



*Mineralogy of The*  
**SPRING CREEK AREA**  
LAST CHANCE MINING DISTRICT  
PLUMAS COUNTY, CALIFORNIA

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*First discovered between 1905 and 1909, the mines of the Last Chance mining district produced significant quantities of copper and molybdenum until closing in the 1920's. Extensive collecting at the abandoned mines has revealed over 65 mineral species in a complex polymetallic quartz vein system, including bismutoferrite, bismutostibiconite, clinobisvanite, koechlinite, namibite, schumacherite, posnjakite, wroewolfeite, idaite, cornwallite, clinoclase, cornubite and lindgrenite.*

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## INTRODUCTION

California has a long history of being a significant producer of copper, with a production history extending from the late 1880's to about 1930. One of the former major producing areas was the Plumas copper belt that includes the Engles, Reward, Superior and Walker mines, along with a score of smaller producers (Clark and Smith, 1972). A second, smaller copper-producing area lies just to the east of this belt in the Diamond Mountains. Here several small mines and prospects have produced copper in association with molybdenum, uranium and silver.

We first visited this area in 1971, and located a copper prospect that consisted of several shallow pits, a caved shaft and several small dumps which were all heavily covered with forest debris. An old claim marker was found relocating the prospect as the Lodi #4. Minerals collected at that time included bornite, chalcopyrite and molybdenite in a fractured quartz matrix. Also identified were several secondary copper minerals, including chrysocolla, brochantite and lindgrenite.

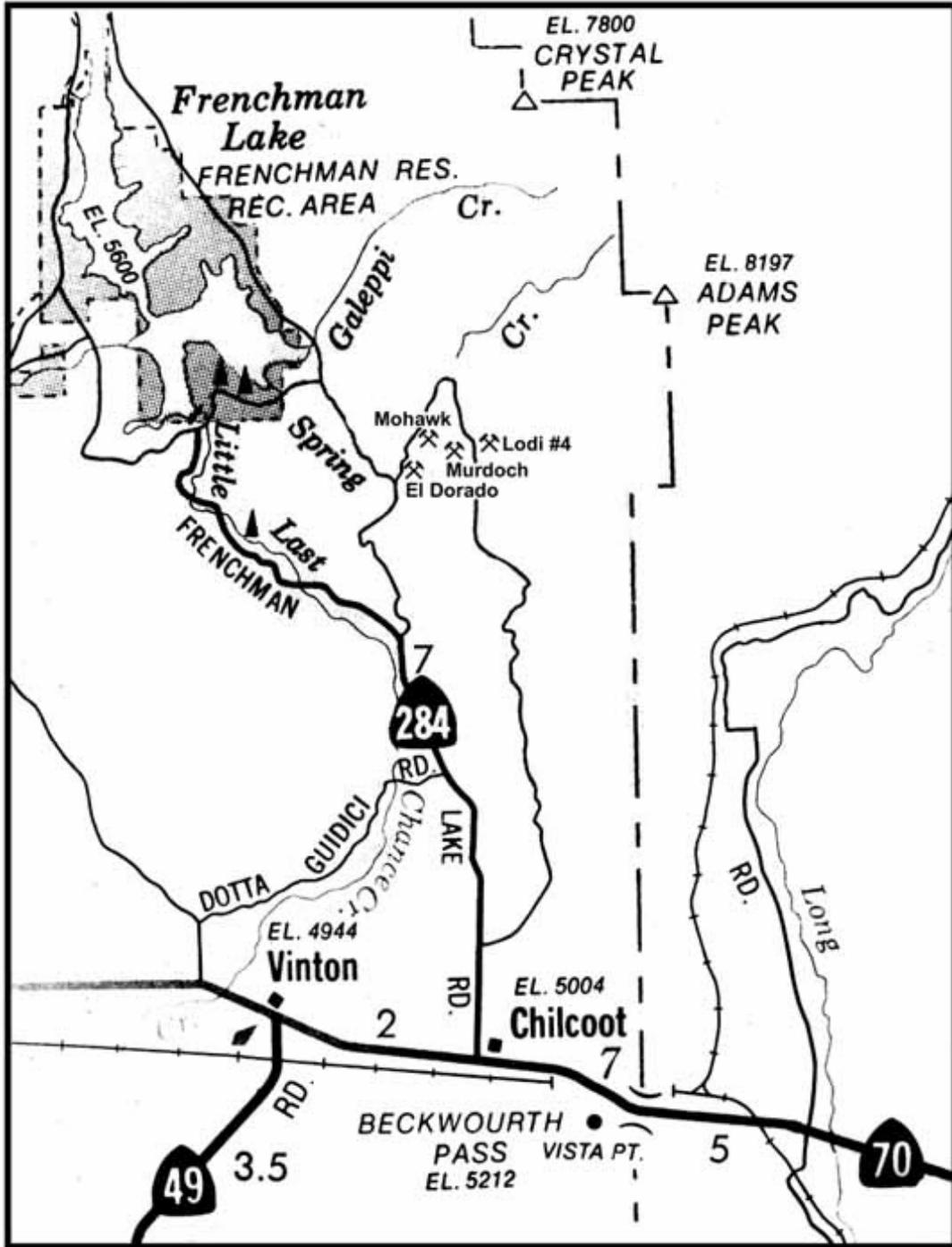
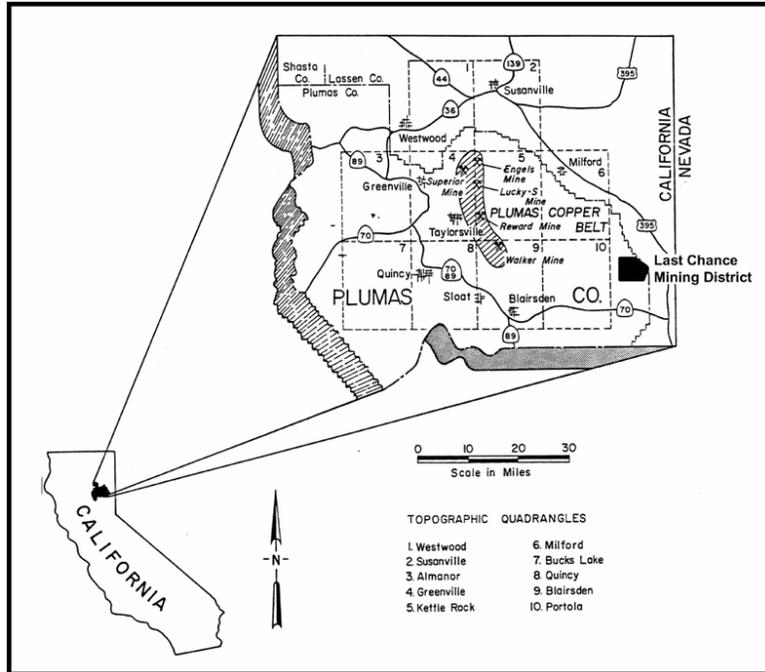


Figure 1a. Map showing the location of the mines along Spring Creek.

This material was reexamined in 1985 and a number of rare secondary bismuth minerals were also recognized. No bismuth minerals are recorded in the literature from Plumas County. Smith (1970) recorded trace amounts of the element in samples of the Mesozoic granitic rocks of the Plumas copper belt to the west. In subsequent trips to the area, additional sulfide samples were collected to determine the source of the bismuth minerals identified earlier.



**Figure 1b.** Map showing the location of the Last Chance Mining District.

The results of our study indicate that a very complex mineralogy occurs in the Spring Creek area. Over 65 minerals have been identified including the rare species lindgrenite, idaite, wittichenite, bismutoferrite, bismutostibiconite, clinobisvanite, koechlinite, namibite, schumacherite, posnjakite, wroewolfeite, clinoclase, cornwallite and cornubite.



**Figure 2.** Scene of the El Dorado mine collapsed adit.

## LOCATION

The copper mines of the Last Chance mining district are located along the upper portion of the Spring Creek drainage system on the west slope of the Diamond Mountains. This area lies at an altitude of 2100 meters and is located within the Plumas National Forest, approximately 16 km

northeast of Chilcoot and east of Frenchman Reservoir. The district can be reached by Forest Service roads from several points along the main Frenchman Lake Road.

The area topography is typical of the northern Sierra Nevada Mountains, consisting of steep mountains with timbered slopes with grassy meadows containing small streams. Weathered outcrops of granite are common in the area and protrude through the thin arkosic soil.

## HISTORY

Copper was important in the early days of California mining and was produced in commercial quantities from 51 of California's 58 counties. Clark and Smith (1972) have summarized this production, estimated to be in excess of 800,000 metric tons. The bulk of this production came from vein or replacement deposits in meta-rhyolites, schists, greenstones and similar rocks associated with granitic intrusions. The major producing areas have been the Sierra Nevada Foothill belt, the Shasta area and the Plumas copper belt. This latter region is unusual in that it is entirely within granitic intrusions.

The earliest record of copper mining in the Last Chance mining district is given by MacBoyle (1920); Eric (1948) has summarized the later activity. The major properties in the district included the Mohawk (Last Chance) mine, with a total output of over 1,000 tons of 6% chalcopryite ore, the El Dorado (Dufay) mine, which produced one carload of high-grade ore, and the Murdock (Plumas Jumbo) mine, with a total output of about 90 tons (no ore grade listed). The Lodi #4 mine, considered to be a portion of the Murdock mine, has no recorded production. The last reported copper mining in the district took place in 1913 and, although the mines have been relocated sporadically, no production has taken place since that date. At present all the shafts and tunnels are caved and the miner's cabins, a small community and concentrating mill at the head of the valley have disappeared, leaving nothing but foundations and weathered lumber.



*Figure 3. The ore-loading hopper of the Mohawk mine.*

## GEOLOGY

The geologic features of the northern Sierra Batholith, which encompasses the Diamond Mountains, has been studied by a number of authors including Durell (1966, 1987), Oliver *et al.* (1982) and Van Couvening (1962).

The Chilcoot quadrangle consists of Mesozoic metamorphic and plutonic rocks of the Sierran basement complex, Cenozoic volcanic and sedimentary rocks which predate the Sierra

Nevada uplift, and post-uplift deposits, mainly Quaternary sediments. Major unconformities separate these rock groups from one another and all the formation contacts within the latter two groups are also unconformities.

The Sierra Nevada Batholith is widely exposed in the quadrangle and underlies all the other rocks. Cenozoic volcanic and sedimentary formations, which were metamorphosed and intruded by the batholith, are preserved in roof pendants composed mainly of steeply dipping layers of meta-andesite and meta-tuff. Coarse-grained plutonic rocks of the batholith form the rugged central mass of the Diamond Mountains as well as the nearby Antelope Range and Fort Sage Mountain. Outcrops of these plutonic rocks exhibit widely spaced joint systems that tend, in conjunction with the weathering processes, to produce irregular terrain in which knobs, domes and asymmetrical humps of smoothly rounded granite protrude from a pale-colored arkosic soil. Throughout the quadrangle pegmatites are exposed and consist mainly of white, gray or pink perthitic orthoclase and colorless or white quartz along with very minor amounts of plagioclase and lepidolite.

Along Spring Creek, which is wholly within the Mesozoic granite, the basement rocks are sporadically exposed along the heavily wooded slopes. Quartz fissure veins are evident throughout the area and have intruded the granitic rocks along a fracture system that trends north-south. Where exposed, they are highly fractured and tend to dip steeply to the west. The veins typically have a lateral extent of about 200 meters and a width of 5 meters.

Copper mineralization is confined to these quartz veins and to a thin margin of the adjoining decomposed granitic rocks. The quartz veins, which were worked for copper along the lower part of Spring Creek (El Dorado and Mohawk mines), contain ore composed of pyrite and chalcopyrite, typical of many of the California copper belt mines. The two upper mines (Lodi #4 and Murdock) contain bornite and chalcopyrite with minor molybdenite, tetrahedrite and chalcocite. These latter mines host abundant secondary mineralization that includes a suite of rare bismuth and copper minerals.

## **DISTRICT MINES**

The mines in the district have been abandoned for many years and, except for some exploratory trenches cut by recent prospectors, little interest has been shown in the area except for a brief uranium "boom" in the 1950's, when many claims were explored and relocated. All the workings are heavily covered with forest litter and many of the dumps can only be found by digging in the loose duff. The underground workings are caved and inaccessible.

### **El Dorado (Dufay) Mine**

The El Dorado mine, discovered in 1909, is located in the SW 1/4 of section 25, T24N, R16E, MDM (39° 24' 12" N; 120°, 8' 18" W) along the south side of Spring Creek. A narrow dirt road leads to the workings from the Forest Service road along Spring Creek. This small mine consists of a single caved adit with several drifts that explore a quartz seam in weathered granite. All the workings are inaccessible, but the adit is reported to be 67 meters long with several drifts (MacBoyle, 1920; Eric, 1948). The ore mined during the early days consisted of chalcopyrite and minor amounts of malachite and chrysocolla.

### **Mohawk (Last Chance) Mine**

The Mohawk mine, discovered in 1905, is the largest of the district mines. It is located along Spring Creek in the SW 1/4 of section 25, T24N, R16E, MDM (39° 24' 0" N, 120° 8' 18" W). The workings consist of a caved vertical shaft of 60 meters depth with levels at 17, 40 and 60 meters and has about 200 meters of drifts and crosscuts (MacBoyle, 1920; Eric, 1948). Just to the west of the main shaft is a short caved adit showing secondary copper stains along the quartz-granite contact surface. The main shaft explores several quartz veins that contain chalcopyrite-pyrite ore along with minor amounts of molybdenite.

The only structures remaining from its days as an active mine are a log cabin and a two-bin

hopper for loading ore. All the timber structures around the shaft, the headframe and collar, are gone.

#### **Murdock (Plumas Jumbo) Mine**

The Murdock mine, discovered in 1909, is located in the SE 1/4 of section 25, T24N, R16E and the NW 1/4 of section 30, T24N, R17E, MDM (39° 24' 12" N, 120° 7' 54" W). The property was a portion of the original Plumas Jumbo mine but has been relocated. It was developed by several shafts and adits, all of which are caved and inaccessible. The underground workings are reported to consist of a 35-meter shaft with 50 meters of drifts at the bottom, two adits, 42 and 100 meters in length, and a 14-meter shaft (MacBoyle, 1920; Eric, 1948). All of these workings follow a series of highly fractured quartz veins. The principal ore mineral found here was chalcopyrite with minor tetrahedrite.



*Figure 4. One of many trenches at the Lodi #4 mine containing secondary copper and bismuth minerals.*



*Figure 5. Old ore piles at the Murdock mine containing secondary copper arsenate and phosphate minerals.*

#### **Lodi #4 (Murdock) Mine**

The Lodi #4 mine is located in the NW 1/4 of section 30, T24N, R16E, MDM (39° 24' 12" N, 120° 7' 54" W) about 500 meters north of the Murdock mine. It consists of a number of shallow pits and trenches grouped around a shallow shaft. The shaft is completely caved and its presence is marked by a shallow depression with dumps radiating out around it. This mine was

part of the original Murdock mine but was relocated as a separate claim prior to 1971. The workings explored several fractured quartz veins carrying bornite, chalcopyrite and molybdenite.

## **MINERALOGY**

### ***Ore Microscopy***

Sulfide ore samples from the several mines were prepared using standard ore preparation techniques and carefully examined by both optical and electron microscopy. The results show that the El Dorado and Mohawk mines have a simple sulfide ore mineralogy consisting of a pyrite-chalcopyrite mixture that contains minor molybdenite. The Murdock and Lodi #4 mines, however, have a more complex ore mineralogy consisting of a chalcopyrite-tetrahedrite mixture and a chalcopyrite-bornite-molybdenite mixture respectively, with secondary reworking of the original sulfides.

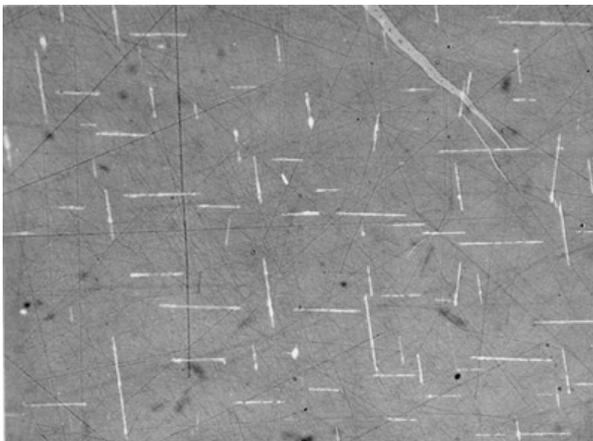
### **Pyrite-Chalcopyrite ore**

Polished sections of the pyrite-chalcopyrite ore show a simple textural relationship, with massive chalcopyrite occurring as irregular masses in pyrite. Molybdenite occurs in small amounts in the quartz as individual or multiple groupings of euhedral crystals and foliated masses. Both chalcocite and covellite occur as replacements of chalcopyrite along fractures and as a general rind surrounding the ore masses.

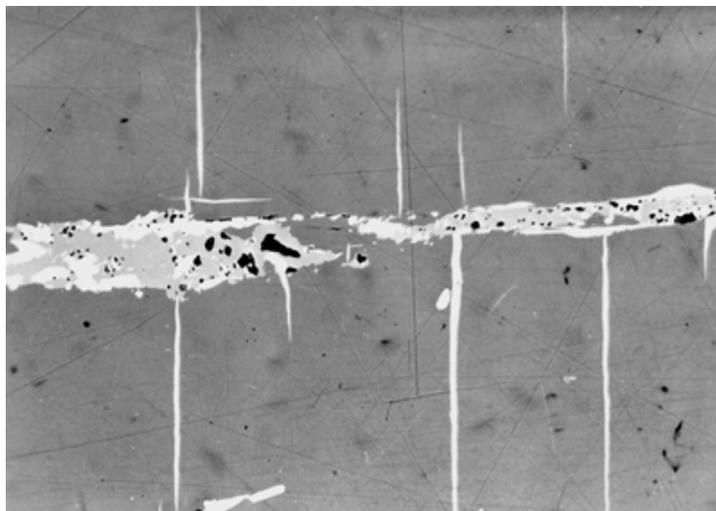
Microscopically, the polished ore sections revealed several interesting features. In the Mohawk mine ore, exsolved lamellae of cubanite, an important geological thermometer, were observed along the crystallographic planes of chalcopyrite. Also within the chalcopyrite are star-shaped particles of sphalerite, which also appear to be an exsolution product. Sphalerite stars are considered to be restricted to high-temperature formation. Other minor exsolution products within the chalcopyrite include mackinawite, pyrrhotite, hessite and native bismuth.

### **Chalcopyrite-Tetrahedrite ore**

The sulfide ores of the Murdock and Lodi #4 mines are more complex than those of the El Dorado and Mohawk mines. At the Murdock mine, chalcopyrite is the major copper mineral present, with lesser amounts of tetrahedrite and molybdenite. Bismuth minerals such as aikinite (?) and emplectite occur in rare grains in the quartz. Small amounts of bornite also occur, usually as intergrowths with chalcopyrite.



*Figure 6. Polished section of bornite from the Lodi #4 mine showing exsolved pale gray wittichenite and lighter chalcopyrite lenticles, 1 x 50 microns, along the bornite {100}. G. Dunning photomicrograph.*



*Figure 7. Polished section of bornite from the Lodi #4 mine showing exsolved pale gray wittichenite and lighter chalcopyrite veinlets with later chalcopyrite blades perpendicular to the wittichenite. Field of view 0.2 x 0.3 mm. G. Dunning photomicrograph.*

### **Bornite-Chalcopyrite-Molybdenite ore**

The primary copper mineral at the Lodi #4 mine is bornite, associated with chalcopyrite, chalcocite, covellite and molybdenite in varying proportions.

In polished section, the bornite and chalcopyrite show abundant fractures containing veinlets of chalcocite, digenite and covellite. Inclusions of molybdenite, galena, native bismuth and wittichenite were observed throughout the bornite but occur rarely in the chalcopyrite.

Wittichenite occurs as very small exsolved blebs and lamellae, commonly arranged in rows and often coalesced into lenticular shapes parallel to the bornite {111} and {100} crystallographic planes. This exsolved structure is illustrated by Oen and Kieft (1976). Wittichenite also occurs along the bornite grain boundaries with chalcopyrite as elongated accumulations.

Chalcopyrite is also seen as individual masses within the quartz veins associated with molybdenite and as a replacement of bornite.

Molybdenite observed in the copper sulfide polished sections occurs as masses of highly distorted plates within both bornite and chalcopyrite, and is often associated with quartz. From the textural relationships observed, the molybdenite formed earlier or concurrently with the bornite. Thin flakes of molybdenite are commonly surrounded by bornite. Quartz veins cutting the bornite are typically filled with molybdenite plates that form “plugs” along the fractures. This later molybdenite may represent a remobilization of earlier-formed molybdenite during a later hydrothermal phase.

Idaite, a commonly overlooked disintegration product of bornite, occurs with chalcopyrite lamellae in weathered bornite. Bornite containing idaite is not common, and appears to have been confined to one specific zone of mineralization associated with secondary bismuth minerals.

### **Primary Minerals**

#### **Acanthite** $\text{Ag}_2\text{S}$

Minute grains of acanthite, less than 0.1 mm in size, occur as inclusions in quartz at the Lodi #4 mine. Silver values noted in assay returns of the early-day copper ores may be due to this mineral scattered throughout the host quartz.

**Aikinite (?)**  $\text{PbCuBiS}_3$

A single sample of quartz from the Murdock mine was found to contain several metallic grains which gave a ratio of elements similar to that of aikinite by energy-dispersive spectrometry (EDS) when compared to a standard aikinite sample. There was insufficient material for further work.

**Berthierite**  $\text{FeSb}_2\text{S}_4$

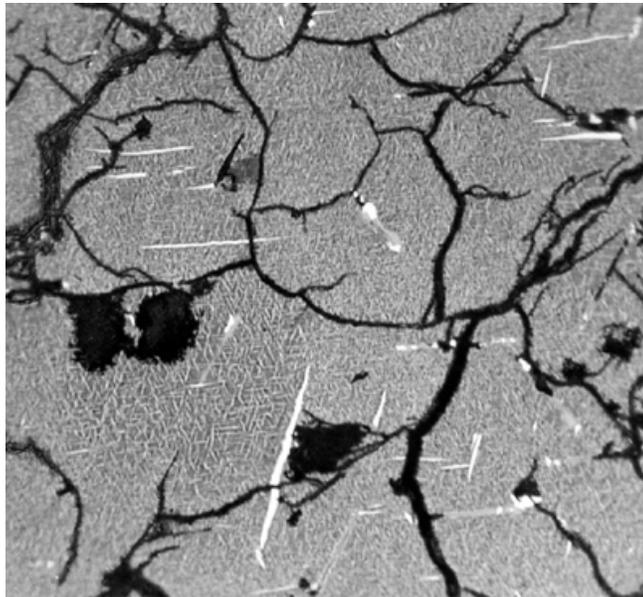
Several small grains of berthierite associated with tetrahedrite in quartz have been identified by X-ray diffraction (XRD) analysis in samples from the Murdock mine. Both minerals show the effects of weathering.

**Bismuth** Bi

Minute rounded grains of native bismuth, identified by EDS, occur as exsolved blebs in the massive bornite of the Lodi #4 mine, and are commonly associated with irregular grains of hessite, galena and wittichenite. Native bismuth has also been noted as exsolved masses in the chalcopyrite of the Murdock mine, associated with hessite.

**Bismuthinite**  $\text{Bi}_2\text{S}_3$

Thin, vertically striated crystals of bismuthinite were identified by EDS from a single sample of quartz from the Murdock mine. The bismuthinite is closely associated with chalcopyrite and emplectite.



*Figure 8. Polished section of "bornite" from the Lodi #4 mine showing fine background lamellar texture of idaite and chalcopyrite partially parallel to (111) of the bornite. The structure shows what is termed "crack-disease" resulting from the decomposition of bornite. Field of view 0.2 x 0.3 mm. G. Dunning photomicrograph.*

**Bornite**  $\text{Cu}_5\text{FeS}_4$

Bornite is the principal ore mineral at the Lodi #4 mine. It occurs as irregular pods and veins in quartz associated with chalcopyrite and molybdenite, and is the host sulfide for several other minerals including galena, hessite, stromeyerite, native bismuth and wittichenite. Bornite has also been observed associated with chalcopyrite in polished sections from the Murdock mine.

**Copper** Cu

Narrow seams of native copper, associated with chalcopyrite, were identified by EDS in polished sections of quartz from the Murdock mine.

**Chalcocite** Cu<sub>2</sub>S

Chalcocite formed as a secondary enrichment product of bornite along a network of fractures within the bornite and is usually associated with digenite and covellite. Exsolved hypogene lamellar chalcocite has been observed replacing bornite along the {100} crystallographic planes in a late-stage bornite mineralization phase that replaces both chalcopyrite and earlier deposited bornite. The mineral is most abundant at the Lodi #4 mine but has been observed in small amounts throughout the Spring Creek area copper mines.

**Chalcopyrite** CuFeS<sub>2</sub>

Chalcopyrite, which occurs throughout the Spring Creek district, is the principal copper mineral of the ores of the El Dorado, Mohawk and Murdock mines. Intergrowths and exsolutions of chalcopyrite within bornite are common and some very striking examples of chalcopyrite “flames” in bornite have been observed. Like bornite, the chalcopyrite is often extensively fractured and altered to secondary copper sulfides.

**Cinnabar** HgS

Cinnabar has been identified as very rare reddish brown coatings on quartz in the ore of the Lodi #4 mine. It occurs with the unusual hydrothermal bismuth mineralization and appears to be of primary origin. Minute quantities of cinnabar have also been identified in the ore of the Murdock mine, where it occurs as earthy brick-red inclusions in stibiconite. Here, it has formed by the decomposition of mercurian tetrahedrite.

**Covellite** CuS

Covellite commonly replaces chalcopyrite and bornite in the district and is especially abundant in the chalcopyrite ores.

**Cubanite** CuFe<sub>2</sub>S<sub>3</sub>

Thin lamellae of cubanite were identified in polished sections of chalcopyrite from the Mohawk mine. They are orientated parallel to the {111} crystal planes.

**Digenite** Cu<sub>9</sub>S<sub>5</sub>

Polished sections of bornite and chalcopyrite from the Lodi #4 mine show small amounts of digenite as an intermediate enrichment phase between chalcocite and covellite.

**Emplectite** CuBiS<sub>2</sub>

A copper bismuth sulfide associated with chalcopyrite and bismuthinite was noted in a single sample from the Lodi #4 mine and subsequently identified by XRD as emplectite.

**Galena** PbS

Minute grains of galena were observed in the polished sections of bornite from the Lodi #4 mine. The galena is associated with hessite and wittichenite.

**Gold** Au

Small pieces of sheet gold in quartz have come from the Lodi #4 mine.

**Hessite** Ag<sub>2</sub>Te

Rare inclusions of hessite were observed in polished sections of bornite from the Lodi #4 mine and in chalcopyrite from the Mohawk mine.

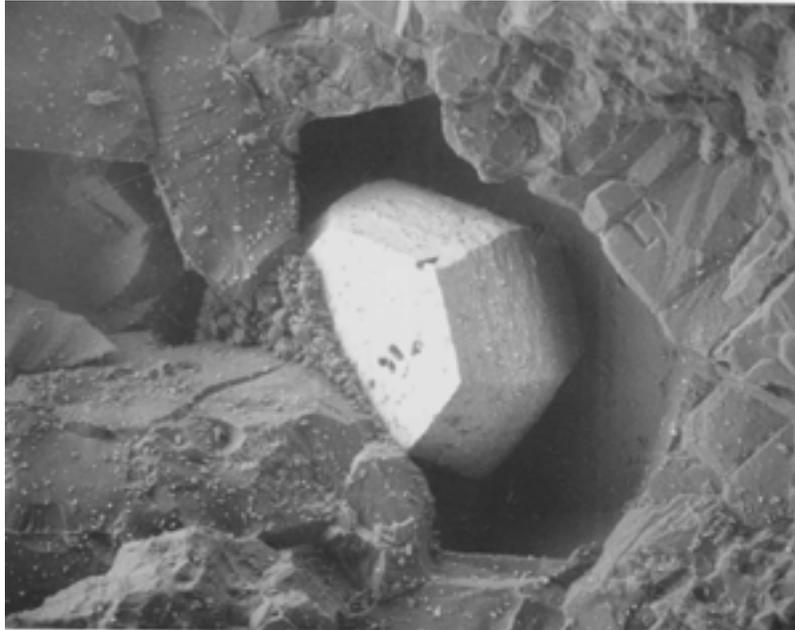
**Idaite** Cu<sub>3</sub>FeS<sub>4</sub>

Several samples of bornite with an unusual orange tint were found in one of the dumps of the

Lodi #4 mine. Polished sections revealed an unusual texture composed of fine spindles of chalcopyrite orientated along the crystallographic planes of bornite. It was associated with a highly anisotropic mineral which was later identified as idaite, a disintegration product of bornite. Ramdohr (1969) illustrates the fine spindle texture of idaite in association with bornite.

**Mackinawite**  $(\text{Fe,Ni})_9\text{S}_8$

Mackinawite has been observed in polished sections of the Mohawk mine copper ores.



*Figure 9. Molybdenite crystal 0.3 mm in quartz cavity from the Lodi #4 mine. G. Dunning SEM photo and specimen.*

**Molybdenite**  $\text{MoS}_2$

Molybdenite occurs as small, well-formed crystals and foliated masses throughout the district. It is especially abundant at the Lodi #4 mine where it is commonly associated with bornite and chalcopyrite and comprises a significant portion of the ore.

**Pyrite**  $\text{FeS}_2$

Pyrite is common in the ores of the Mohawk and El Dorado mines.

**Pyrrhotite**  $\text{Fe}_{1-x}\text{S}$

Small exsolved grains of pyrrhotite were identified in chalcopyrite from the Mohawk mine, where it is associated with cubanite, sphalerite and mackinawite.

**Sphalerite**  $\text{ZnS}$

Sphalerite “stars” were observed within chalcopyrite grains in ore samples from the Mohawk mine. This habit is consistent with cubanite-chalcopyrite mixtures discussed by Ramdohr (1969).

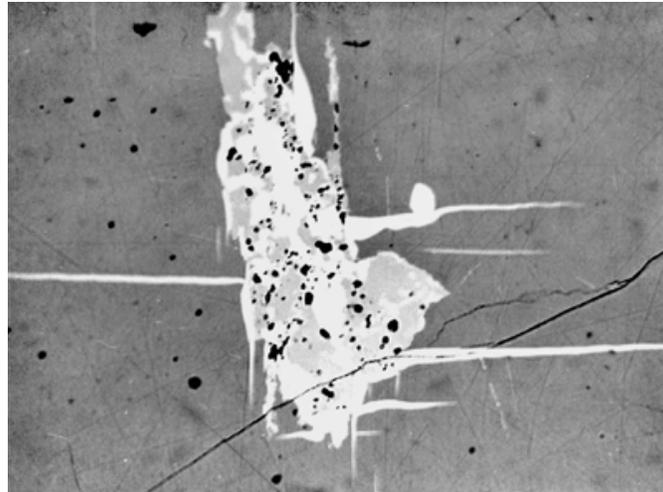
**Stromeyerite**  $\text{AgCuS}$

Rare grains of stromeyerite occur in the bornite at the Lodi #4 mine and in the chalcopyrite at the Murdock mine.

**Tetrahedrite**  $(\text{Cu,Fe})_{12}\text{Sb}_4\text{S}_{13}$

Massive tetrahedrite is commonly associated with chalcopyrite and molybdenite at the

Murdock mine. Only rarely has it been found at the Lodi #4 mine, associated with bornite. It usually occurs as massive material although a few poorly developed crystals have been found in quartz cavities. EDS analysis shows small amounts of arsenic and mercury, accounting for the several arsenates and cinnabar observed at the Murdock mine.



**Figure 10.** Wittichenite bleb with chalcopyrite intergrowths and chalcopyrite blades extending along the bornite {111}. Field of view 0.2 x 0.3 mm. Lodi #4 mine. G. Dunning photomicrograph.

**Wittichenite**  $\text{Cu}_3\text{BiS}_3$

Polished sections of bornite from the Lodi #4 mine contain numerous exsolved blebs of wittichenite, identified by EDS and optical properties. It occurs along the {111} and {100} crystallographic planes and is commonly associated with exsolved chalcopyrite, which formed during an earlier period.

**Secondary Minerals**

**Anglesite**  $\text{PbSO}_4$

Rare microcrystals of anglesite have been noted in oxidized ore from the Murdock mine. They coat rough oxidized crystals of aikinite (?) associated with bismite and bismutite. The crystals are less than 50 microns in size and take the form of simple dipyrramids with the  $c$  {001},  $d$  {101} and  $y$  {111} forms most abundant.

**Barite**  $\text{BaSO}_4$

A single grain of barite was noted in association with witherite in massive quartz at the Lodi #4 mine.

**Bismite**  $\text{Bi}_2\text{O}_3$

Bismite was identified in samples of quartz from the Lodi #4 mine dumps where it has formed yellow coatings in fractures in an unusual quartz zone containing other bismuth minerals. Crystals and massive coatings of bismite have been noted at the Murdock mine and makes up much of the pseudomorphic material after bismuthinite, aikinite (?) and emplectite. The crystals may reach 0.25 mm and occur on pseudomalachite.

**Bismutite**  $\text{Bi}_2(\text{CO}_3)\text{O}_2$

Bismutite occurs as very rare, pale to straw-yellow crusts showing a radial fibrous habit coating

cavities in quartz at the Lodi #4 mine. It was identified by XRD.

**Bismutoferrite**  $\text{BiFe}_2(\text{SiO}_4)_2(\text{OH})$

Bismutoferrite, identified by XRD and EDS, has been found as a constituent of the secondary bismuth mineralization. It occurs as yellow masses of microscopic flakes less than 20 microns in size at the Lodi #4 mine. This secondary bismuth mineralization occurs in a very limited area of brecciated quartz; only a small amount of the material was found. The bismutoferrite is associated with quartz containing minute hematite crystals.

**Bismutostibiconite**  $\text{Bi}(\text{Sb}^{5+}, \text{Fe}^{3+})_2\text{O}_7$

Rare bismutostibiconite has been identified by XRD and EDS at the Lodi #4 mine, associated with bismutoferrite and clinobisvanite. Only massive pale yellowish brown material has been found.

**Brochantite**  $\text{Cu}_4(\text{SO}_4)(\text{OH})_6$

Brochantite is relatively abundant at the Lodi #4 and to a lesser degree at the Murdock mine. It forms dark green veins that occasionally show minute crystals and is one of the initial alteration products of bornite, chalcopyrite and chalcocite. When associated with the white quartz, the brochantite can form very attractive specimens.

**Chalcanthite**  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$

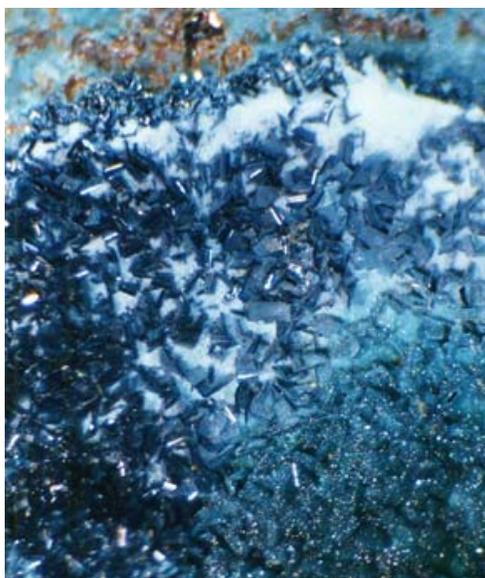
Crusts of chalcanthite occur on the dumps of the Mohawk and El Dorado mines, but only in the late spring and summer months, in protected areas on the dumps.

**Chrysocolla**  $(\text{Cu}, \text{Al})_2\text{H}_2\text{Si}_2\text{O}_5(\text{OH})_4$

Chrysocolla, the most abundant secondary copper mineral found in the district, occurs as fracture fillings up to several millimeters thick. Its color ranges from deep green to sky-blue. Pseudomorphs of chrysocolla after malachite and lindgrenite have been found in the secondary zone of the Lodi #4 mine.

**Clinobisvanite**  $\text{BiVO}_4$

Clinobisvanite was identified by XRD as bright yellow-orange massive material coating limonite and quartz at both the Lodi #4 and the Murdock mines.



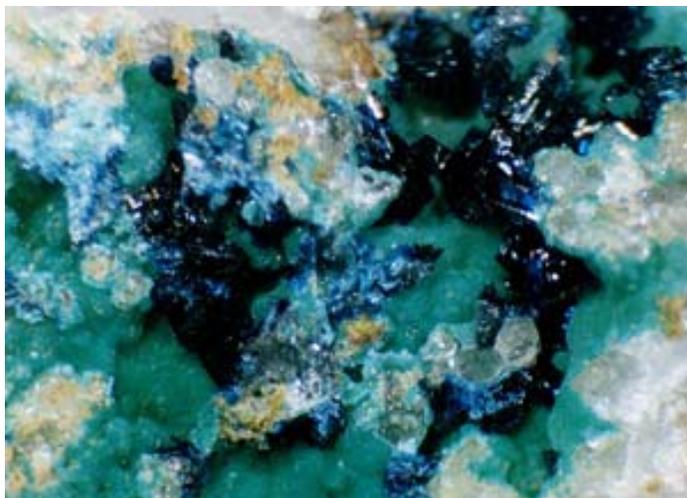
*Figure 11. Deep blue clinoclase crystals with deep green botryoidal cornwallite from Murdock mine. 0.5 x 0.8 mm coverage. G. Dunning specimen; T. Hadley photo.*

**Clinoclase**  $\text{Cu}_3(\text{AsO}_4)(\text{OH})_3$

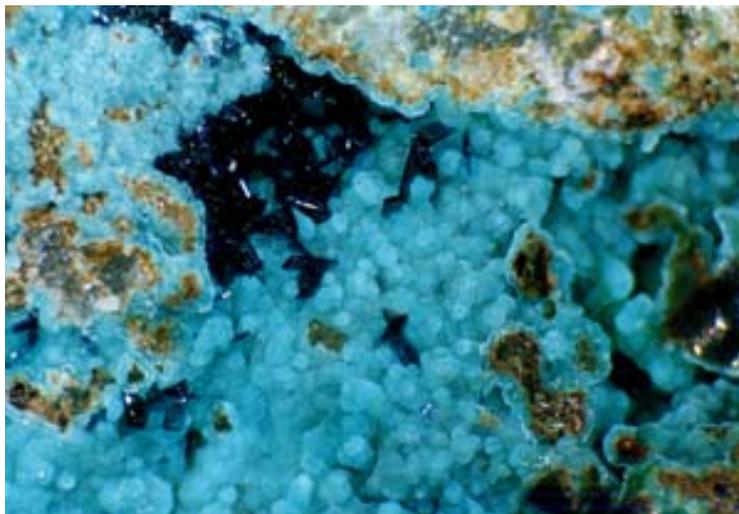
Clinoclase is locally abundant on the dumps of the Murdock mine, closely associated with stibiconite, cornwallite and chrysocolla. It occurs as well-formed, deep blue crystals in pockets in the stibiconite and as deep blue coatings on quartz. This mineral forms very attractive crystal groups with the bright green cornwallite.

**Cornubite**  $\text{Cu}_5(\text{AsO}_4)_2(\text{OH})_4$

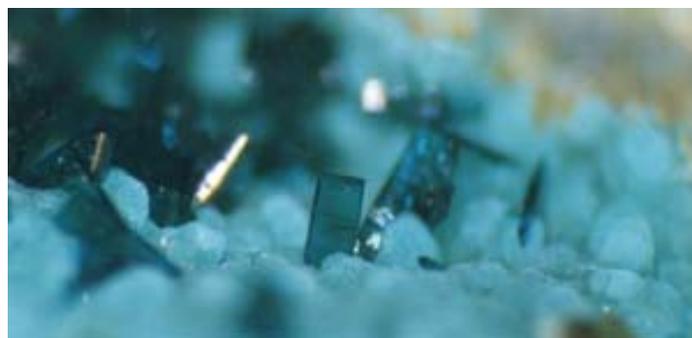
Cornubite is quite rare in the oxidized mineral suite of the Murdock mine; only a few samples have been found. It occurs as bright green coatings associated with cornwallite.



*Figure 12.* Deep blue clinoclase crystals on cornwallite from the Murdock mine. 0.5 x 0.5 mm coverage. G. Dunning specimen; T. Hadley photo.



*Figure 13.* Deep blue clinoclase crystals on cornwallite from the Murdock mine. 0.1 x 0.1 mm coverage. G. Dunning specimen; T. Hadley photo.



**Figure 14.** Single deep-blue clinoclase crystal, 0.005 mm, on cornwallite from the Murdock mine. G. Dunning specimen; T. Hadley photo.

**Cornwallite**  $\text{Cu}_5(\text{AsO}_4)_2(\text{OH})_4 \cdot \text{H}_2\text{O}$

Cornwallite is abundant on the dumps of the Murdock mine, where it occurs as bright to dark green crystalline crusts and nearly black euhedral crystals. Pseudomalachite typically occurs in association with cornwallite. The mineral was identified by EDS and XRD.

**Cuprite**  $\text{Cu}_2\text{O}$

Minute, deep-red grains of cuprite occur in quartz from the oxidized zone of the Lodi #4 mine. Associated minerals include malachite, pseudomalachite and chrysocolla. Cuprite has also been noted from the oxidized ore of the Murdock mine, associated with chalcopyrite.

**Cuprosklodowskite**  $(\text{H}_3\text{O})_2\text{Cu}(\text{UO}_2)_2(\text{SiO}_4)_2 \cdot 2\text{H}_2\text{O}$

Cuprosklodowskite is one of the uranium-bearing minerals noted by Troxel *et al.* (1959) as being associated with metazeunerite and metatorbernite at the Mohawk mine. It was noted in shear zones and in the quartz veins within decomposed granitic rock.

**Cuprotungstite**  $\text{Cu}_2(\text{WO}_4)(\text{OH})_2$

Pale green microcrystals of cuprotungstite associated with chrysocolla have been identified coating cavities in quartz at both the Murdock and El Dorado mines where it has resulted from the alteration of scheelite.

**Dravite**  $\text{NaMg}_3\text{Al}_6(\text{BO}_3)_3\text{Si}_6\text{O}_{18}(\text{OH})_4$

Very thin, acicular crystals of dravite occur in quartz cavities throughout the district. These hair-like crystals are commonly covered by other secondary minerals.



**Figure 15.** Fine acicular yellow needles of ferrimolybdate on quartz, Lodi #4 mine. Field of view 0.2 mm x 0.3 mm. G. Dunning SEM photo and specimen.

**Ferrimolybdate**  $\text{Fe}_2(\text{MoO}_4)_3 \cdot 8\text{H}_2\text{O}$

Ferrimolybdate occurs in all the mines as yellow masses of fibrous crystals. It is especially abundant at the Lodi #4 and Murdock mines.



*Figure 16.* Spherical groups of goethite on quartz from the Lodi #4 mine. Individual spheres 0.1 mm in diameter. G. Dunning specimen; W. Wise photo.

**Goethite**  $\text{FeO}(\text{OH})$

Minute crystals of goethite in small spheroids occur in pockets in quartz at the Lodi #4 mine.

**Gypsum**  $\text{CuSO}_4 \cdot 2\text{H}_2\text{O}$

Gypsum occurs as rare grains and micaceous masses associated with lindgrenite and brochantite at the Lodi #4 mine. It is not abundant; only a single sample was noted.

**Hematite**  $\text{Fe}_2\text{O}_3$

Hematite with deep red internal reflections has been identified as a direct replacement of chalcopyrite masses in quartz at the El Dorado, Mohawk and Murdock mines. The hematite often has a rim of goethite due to later hydration. Cores of unaltered chalcopyrite surrounded by hematite are common in the partially oxidized ores.



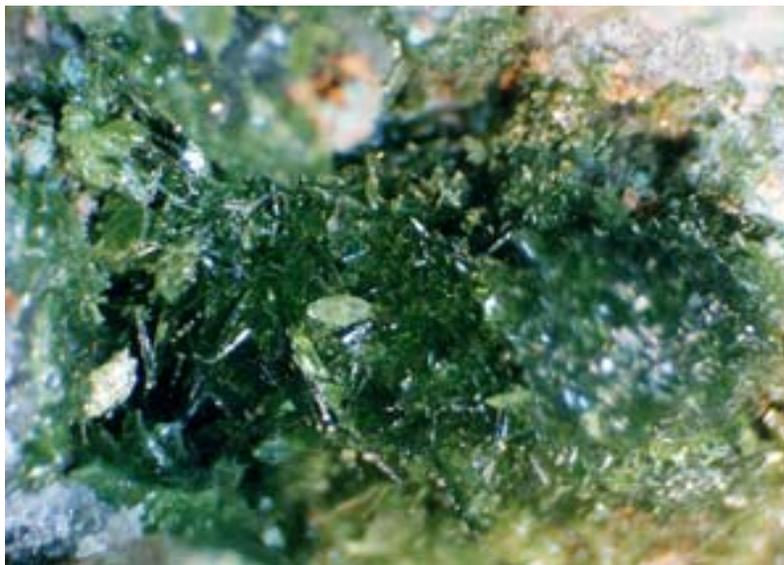
*Figure 17.* Thin scales and plates of koechlinite, some showing face development, in a chalcocite cavity from the Lodi #4 mine. Field of view 0.3 x 0.6 mm. G. Dunning SEM photo and specimen.

**Koehlinite**  $\text{Bi}_2\text{MoO}_6$

Cavities in the partially oxidized bornite-molybdenite ore from the Lodi #4 mine commonly contain thin crystals of a pearly yellow mineral with a platy habit which was identified by XRD as koehlinite. The subhedral to euhedral crystals are flattened parallel to  $\{010\}$  and rarely show the  $c$   $\{001\}$  and  $p$   $\{131\}$  forms. Koehlinite has also been noted in the oxidized ore of the Murdock mine, where it occurs as a fine-grained coating on chrysocolla.



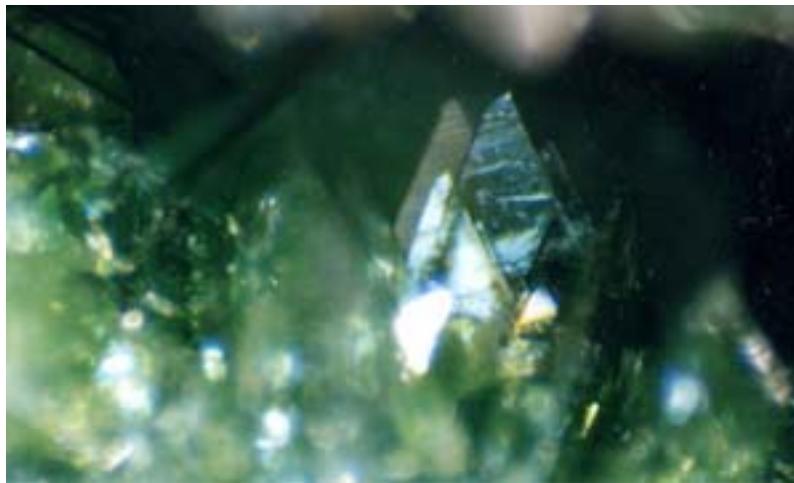
*Figure 18.* Terminated lindgrenite crystals to 1 mm on malachite from the Lodi #4 mine. G. Dunning specimen; T. Hadley photo.



*Figure 19.* Cavity of platy lindgrenite crystals, 2 x 3 mm, in quartz cavity from the Lodi #4 mine. G. Dunning specimen; T. Hadley photo.



*Figure 20. Cavity of platy lindgrenite crystals, 1 x 1 mm, in quartz cavity from the Lodi #4 mine. G. Dunning specimen; T. Hadley photo.*



*Figure 21. Terminated lindgrenite crystals, 0.005 mm, from the Lodi #4 mine. G. Dunning specimen; T. Hadley photo.*

**Lindgrenite**  $\text{Cu}_3(\text{MoO}_4)_2(\text{OH})_3$

Lindgrenite, one of the first minerals identified in the suite collected in 1971, occurs as thin yellow-green euhedral crystals in cavities and as olive-green crystalline crusts on quartz. Lindgrenite is locally abundant in the ores of the Lodi #4 mine. Pseudomorphs of chrysocolla after lindgrenite are occasionally encountered. Lindgrenite also occurs in the ores of the Murdock mine.

**Malachite**  $\text{Cu}_2(\text{CO}_3)(\text{OH})_2$

Malachite and chrysocolla are ubiquitous throughout the area. Radiating masses of malachite up to several centimeters across are common in the ore of the Lodi #4 mine, and small crystals with lindgrenite crystals perched on them are not uncommon. At the Mohawk and El Dorado mines malachite constituted an important part of the ore shipped.

**Metatorbernite**  $\text{Cu}(\text{UO}_2)_2(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$

Small, pale green tetragonal crystals of metatorbernite, less than 1 mm in size, occur in cavities in the quartz. Both eastern Plumas County and adjoining Lassen County contain many small uranium deposits (Troxell *et al.*, 1959; Van Couvering, 1962; Walker *et al.*, 1956; Pemberton, 1983).

**Melanterite**  $\text{Fe}^{+2}\text{SO}_4 \cdot 7\text{H}_2\text{O}$

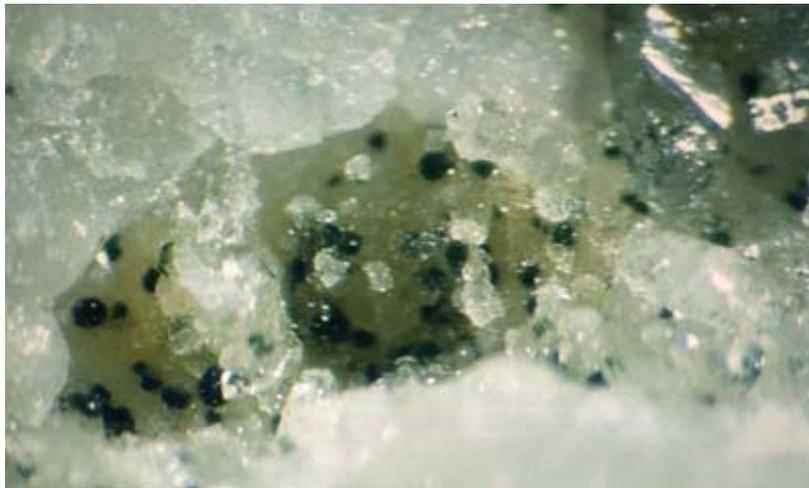
Melanterite from the Mohawk and El Dorado mines has formed directly on weathered pyrite masses.

**Metazeunereite**  $\text{Cu}(\text{UO}_2)_2(\text{AsO}_4)_2 \cdot 8\text{H}_2\text{O}$

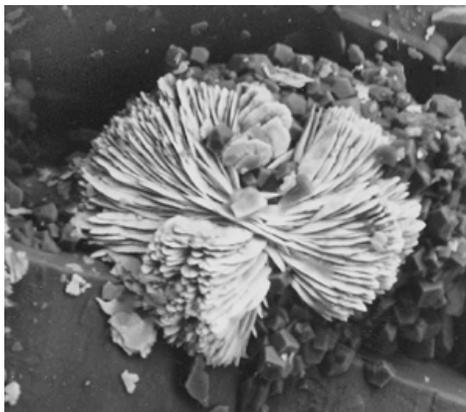
Minor amounts of metazeunereite have been reported from the Mohawk mine by Troxell *et al.* (1959). It was found in quartz veins in decomposed granite.

**Mottramite**  $\text{PbCu}(\text{VO}_4)(\text{OH})$

Mottramite was identified from material at the Murdock mine by EDS and XRD. It is nowhere abundant, occurring as yellow-brown to greenish brown coatings on quartz and chrysocolla.



*Figure 22.* Individual spheres of namibite on quartz, 0.05 mm in diameter, from the Lodi #4 mine. G. Dunning specimen; W. Wise photo



*Figure 23.* Spherical group of dark green namibite crystals on quartz, 0.05 mm in diameter, from the Lodi #4 mine. G. Dunning specimen and SEM photo.



**Figure 24.** Exceptional coverage of 0.05 mm namibite crystal groups from the Lodi #4 mine. G. Dunning specimen; T. Hadley photo.

**Namibite**  $\text{Cu}(\text{BiO})_2(\text{VO}_4)(\text{OH})$

Namibite, a rare Cu-Bi-hydroxo-vanadate, was identified by EDS and XRD from the Lodi #4 mine in the section containing other bismuth minerals. The mineral occurs as minute dark green spheroids less than 1 mm in diameter. These spheroids consist of bundles of spear-shaped crystals flattened on one face. Most of the spheroids are covered by a second-stage of quartz formation. However, namibite can be observed within the quartz. A single sample of quartz was found which contained at least 100 individual spheroids of namibite.

**Partzite**  $\text{Cu}_2\text{Sb}_2(\text{O},\text{OH})_7$

Partzite occurs as thin, dark green veins in massive tetrahedrite at the Murdock mine.

**Pharmacosiderite**  $\text{KFe}_4(\text{AsO}_4)_3(\text{OH})_4 \cdot 6-7 \text{H}_2\text{O}$

Rare cubic crystals of pharmacosiderite have been identified from the secondary mineral assemblage of the Murdock mine associated with powellite (R.Thomssen, p.c., 1997).

**Posnjakite**  $\text{Cu}_4(\text{SO}_4)(\text{OH})_6 \cdot \text{H}_2\text{O}$

The rare copper sulfate posnjakite was found associated with bornite from the Lodi #4 mine. It occurs as deep blue coatings on quartz and bornite, and is quite rare at this locality.



**Figure 25.** Minute octahedral crystals of powellite to 50 microns covering quartz from the Lodi #4 mine. G. Dunning SEM photo and specimen.

**Powellite**  $\text{CaMoO}_4$

Powellite is ubiquitous throughout the area, though it usually can only be seen with the aid of an ultraviolet lamp. Powellite coats fracture surfaces and forms minute dipyramidal crystals in cavities in quartz. The material is white to gray and has a cream-yellow fluorescence.



*Figure 26. Rounded subhedral crystals of pseudomalachite, to 70 microns, from the Murdock mine. G. Dunning SEM photo and specimen.*

**Pseudomalachite**  $\text{Cu}_5(\text{PO}_4)_2(\text{OH})_4 \cdot \text{H}_2\text{O}$

Dark green veins and rounded crystal groups of pseudomalachite occur at the Murdock and Lodi #4 mines as coatings on chrysocolla in quartz.

**Quartz**  $\text{SiO}_2$

Quartz is one of the vein-forming minerals and has been deposited in several stages. Some growth forms of quartz occur as small helictites and rings.

**Scheelite**  $\text{CaWO}_4$

Scheelite has been found as small grains on quartz in most of the district mines.

**Schorl**  $\text{NaFe}_3^{2+}\text{Al}_6(\text{BO}_3)_3\text{Si}_6\text{O}_{18}(\text{OH})_4$

Schorl is common in all the mines of the district.



*Figure 27. Greenish yellow spray of schumacherite crystals on quartz, 0.25 mm long, from the Lodi #4 mine. G. Dunning SEM photo; J. Cooper specimen.*

**Schumacherite**  $\text{Bi}_3[(\text{V,As,P})\text{O}_4]_2\text{O}(\text{OH})$

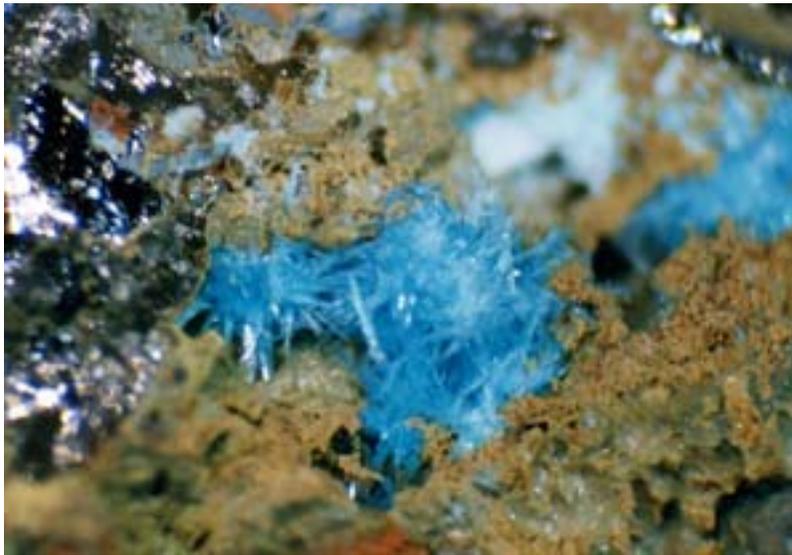
Samples of quartz containing minute, greenish yellow crystals with an unusual bow-tie habit were collected at the Lodi #4 mine in 1986. This material was subsequently identified as the rare bismuth vanadate, schumacherite by XRD. It is extremely rare at this locality.

**Stibiconite**  $\text{Sb}^{3+}\text{Sb}_2^{5+}\text{O}_6(\text{OH})$

Stibiconite commonly occurs as soft green to olive-colored masses that are pseudomorphous after tetrahedrite and are surrounded by quartz in the oxidized ores of the Murdock mine. This material was thought to be partzite at first, but a re-examination of the material confirmed its identity as stibiconite, colored green by minute inclusions of malachite. It has also been noted in the Lodi #4 mine as rare minute grains in quartz.

**Witherite**  $\text{BaCO}_3$

Witherite was found as a minute massive coating within a cavity at the Lodi #4 mine.



*Figure 28. Deep sky-blue mass of slender wroewolfeite crystals, 1 x 3 mm, on goethite from the Murdock mine. G. Dunning specimen; T. Hadley photo.*

**Wroewolfeite**  $\text{Cu}_4(\text{SO}_4)(\text{OH})_6 \cdot 2\text{H}_2\text{O}$

Wroewolfeite, a rare copper sulfate, has been found in the oxidized ore of the Murdock mine associated with goethite and derived from the weathering of tetrahedrite. It forms deep blue to sky-blue radiating groups of crystals. It is not common at this locality and only a few samples have been recovered.

**Wulfenite**  $\text{PbMoO}_4$

A single crystal of wulfenite was found in a cavity associated with powellite at the Lodi #4 mine.

**PARAGENESIS**

A paragenetic history for the Last Chance mining district copper deposits was developed from the sulfide relationships observed in polished sections and the secondary minerals resulting from their oxidation.

Maximum thermal stabilities of sulfides compiled by Craig and Scott (1974) were used to place the observed sulfides in their most probable order of formation.

For the more complex secondary mineral assemblages, such as those found at the Lodi #4 and Murdock mines, the mineral relationships observed in hand samples were used to arrange the

assemblage in the most probable order, although due to the isolated nature of some minerals, exact positioning was not possible.

During the oxidization of the sulfide ores, pH, Eh, temperature and dissolved oxygen influence the formation and stability of the secondary minerals. In this area, periods of deposition, solutioning and redeposition were common. The nature of the fractured quartz produced isolated areas where unusual minerals were formed with no apparent relation to other minerals in the same area and assemblage. For this reason a realistic paragenesis of the complex secondary mineral assemblage must be considered speculative.

### ***Primary Sulfide Ores***

The polymetallic sulfide ores studied in the district are all thought to originate from the Mesozoic granite batholith. Although there are numerous quartz pegmatite veins exposed along the western flank of the Diamond Mountains, the major copper mineralization is confined to the Spring Creek area. The ascending mineralizing solutions followed fractures in the quartz, and sulfides of copper, molybdenum, iron and antimony with subordinate bismuth, silver and lead were deposited in them. During ore deposition, cooling rates varied, which produced some segregation of the deposits.

### **El Dorado and Mohawk mines**

Polished sections of ore from both the El Dorado and Mohawk mines were examined and evidence of high-temperature formation was noted. Samples from the Mohawk mine show significant cubanite along with small inclusions or exsolutions of pyrrhotite, sphalerite and mackinawite within the chalcopyrite. Cubanite is an important geological thermometer and suggests a high temperature of formation. High-temperature CuFeS (chalcopyrite) can dissolve appreciable quantities of cubanite (Yund and Kullerud, 1966). As cooling progresses, the dissolved cubanite exsolves as lamellae parallel to the {111} face of the chalcopyrite. The temperature at which this takes place is between 200°C and 210°C, if the cooling rate is not too rapid (Craig and Scott, 1974; Dutrizac, 1976). The chalcopyrite immediately surrounding the cubanite lamellae is shattered by minute stress cracks that occurred during the exsolution of the cubanite. Some high-temperature chalcopyrite also contains mackinawite that may be identified by its strong anisotropic properties. Another exsolution product of the high-temperature chalcopyrite is sphalerite that occurs in radiating, starlike particles.

The ores of the El Dorado mine do not show these high-temperature exsolution features, and while similar in chemical content, are presumed to have cooled much faster, thus not allowing these features to form. Based on the textural relationships and the thermal stabilities listed by Craig and Scott (1974), it appears that molybdenite formed first, followed by pyrite below 743°C and chalcopyrite below 560°C. Sphalerite exsolved from the chalcopyrite-cubanite solid solution at 500°C, followed by pyrrhotite and then cubanite between 210°C and 200°C. Mackinawite formed last below 200°C.

### **Murdock mine**

At the Murdock mine the copper ores are more complex and differ in mineralogy with an initial molybdenite deposition followed by chalcopyrite-tetrahedrite mineralization, possibly at 500°C or less. Some berthierite occurs associated with the tetrahedrite and appears to have formed at about the same time. Bornite is not common and has been observed only as isolated blebs in chalcopyrite. Other than the bornite, the chalcopyrite contains no exsolution features.

Minor amounts of quartz containing small amounts of bismuthinite, chalcopyrite, emplectite and aikinite (?) associated with bismuth ocher were found and probably represents a range of temperature from a high of 700°C for bismuthinite to a low of 350°C for emplectite (Sugaki and Shima, 1971, 1972).

### **Lodi #4 mine**

Although the Lodi #4 mine lies within 1000 meters of the Murdock mine, the two deposits differ greatly in sulfide mineral content. Molybdenite probably formed first at a temperature below 1000°C. The copper mineralization consists of a bornite solid solution containing

chalcopyrite, wittichenite and other minerals. Exsolution products include galena, chalcopyrite and wittichenite. Wittichenite was one of the first minerals to exsolve after molybdenite formed, and as the bornite cooled past 550°C, chalcopyrite and wittichenite formed along the crystallographic planes and grain boundaries.

Following this period of exsolved sulfide formation, some remobilization of the wittichenite within the bornite occurred, resulting in larger wittichenite accumulations. During this period of bornite cooling, a second period of fracturing occurred, introducing additional bornite veinlets cutting the earlier bornite and chalcopyrite. Rare hypogene chalcocite formed during this period but wittichenite was not observed.

Some bornite has been cut by quartz veins containing highly distorted molybdenite flakes. It is presumed that these veins were derived by dissolution and remobilization of earlier-formed quartz containing molybdenite.

### ***Secondary Mineralization***

Pyrite-chalcopyrite ores of the Mohawk and El Dorado mines have produced the least varied secondary suite. Malachite, brochantite, chalcantite, melanterite and goethite, which occur as massive material and as crusts on the surrounding rock, are the result of normal weathering.

Chalcopyrite-tetrahedrite ore of the Murdock mine has produced a complex suite of oxides, carbonates, sulfates, arsenates, phosphates, vanadates, molybdates and silicates. Phosphates and arsenates are abundant in the massive quartz as seams associated with stibiconite.

From an extensive examination of the ore, the probable order of secondary mineral formation observed at the Murdock mine is (1) *oxides*: hematite, goethite, stibiconite; (2) *carbonates*: malachite and bismutite; (3) *sulfates*: brochantite and wroewolfeite; (4) *arsenates*: clinoclase, cornwallite, cornubite and pharmacosiderite; (5) *silicates*: chrysocolla; (6) *vanadates*: clinobisvanite and mottramite; (7) *molybdates*: ferrimolybdate, lindgrenite and powellite and (8) *phosphates*: pseudomalachite and metatorbernite.

The bornite-chalcopyrite-molybdenite ore of the Lodi #4 mine shows some unique features that differ from those of the Murdock mine. The oxidation of the bornite-chalcopyrite-molybdenite ore was aided by numerous fractures and strain features which offered direct access to low-temperature hydrothermal solutions. This action has produced secondary enrichment consisting of chalcocite, digenite and covellite along fractures in the bornite-chalcopyrite fraction of the ore. As oxidation progressed, copper and some iron were removed and redeposited as chrysocolla and goethite along the abundant fractures in the quartz veins. There is evidence of a second hydrothermal quartz deposition in the sulfide veins that has not been noted in other portions of the district. During this period of hydrothermal action, the bismuth-containing copper-iron sulfides produced rare namibite, bismutoferrite, bismutostibite, clinobisvanite and schumacherite. No source for the vanadium has been observed in the mineralized veins. It is suspected that the vanadium was introduced as part of the hydrothermal action from the granitic rocks. The identification of small amounts of mottramite in the Murdock ores but not at the Lodi #4 is interesting.

The hydrothermal activity has altered the molybdenite and formed molybdates in much of the host quartz. The rare molybdate lindgrenite is prominent in this altered ore and makes up the bulk of the secondary copper minerals found in the quartz veins, while powellite and ferrimolybdate commonly form thin coatings of minute crystals over large sections of the dump. The rare bismuth molybdenum oxide, koechlinite, has formed from the molybdenite veins within the bornite-chalcopyrite-molybdenite ore. Oxidation cavities within this sulfide matrix contain delicate koechlinite crystals. Koechlinite has also formed thin, pale yellow films along the contact surfaces between bornite and quartz. Koechlinite has also been transported along fractures in the quartz and occurs coating much of the chrysocolla of the area.

Carbonates form a very minor part of the oxidized mineral suite at the Lodi #4 mine. Malachite is the most common carbonate, occurring as radiating masses that are frequently replaced by chrysocolla. Small patches of bismutite constitute the other carbonate, which is associated with small grains of bismite.

Because of the isolated nature of the secondary minerals, it is difficult to assign an order to

the secondary mineral formation sequence. Many secondary alteration sequences are masked by other sequences that are more general and widespread. Chrysocolla has been observed replacing lindgrenite, malachite and brochantite. Minerals observed coating chrysocolla include clinobisvanite, koechlinite, pharmacosiderite and powellite, which appears to have been some of the last minerals formed in the oxidation sequence.

## DISCUSSION

The copper ores exposed along Spring Creek in the Last Chance mining district are comparable to the copper deposits of the Plumas copper belt to the west, especially those within the Sierran Mesozoic granite.

In the Plumas copper belt, chalcopyrite is the principal copper mineral, with subordinate bornite. Accessory minerals include sphalerite, galena, stibnite, tetrahedrite and jamesonite. Studies by Smith (1970) of the trace element content of the granitic plutons show small but significant quantities of copper, zinc, molybdenum, tin, bismuth, silver, antimony, arsenic and boron in the analyses. These elements, except tin, have been identified in the Last Chance district.

Turner and Rogers (1914) and Graton and McLaughlin (1917) have concluded from studies of polished ore samples and underground observations that the copper ores of the Plumas copper belt were either of late magmatic or hydrothermal origin. No maximum temperature of formation was stated for these ores. The chalcopyrite ores of the Last Chance district may be related genetically to the Plumas copper belt ores and may be classed as either a hydrothermal phase of the magmatic sequence or of pegmatitic-pneumatolitic origin.

McQueen and Larson (1985) have described an occurrence of wittichenite exsolving from Bi-bearing bornite solid solutions at the Glen deposit, Wee Jasper, New South Wales. This small metasomatic copper deposit contains bornite, chalcopyrite, wittichenite, native silver, hematite and magnetite in a calcite-quartz chlorite gangue. Ore textures reflect an exsolution sequence involving initial non-coherent exsolution of wittichenite and chalcopyrite followed by coherent chalcopyrite exsolution from the remaining bornite.

Oen and Kieft (1976) cite an occurrence of silver-bearing wittichenite-chalcopyrite-bornite intergrowths from the Mangalde pegmatite, Visea district, Portugal. Here the textural relationships of the intergrowths shows a stage of wittichenite and chalcopyrite segregation from bornite solid solutions, followed by a stage of recrystallization and accumulation of wittichenite into larger blebs, veinlets and rims around stannoidite, galena and native bismuth. A final stage includes recrystallization and accumulation of the chalcopyrite into larger blebs, blades, veinlets and rims around the earlier accumulations of wittichenite. These intergrowths were presumably formed by unmixing at high temperature (400–500°C) of Ag-Bi bornite solid solutions subsequent to cooling below 270°C, the melting temperature of native bismuth.

Textural relationships observed at the Lodi #4 mine with respect to the exsolution of chalcopyrite and wittichenite from the bornite solid solutions are remarkably similar to those of the Mangualde pegmatite. The Mangualde pegmatite and Wee Jasper, New South Wales, ore textures are thought to be the result of high-temperature Bi-bearing bornite solid solutions, possibly at temperatures between 400° and 500°C, being intruded into quartz filled fractures. A similar origin is thought to have occurred at the Lodi #4 mine.

The amount of variation in the content of the sulfide ores between the Lodi #4 mine and the Murdock mine is most unusual since the two claims are on the same vein system and are quite close to each other. The mineralization at the Murdock mine is of the chalcopyrite-tetrahedrite type, whereas the predominant mineralization type at the Lodi #4 mine is bornite-chalcopyrite. A concentration of antimony appears to have formed at the Murdock mine and allowed tetrahedrite to form. Tatsuka and Morimoto (1977) state that tetrahedrite solid solution can coexist at 500°C with all the stable phases in the Cu-Sb-S, Cu-Fe-S and Fe-Sb-S systems. Digenite-bornite solid solutions can coexist with tetrahedrite throughout the compositional range. Tetrahedrite solid solution with about five percent iron can coexist with chalcopyrite, pyrrhotite, berthierite and other sulfides in solid solution.

Since tetrahedrite can contain many elements in substitution, it is possible that it has contributed many of the unusual elements that have been found in the ore of the Murdock mine

and, to a lesser extent, the Lodi #4 mine. This origin would easily explain the presence of arsenic and mercury in the ores. All of the unaltered samples of tetrahedrite examined thus far have shown these elements in their chemistry.

**Table 1. Minerals found in the Last Chance mining district.**

Mineral	Composition	Minerals present and rarity at each mine			
		Lodi #4	Murdock	Mohawk	El Dorado
<b>Native Elements</b>					
Bismuth	Bi	X(R)		X(R)	
Copper	Cu		X(R)		
Gold	Au	X(R)			
<b>Sulfides and Sulfosalts</b>					
Acanthite	Ag <sub>2</sub> S	X(R)			
Aikinite (?)	PbCuBiS <sub>3</sub>		X(R)		
Berthierite	FeSb <sub>2</sub> S <sub>4</sub>		X(R)		
Bismuthinite	Bi <sub>2</sub> S <sub>3</sub>		X(UC)		
Bornite	Cu <sub>5</sub> FeS <sub>4</sub>	X(C)	X(R)		
Chalcocite	Cu <sub>2</sub> S	X(C)	X(UC)	X(UC)	X(UC)
Chalcopyrite	CuFeS <sub>2</sub>	X(C)	X(C)	X(C)	X(C)
Cinnabar	HgS	X(R)	X(R)		
Covellite	CuS	X(C)	X(UC)	X(UC)	X(UC)
Cubanite	CuFe <sub>2</sub> S <sub>3</sub>			X(UC)	
Digenite	Cu <sub>9</sub> S <sub>5</sub>	X(UC)			
Emplectite	CuBiS <sub>2</sub>		X(UC)		
Galena	PbS	X(R)			
Hessite	Ag <sub>2</sub> Te	X(R)		X(R)	
Idaite	Cu <sub>3</sub> FeS <sub>4</sub>	X(R)			
Mackinawite	(Fe,Ni) <sub>9</sub> S <sub>8</sub>			X(R)	
Molybdenite	MoS <sub>2</sub>	X(C)	X(C)	X(C)	X(C)
Pyrite	FeS <sub>2</sub>			X(C)	X(C)
Pyrrhotite	Fe <sub>1-x</sub> S			X(R)	
Sphalerite	ZnS			X(R)	
Stromeyerite	AgCuS	X(R)	X(R)		
Tetrahedrite	(Cu,Fe) <sub>12</sub> Sb <sub>4</sub> S <sub>13</sub>	X(R)	X(C)		
Wittichenite	Cu <sub>3</sub> BiS <sub>3</sub>	X(UC)			
<b>Oxides</b>					
Bismite	Bi <sub>2</sub> O <sub>3</sub>	X(UC)	X(UC)		
Bismutostibiconite	Bi(Sb,Fe) <sub>2</sub> O <sub>7</sub>	X(R)			
Cuprite	Cu <sub>2</sub> O	X(R)	X(R)		
Goethite	FeO(OH)	X(C)	X(C)	X(C)	X(C)
Hematite	Fe <sub>2</sub> O <sub>3</sub>		X(C)	X(C)	X(C)
Koehnlinite	Bi <sub>2</sub> MoO <sub>6</sub>	X(UC)	X(UC)		
Partzite	Cu <sub>2</sub> Sb <sub>2</sub> (O,OH) <sub>7</sub>		X(R)		
Stibiconite	Sb <sup>3+</sup> Sb <sup>5+</sup> O <sub>6</sub> (OH)	X(R)	X(C)		
<b>Carbonates</b>					
Bismutite	Bi <sub>2</sub> (CO <sub>3</sub> )O <sub>2</sub>	X(R)	X(R)		
Malachite	Cu <sub>2</sub> (CO <sub>3</sub> )(OH) <sub>2</sub>	X(C)	X(C)	X(C)	X(C)
Witherite	BaCO <sub>3</sub>	X(R)			

**Sulfates**

Anglesite	PbSO <sub>4</sub>		X(R)			
Barite	BaSO <sub>4</sub>	X(R)				
Brochantite	Cu <sub>4</sub> (SO <sub>4</sub> )(OH) <sub>6</sub>	X(UC)	X(UC)			X(UC)
Chalcanthite	CuSO <sub>4</sub> • 5H <sub>2</sub> O	X(R)		X(UC)		X(UC)
Gypsum	CaSO <sub>4</sub> • 2H <sub>2</sub> O	X(R)				
Melanterite	FeSO <sub>4</sub> • 7H <sub>2</sub> O			X(UC)		X(UC)
Posnjakite	Cu <sub>4</sub> (SO <sub>4</sub> )(OH) <sub>6</sub> • H <sub>2</sub> O	X(R)				
Wroewolfeite	Cu <sub>4</sub> (SO <sub>4</sub> )(OH) <sub>6</sub> • 2H <sub>2</sub> O		X(R)			

**Vanadates**

Clinobisvanite	BiVO <sub>4</sub>	X(UC)	X(R)			
Mottramite	PbCu(VO <sub>4</sub> )(OH)		X(UC)			
Namibite	Cu <sup>1+</sup> (BiO) <sub>2</sub> (VO <sub>4</sub> )(OH)	X(R)				
Schumacherite	Bi <sub>3</sub> [(V,As,P)O <sub>4</sub> ] <sub>2</sub> O(OH)	X(R)				

**Arsenates, Phosphates**

Clinoclase	Cu <sub>3</sub> (AsO <sub>4</sub> )(OH) <sub>3</sub>		X(UC)			
Cornubite	Cu <sub>5</sub> (AsO <sub>4</sub> ) <sub>2</sub> (OH) <sub>4</sub>		X(R)			
Cornwallite	Cu <sub>5</sub> (AsO <sub>4</sub> ) <sub>2</sub> (OH) <sub>4</sub> • H <sub>2</sub> O		X(C)			
Metatorbernite	Cu(UO <sub>2</sub> ) <sub>2</sub> (PO <sub>4</sub> ) <sub>2</sub> • 8H <sub>2</sub> O	X(UC)	X(R)		X(UC)	
Metazeunerite	Cu(UO <sub>2</sub> ) <sub>2</sub> (AsO <sub>4</sub> ) <sub>2</sub> • 8H <sub>2</sub> O				X(UC)	
Pharmacosiderite	KFe <sub>4</sub> (AsO <sub>4</sub> ) <sub>3</sub> (OH) <sub>4</sub> • 6-7 H <sub>2</sub> O		X(R)			
Pseudomalachite	Cu <sub>5</sub> (PO <sub>4</sub> ) <sub>2</sub> (OH) <sub>4</sub> • H <sub>2</sub> O	X(UC)	X(UC)	X(UC)		X(R)

**Molybdates, Tungstates**

Cuprotungstite	Cu <sub>2</sub> (WO <sub>4</sub> )(OH) <sub>2</sub>		X(UC)			X(UC)
Ferrimolybdite	Fe <sub>2</sub> (MoO <sub>4</sub> ) <sub>3</sub> • 8H <sub>2</sub> O	X(C)	X(C)	X(C)		X(UC)
Lindgrenite	Cu <sub>3</sub> (MoO <sub>4</sub> ) <sub>2</sub> (OH) <sub>3</sub>	X(C)	X(C)			
Powellite	CaMoO <sub>4</sub>	X(C)	X(C)	X(UC)		X(UC)
Scheelite	CaWO <sub>4</sub>		X(UC)			X(UC)
Wulfenite	PbMoO <sub>4</sub>	X(R)				

**Silicates**

Bismutoferrite	BiFe <sub>2</sub> (SiO <sub>4</sub> ) <sub>2</sub> (OH)	X(R)				
Chrysocolla	(Cu,Al) <sub>2</sub> H <sub>2</sub> (Si <sub>2</sub> O <sub>5</sub> )(OH) <sub>4</sub>	X(C)	X(C)	X(C)		X(C)
Cuprosklodowskite	(H <sub>3</sub> O) <sub>2</sub> Cu(UO <sub>2</sub> ) <sub>2</sub> (SiO <sub>4</sub> ) <sub>2</sub> • 2H <sub>2</sub> O					X(UC)
Dravite	NaMg <sub>3</sub> Al <sub>6</sub> (BO <sub>3</sub> ) <sub>3</sub> (Si <sub>6</sub> O <sub>18</sub> )(OH) <sub>4</sub>	X(C)	X(C)	X(C)		X(C)
Quartz	SiO <sub>2</sub>	X(C)	X(C)	X(C)		X(C)
Schorl	NaFe <sub>3</sub> Al <sub>6</sub> (BO <sub>3</sub> ) <sub>3</sub> (Si <sub>6</sub> O <sub>18</sub> )(OH) <sub>4</sub>	X(C)	X(C)	X(C)		X(C)

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X = mineral present, C = common, UC = uncommon, R = rare

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**Table 2. Paragenetic position for the Spring Creek area mines.  
EL DORADO AND MOHAWK MINES**

Mineral	Early	Late
Molybdenite	_____	
Pyrite		_____
Chalcopyrite		_____
Sphalerite		_____
Bismuth		_____
Cubanite		_____
Pyrrhotite		_____
Mackinawite		_____
Chalcocite		_____
Covellite		_____
Hessite		_____

**MURDOCH MINE**

Mineral	Early	Late
Molybdenite	_____	
Bismuthinite	_____	
Chalcopyrite	_____	
Bornite	_____	
Tetrahedrite	_____	
Copper		_____?
Berthierite	_____	
Aikinite (?)	_____	
Emplectite	_____	
Chalcocite		_____
Covellite		_____
Stromeyerite		_____
Cinnabar		_____

**LODI #4 MINE**

Mineral	Early	Late
Molybdenite	_____	_____ remobilized
Galena	_____	
Gold	_____?	
Chalcopyrite	_____	
Bornite	_____	_____
Tetrahedrite	_____	
Wittichenite	_____	_____
Bismuth		_____
Idaite		_____?
Cinnabar		_____?
Hessite		_____
Acanthite		_____
Chalcocite		_____
Covellite		_____
Digenite		_____
Stromeyerite		_____

## ACKNOWLEDGMENTS

Drs. George W. Robinson and Carl Francis reviewed an earlier draft of this paper and provided many helpful suggestions for its improvement. Thanks also to Ted Hadley who provided the color photography of several minerals.

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