of us (DWB) is gratefully acknowledged. Much of the X-ray diffraction data was collected by Kenneth Esposito. Drafting was done by Robert M. Dahl.

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