The Gold Hill Mine, Tooele County, Utah

Michael Kokinos
4620 Doe Street
Shingle Springs, California 95682

William S. Wise
Department of Geological Sciences
University of California
Santa Barbara, California 93106

The Gold Hill mine in western Utah has long been an important locality for secondary zinc, copper, bismuth, lead and iron minerals. It is the type locality for austinite, and in recent years several new and rare minerals have also been discovered in the oxidation zone of this old mine.

INTRODUCTION

The Gold Hill mine is located in western Tooele County, Utah, in the north end of the Deep Creek Mountains, which lie in the east-central part of the Great Basin (see Fig. 1). The mine is in the Gold Hill mining district, previously called the Clifton mining district, which has been mined for gold, silver, copper, lead, zinc, tungsten, arsenic and bismuth since 1857. In addition, minor amounts of antimony, vanadium, tin and molybdenum have been recovered from some of the ores.

The Gold Hill area is most easily reached by driving 27 miles southwest from Wendover, Utah, on U.S. 93A, then 28 miles southeasterly to the settlement of Gold Hill (Fig. 1). A highway sign identifies the turn-off to Gold Hill from highway 93A. The first 17 miles are paved, and the last 11 are a well-graded gravel road.

HISTORY

The district was discovered in about 1857 when travel to California was heavy through the Overland Canyon, about 6 to 7 miles south of the present town of Gold Hill. Travelers, who stopped to prospect after seeing samples rich in galena from that area, gradually traveled north to the Gold Hill area. Here they found and developed the many rich surface deposits and established the town of Clifton (El-Shatoury and Whelan, 1970).

Over 50 mines in the district were developed to some extent, but less than half of them shipped any recorded ore (Nolan, 1935). Initial production from the district was probably made during the period 1871–72 with the construction of a smelter at Clifton, 6 miles south of Gold Hill. Fifteen hundred tons of high-grade lead-silver ore were reduced. In 1874 the smelter was moved to Gold Hill where an additional 500 tons were treated (Nolan, 1935).

In 1892 a mill was constructed to handle gold ores from the Cane Springs, Alvarado and Gold Hill properties. Reported gold production from these three mines during the period 1892 and 1895 totaled $208,000. An estimated 50% of the ore and 60% of the gold came from the Alvarado mine. Activity in the area diminished during the period following 1895, until about 1906 when a group formed the Western Utah Copper Company and acquired the Gold Hill mine (Nolan, 1935).

The Deep Creek Railroad, a branch line of the Western Pacific Railroad from Wendover to Gold Hill, was completed in 1917. During that year production was greater than in any previous or subsequent year except 1920 and 1944. More than 50% of the 1917 district ore tonnage was produced from the Gold Hill mine. Large tonnages of ores containing arsenopyrite were discovered in the Gold Hill and U.S. mines in 1923 and 1924. Considerable arsenic ore was shipped from the two properties, but collapse of the arsenic market in 1925 resulted in severe curtailment of operations. Except for the period September 1943 to January 1945, when 98,784 tons of arsenic ore were mined from the U.S. property, the two mines have been inactive (Wilson, 1959).

The Yellow Hammer and Reaper mines are owned by Cecil Woodman, who was born and raised in Gold Hill. Over the years he has assisted many collectors and has provided us with substantial information about the mines and history of the district. He is currently residing with relatives in Washington, and we understand doing very well for 90 years of age.

Gold Hill mine

A group of nine claims and fractions that cover the northwest slope of Gold Hill (Figs. 3 and 4) comprise the Gold Hill mine, once called

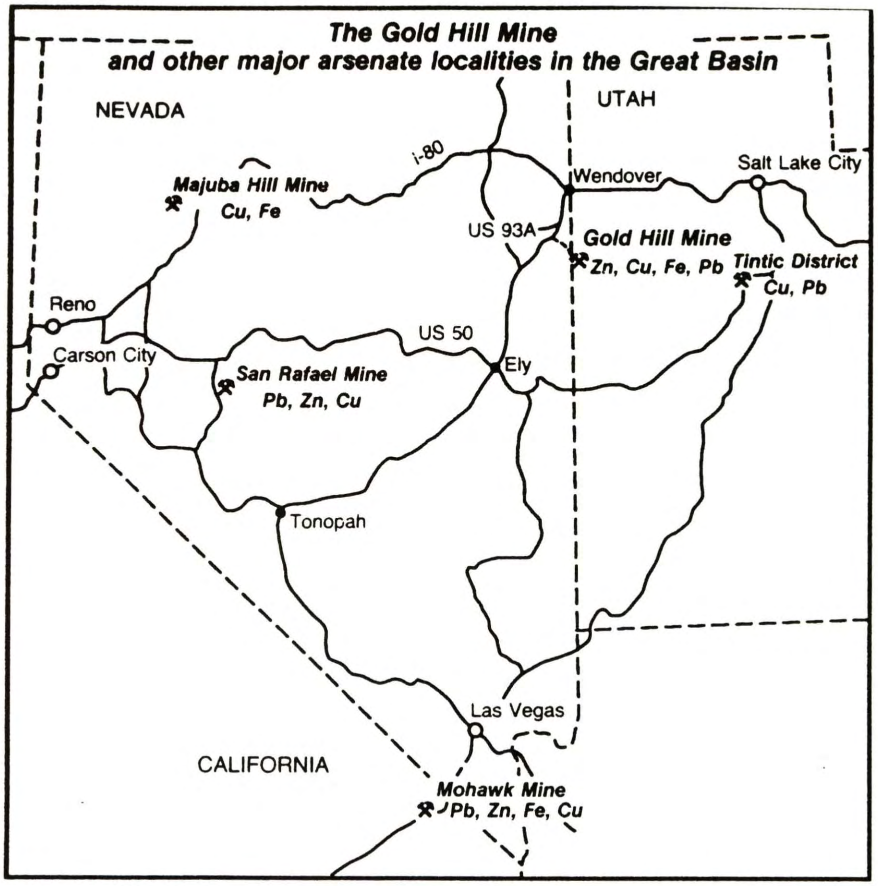

Figure 1. **Map of the Great Basin, showing access to the major arsenate localities.**

the Western Utah mine. The mine produced a large part of the copper and lead and appreciable percentages of the gold and silver credited to the Gold Hill district. In addition, this mine together with the U.S. mine has yielded virtually all of the arsenic ore mined in the district (Nolan, 1935). The average assay value of ore mined was 4.66% arsenic, 2.07% lead and 0.275% copper, with 4.0 ounces of silver and 0.0075 ounces of gold per ton (Wilson, 1959). From 1906 through 1916 a considerable body of copper ore was developed at about the 150-foot level (i.e. 150 feet below the top of the hill), and smaller bodies of lead-silver ore were found on a lower level. Actual production began early in 1917, shortly after the completion of the Deep Creek Railroad.

GEOLOGY

The geology and the ore deposits of the Gold Hill district have been studied by several geologists, most notably Kemp and Billingsley (1918), Nolan (1935) and El-Shatoury and Whelan (1970). Our observations agree with much of the earlier work, which concluded that the orebody at Gold Hill was emplaced in three stages, all following the intrusion of quartz monzonite into Paleozoic limestones during the early Tertiary Period. The initial effect of the intrusion was the development of extensive skarn deposits along the western contact with the Ochre Mountain Limestone (Carboniferous). This skarn, well exposed in the present glory hole, consists largely of wollastonite, grossular-andradite garnet, diopside and zoisite. It and later sulfide deposits are bounded on the east by steeply dipping beds of quartzite of the Manning Canyon Formation. Figure 5 illustrates the general geologic relations of the mineralization.

Following the formation of the skarn, sulfides were deposited by hydrothermal fluids emanating from the cooling pluton. Mineral deposition occurred in three stages, each forming a different type of deposit. The first to form were replacement veins along fractures in the skarn and limestone, and contain chiefly chalcopyrite, tennantite and gold with some quartz. These were followed by massive replacement of sections of the limestones, forming bodies characterized by

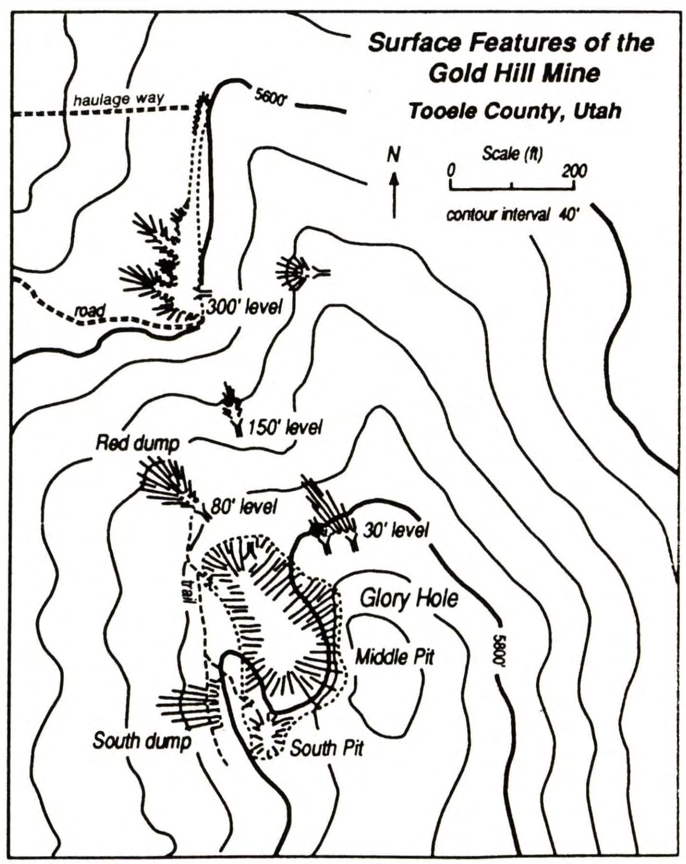

Figure 2. **Surface features of the Gold Hill mine.**

voluminous jasperoid and arsenopyrite, but with local concentrations of sphalerite, galena, pyrite or chalcopyrite. Finally, quartz-rich veins containing tennantite and chalcopyrite filled fractures in skarn, and

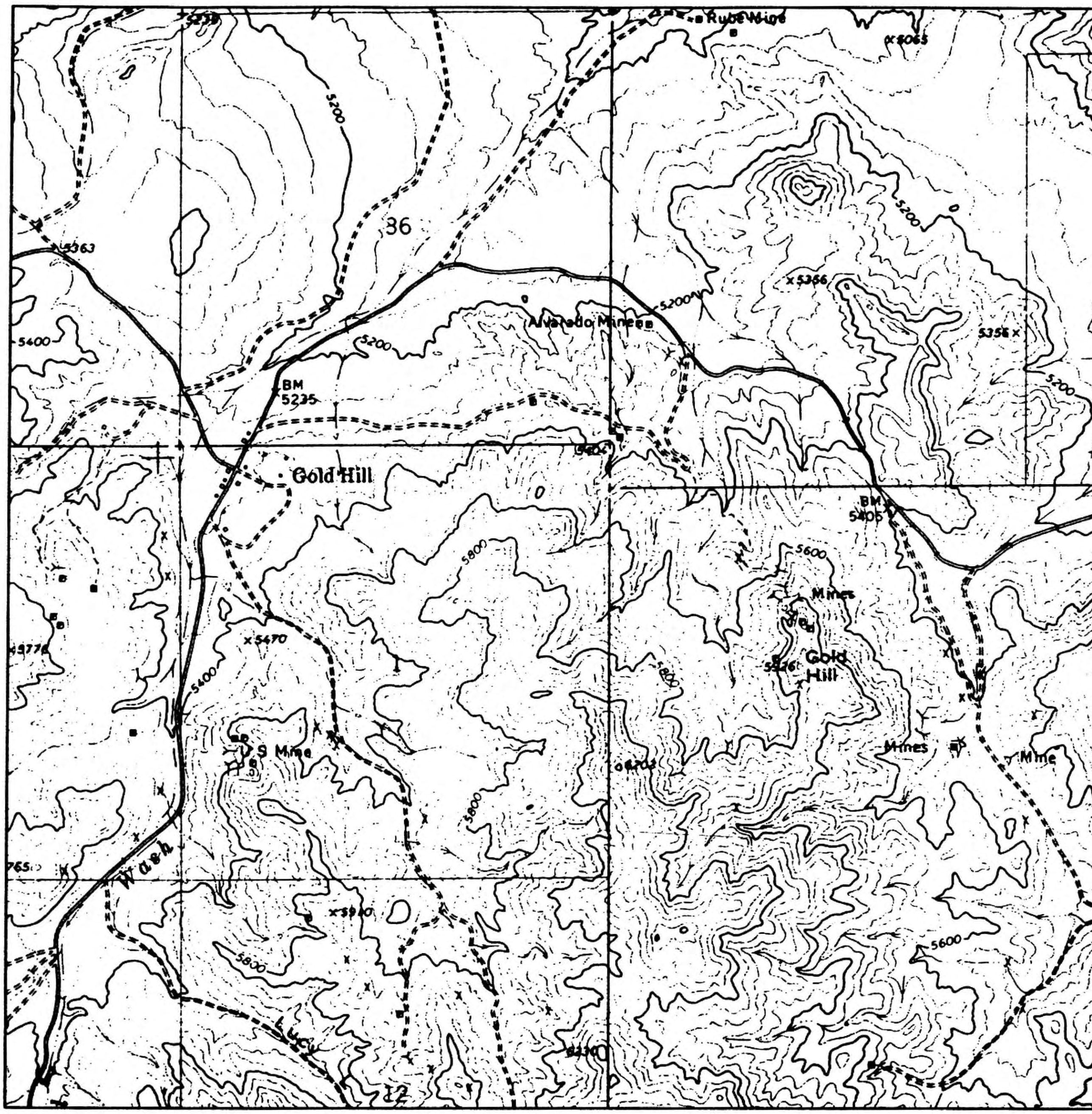

Figure 3. **Topographic map of the settlement of Gold Hill and vicinity. From the U.S. Geological Survey *Gold Hill* 7.5-minute quadrangle.**

extended into the limestone, forming irregular, lenticular replacement veins.

Before and during late Tertiary uplift much of the mineral deposits at Gold Hill underwent extensive oxidation of the sulfide minerals. Effects of this alteration extend to the deepest parts of the mine (900 feet below the present surface). Close to the surface very little of the primary sulfide minerals remain, having been replaced by massive amounts of cellular limonite decorated with arsenate, sulfate and other secondary minerals. These minerals have formed mostly in the spaces left by dissolving sulfides, and commonly exhibit complex sequences that reflect changing solution compositions, as the different sulfides and wall rock minerals yielded their metals and anions to the fluid.

The secondary minerals can be grouped into three general assemblages:

Zinc arsenate assemblage

This assemblage formed where sphalerite and arsenopyrite were emplaced in dolomitic limestones. It is characterized by abundant adamite and austinite which formed after early smithsonite, limonite, köttigite/symplesite and arseniosiderite. Talmessite, chalcophanite and hydrohetaerolite also formed in the same environment (see Fig. 6).

Iron and lead arsenate assemblage

Beudantite, carminite, arseniosiderite, thometzekite, mimetite, scorodite, hidalgoite and sodium pharmacosiderite are most common in the gossan where the massive arsenopyrite and galena body has been altered (see Fig. 7).

Copper arsenate and sulfate assemblage

The alteration of the late-stage chalcopyrite-bearing and tennantite-

Figure 4. **View of Gold Hill and the surface workings of the Gold Hill mine from the northwest. The lowest dumps are at the 300 level and the light colored rocks just below and to the right of the summit are skarns exposed in the Glory Hole.**

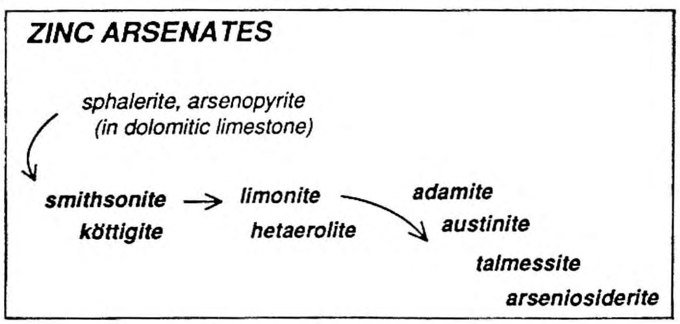

Figure 6. **Paragenetic sequence of the secondary minerals of the zinc arsenate assemblage.**

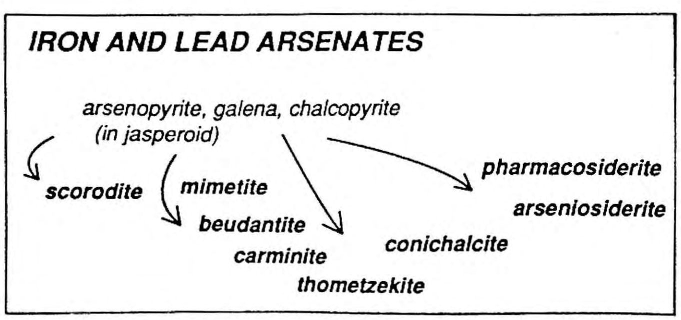

Figure 7. **Paragenetic sequence of the secondary minerals of the lead and iron arsenate assemblage.**

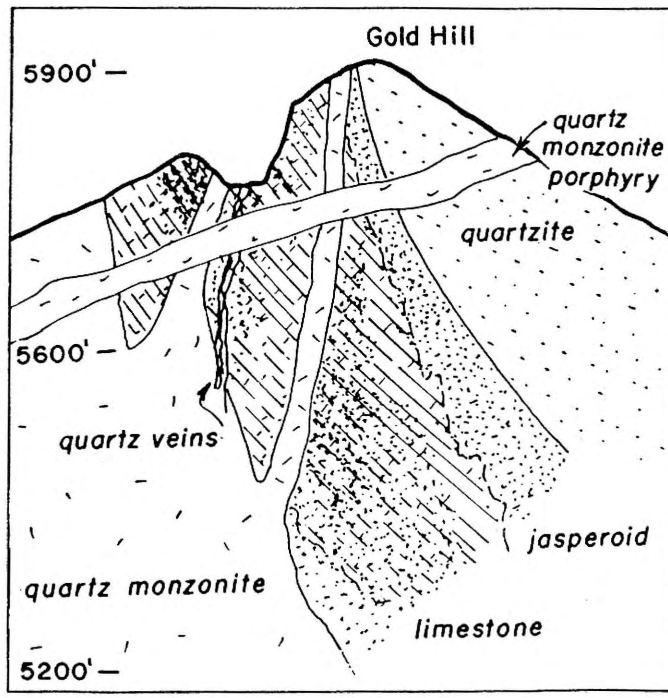

Figure 5. **Interpretive east-west cross-section of the upper portion of the Gold Hill mine, drawn through the Glory Hole.**

bearing replacement veins has yielded conichalcite, olivenite, chrysocolla, cornwallite, connellite, atacamite, brochantite, malachite, mixite, clinoclase, lavendulan, parnauite, strashimirite, tyrolite, silver, chlorargyrite, philipsburgite, an unnamed Cu-Bi arsenate and an undescribed Ca-arsenate (see Fig. 8).

COLLECTING AREAS

Table 1 lists the presently known secondary minerals found at the

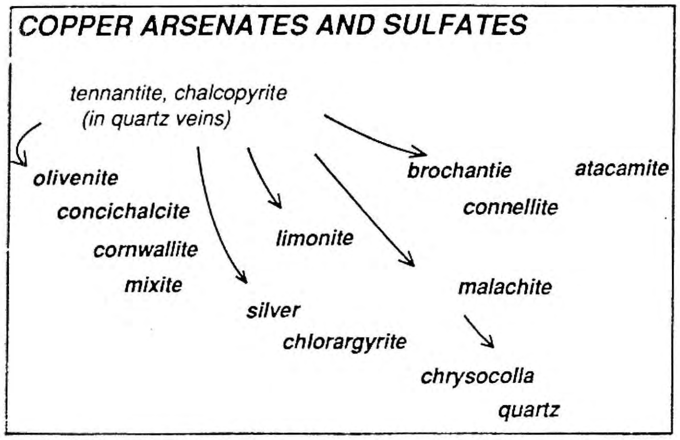

Figure 8. **Paragenetic sequence of the secondary minerals of the copper arsenate and sulfate assemblage.**

mine, and the availability and best collecting areas for each. Figure 2 shows the surface features of the mine. The collecting localities listed in table 1 and mentioned in the text are also shown on Figure 2.

30 Level

The 30-foot level is a shallow inclined shaft. Its associated dump is located immediately west of the entrance to the adit. These workings produce mixite, an unnamed Cu-Bi arsenate, conichalcite and gold in quartz veins. Surface erosion has filled the shaft with debris above the zone producing the minerals. At one time access to the shaft was from a crawl hole just inside the 30 level adit; this is now also blocked by the debris from surface erosion of the shaft.

80 Level

The 80-foot level adit, though badly caved and dangerous, presently terminates at the Glory Hole (see below). The minerals from the Glory Hole include the zinc arsenate and iron-lead arsenate assemblages. The "red dump" associated with the 80 level adit will yield the same wide variety of minerals as the adit, and is well worth exploring from top to bottom.

150 Level

The 150-foot level has a zone where adamite and austinite occur and a zone where copper sulfates and arsenates occur. The dump associated with this level does not contain material from these zones; the ore was apparently dropped through grizzlies and ore transfer raises to the 300 level.

300 Level

Large stopes exist above the 300-foot level, but secondary minerals are very rarely found. However, it does provide access to the 900 level where dietrichite has been found. On the west side of the 300 level dumps along the haulage way, scorodite-rich boulders frequently yield cavities with carminite and arseniosiderite. The upper portions of the dumps contain limonitic blocks with jarosite, sodium pharmacosiderite, conichalcite and austinite, probably from the Glory Hole.

South Pit

The "South pit" is a collecting area for the copper arsenate and sulfate assemblage occurring in cavities in quartz veins. The lower part of the associated south dump has yielded fine cornwallite and olivenite. Most of the minerals, however, were found on the upper part of the dump (above the south-trending trail) and, in recent years, mostly in the pit.

Glory Hole

The "Glory Hole" and "Middle pit" were probably part of the original 80 level. We have given the Middle pit a separate identity from the Glory Hole to better define collecting areas. The two areas produce the zinc arsenate assemblage and some of the iron-lead arsenate assemblage. The mineralogy of the south and southwest walls of the Middle pit is similar to that of the South pit and contains some of the copper arsenate minerals.

MINERALOGY

The minerals described below are grouped by the three assemblages discussed above.

Zinc Arsenate Assemblage

Oxidation of sphalerite-arsenopyrite replacement bodies in dolomitic limestones formed vuggy limonitic masses where, as the carbonate rocks dissolved, iron oxides were precipitated. Crystals of zinc, calcium and magnesium arsenates decorate cavities in the gossan and fracture surfaces in nearby quartzose wall rocks. Several early minerals that have been replaced by limonite are recognized only by their pseudomorphic shape. Of these, smithsonite scalenohedra and monoclinic blades of either köttigite or symplesite are relatively common.

Adamite $Zn_2(AsO_4)(OH)$

Yellow, rounded, crystalline adamite aggregates 1 to 8 cm across were abundant in the 80-level workings, where they were associated with hemimorphite. Also from this level, pale green cuprian adamite

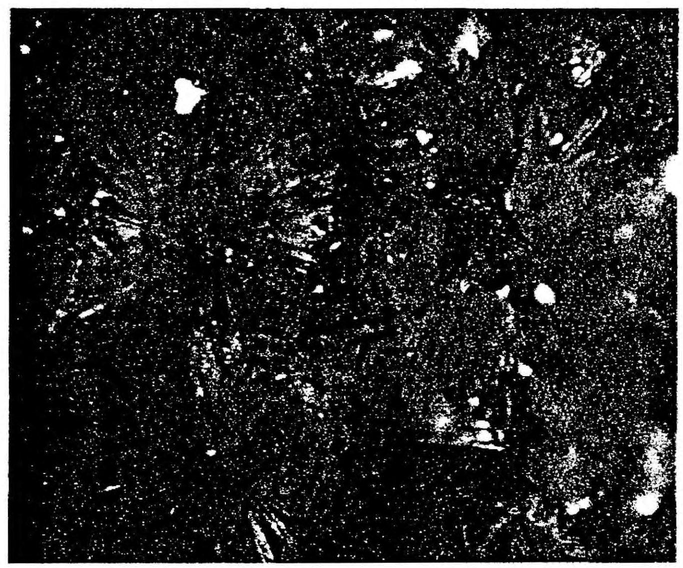

Figure 9. **Cuprian adamite crystals to about 1 mm, in clusters from the Red dump. Kokinos specimen and photo.**

Figure 10. **Pale yellow adamite crystals to 1.1 mm. Dan Behnke specimen and photo.**

***Table 1.* Distribution of secondary minerals of the Gold Hill mine.**

Mineral	South pit	Middle pit	Glory Hole	30 level	80 level	150 level	300 level
Adamite	C	A	A	A	C	C	S
Arseniosiderite	—	—	C	—	S	S	R
Atacamite	R	—	—	—	—	—	—
Austinite	—	C	A	—	C	C	S
Azurite	R	—	—	—	—	C	—
Barite	R	—	C	—	—	C	R
Bayldonite	R	—	—	—	—	—	—
Beudantite	—	—	—	—	C	—	S
Brochantite	C	—	—	—	—	C	—
Calcite	C	—	A	—	C	C	—
Carbonate-fluorapatite	R	—	—	—	—	—	—
Carminite	—	—	R	—	S	—	S
Cerussite	—	—	R	—	S	—	S
Chalcophanite	—	—	C	—	C	—	—
Chlorargyrite	S	—	—	—	—	—	—
Chrysocolla	A	C	C	C	C	C	—
Clinoclase	S	S	—	—	—	S	—
Conichalcite	A	A	A	A	A	C	C
Connellite	S	—	—	—	—	C	—
Copper	S	—	—	—	—	—	—
Cornubite	R	—	—	—	—	—	—
Cornwallite	C	S	—	—	—	S	—
Covellite	—	—	—	—	—	—	S
Cuprite	S	—	—	—	—	—	—
Dietrichite*	—	—	—	—	—	—	—
Hemimorphite	S	—	—	—	S	—	—
Hidalgoite	—	—	—	—	C	—	—
Hydrohetaerolite	—	—	—	—	C	—	—
Jarosite	—	A	—	—	S	—	—
Lavendulan	S	—	—	—	—	—	—
Malachite	C	—	—	—	—	—	—
Metazeunerite	R	—	—	—	—	—	—
Mimetite	S	—	S	—	—	—	—
Mixite	C	S	—	S	S	S	—
Olivenite	C	S	—	—	S	—	—
Parnauite	S	—	—	—	—	R	—
Philipsburgite	—	S	—	—	—	—	—
Quartz (crystals)	A	C	A	A	C	C	C
Scorodite	—	—	C	—	C	—	C
Silver	R	—	—	—	—	—	—
Sodium pharmacosiderite	S	—	—	—	C	—	—
Strashimirite	R	—	—	—	—	—	—
Talmessite	—	—	C	—	—	—	—
Thometzekite	—	—	—	—	R	—	—
Tyrolite	—	—	—	S	—	S	—
Unnamed CuBi-arsenate	—	—	—	S	—	S	—
Unnamed CuCa-arsenate	—	—	—	—	S	—	—
Wulfenite	—	—	R	—	—	—	—

*from 900 level

R, rare; S, scarce; C, common; A, abundant; and — not found

in 0.1 to 2-mm groups of crystals occurred with pale blue hemimorphite clusters. Superb, single crystals of colorless adamite 0.1 to 1 mm in size can be collected along with colorless austinite from the southwest wall of the Glory Hole. On the northwest wall pseudo-octahedral cuprian adamite occurs with minute orange cubes of sodium pharmacosiderite. On the northwest wall of the Middle pit fractures in the gossan contain crystals of colorless adamite on limonite pseudomorphs after smithsonite and köttigite/symplesite, both of which are recognized only by their crystal form.

Most of the adamite crystals we have observed are elongated parallel to *b* and have the forms {101}, {110}, {120} and {010}. The presence of triangular (110) and/or (120) faces is usually sufficient to distinguish adamite from austinite or olivenite. Although we have seen some specific morphological differences between adamite and its copper analog, olivenite, we are not able to apply these differences consistently with intermediate members of the series to distinguish cuprian adamite from zincian olivenite.

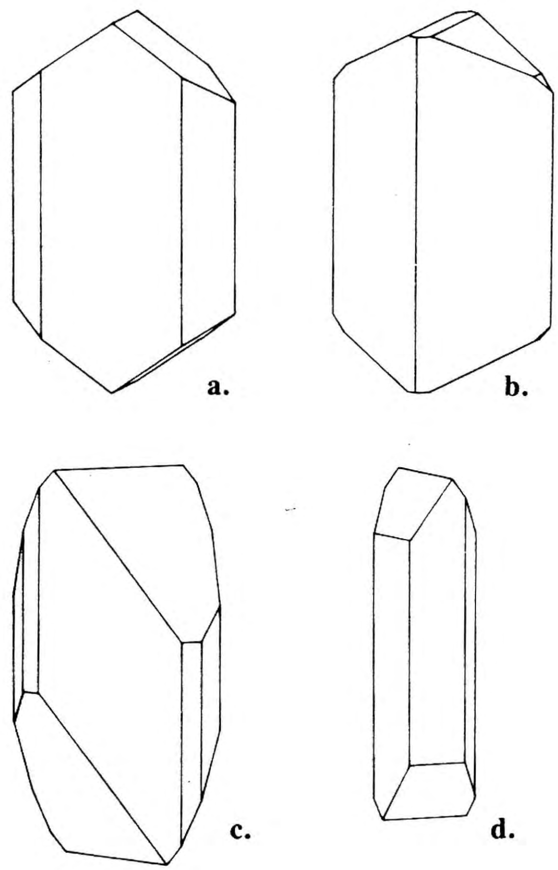

***Figure 11.* Crystal drawings of olivenite, adamite, and austinite. (a) Olivenite, elongated parallel to the *c*-axis, with the forms {100}, {110} and {101}. (b) Adamite, elongated parallel to the *b*-axis and oriented for comparison with olivenite; the forms are {101}, {010}, {120} and {110}. (c) Austinite, oriented with the prominent $(0\bar{1}0)$ and $(1\bar{3}1)$ faces toward the front; other forms are {110} and {130}. (d) Austinite with the simple forms {010}, {110} and $\{1\bar{1}1\}$. Both austinite crystals shown are right-handed.**

Arseniosiderite $Ca_3Fe_3O_2(AsO_4)_3 \cdot 3H_2O$

Arseniosiderite occurs as tiny (0.1 to 0.5-mm), yellow-orange radiating aggregates in the Glory Hole and the 150 level. These occur lining cavities that also contain austinite, hydrohetaerolite, chalcophanite and barite. Balls to 2 mm occur in and with scorodite from the 300 level dump.

Austinite $CaZn(AsO_4)(OH)$

Austinite (Staples, 1935) was first described from specimens collected at unspecified localities in the Gold Hill mine. The best austinite now comes from the southwest side of the Glory Hole and the 150 level, where it occurs as colorless, prismatic to acicular or bladed crystals 0.5 to 1 mm long. The more complex forms, described by Williams and De Azevedo (1967), may have come from the 150 level. Crystals are elongated on [001] and are dominated by the forms {010}, {110} and either {111} or {131}. The presence of either {111} vs. $\{1\bar{1}1\}$ or {131} vs. $\{1\bar{3}1\}$ is used to distinguish left-handed from right-handed crystals.

Austinite coats fractures in massive limonite, and is associated with adamite, chalcophanite, calcite, quartz, arseniosiderite and barite. The 80 level and the northwest wall of the Middle pit produced slightly larger (1.5-mm) bladed crystals of the cuprian variety associated with conichalcite. Bladed crystals growing out of spherical conichalcite were collected from the dumps below the 300 level (Main adit). Close examination of austinite crystals sometimes reveals the right and left-hand forms and twins (a combination of both forms) reported by Staples (1935) and confirmed by Williams and De Azevedo (1967).

Chalcophanite $(Zn,Fe,Mn)Mn_3O_7 \cdot 3H_2O$

Shiny, black, 0.01 to 0.3-mm hexagonal plates and pseudo-octahedral crystals of chalcophanite are common in the 80 level with hydrohetaerolite, and with austinite and adamite in the southwest section of the Glory Hole.

Hydrohetaerolite $Zn_2Mn_4^{+3}O_8 \cdot H_2O$

Hydrohetaerolite is common as dull black, 2 to 8-mm, rounded aggregates, occurring sporadically with overgrowths of chalcophanite in the gossan of the 80 level and the southwest wall of the Glory Hole. Other associated minerals are those of the zinc arsenate assemblage. It can be visually distinguished from black limonite aggregates by its fan-shaped prismatic cleavage surfaces.

Talmessite $Ca_2Mg(AsO_4)_2 \cdot 2H_2O$

Colorless, platy to bladed rosettes, clusters and multiple crystals of talmessite are associated with calcite, austinite and quartz immediately east of the austinite locality in the Glory Hole. Here it occurs in a mass of limonitic gossan replacing dolomitic limestone. No single crystals have been observed; blades appear to be joined on the large (010) face.

Iron and Lead Arsenate Assemblage

Substantial amounts of massive scorodite occur at the mine as the primary alteration product of arsenopyrite. Common beudantite and carminite in these blocks indicate the oxidation of the galena along with the massive arsenopyrite body. This material can be found on the red dump and 300 level dump as pale blue blocks containing massive scorodite and pale brown beudantite with jasperoid, quartz and limonite. It was mined for the arsenic content.

Beudantite $PbFe_3(AsO_4)(SO_4)(OH)_6$

Yellow to cinnamon-brown, 0.5-mm, pseudocubic rhombohedral crystals and massive yellow stringers of beaudantite on limonite have been collected on the red dump. Generally associated are orange cubes of sodium pharmacosiderite. Beudantite can also be found on the 300 level dump as masses of minute (less than 0.1 mm) crystals in cavities in scorodite-bearing boulders. Its association with scorodite and its high luster help to distinguish beudantite from jarosite.

Carminite $PbFe_2(AsO_4)_2(OH)_2$

Occurring as red tufts and clusters of red prismatic crystals 0.1 to 1.5 mm long, carminite is fairly common in crystalline scorodite-bearing boulders. Such boulders have been found on the red dump and the 300 level dumps closest to the haulage way.

Cerussite $PbCO_3$

White, 0.1 to 0.3-mm crystals and aggregates of cerussite are commonly associated with carminite in crystalline scorodite-bearing boulders.

Hidalgoite $PbAl_3(SO_4)(AsO_4)(OH)_6$

Hidalgoite was first found at Gold Hill and identified by Clarkson *et al.* (1971). It occurs as white to pale pistachio-green, porous or cavernous to dense, porcelaneous crusts coating cavities in limonitic gossan from the red dump, where it is relatively common.

Mimetite $Pb_5(AsO_4)_3Cl$

Colorless, transparent to translucent, 0.1 to 1-mm crystals or mimetite have been found on the west wall of the Middle pit. It is also found associated with conichalcite on a small dump associated with the Middle pit.

Sodium pharmacosiderite $(Na,K,Ba)Fe_4(AsO_4)_3(OH)_4 \cdot 7H_2O$

Dull orange, 1-mm tetrahedra of sodium pharmacosiderite with paler orange overgrowths showing cube faces have been found on the red dump. Microprobe analyses of both crystal habits give identical Na:K:Ba ratios of 0.75:0.14:0.11. Some transparent to translucent, pale green cubes on jasperoid along with scorodite have been found on the red dump and in the South pit. Because these have not been analyzed, it is not certain whether they are the sodium or potassium species.

Scorodite $FeAsO_4 \cdot 2H_2O$

Most cavities in the massive scorodite blocks from the 300 level contain sharp, pale blue scorodite crystals 0.1 to 1 mm long, associated with beudantite, carminite, cerussite and thometzekite. Scorodite is also common from the Glory Hole and the 80 level, where it is associated with minor beudantite.

***Figure 12.* Scanning electron micrograph of clusters of thometzekite (wedge-shaped crystals) and carminite (prisms). Length of bar: 0.05 mm.**

Thometzekite $Pb(Cu,Zn)_2(AsO_4)_2 \cdot 2H_2O$

Small, greenish yellow, wedge-shaped crystals of thometzekite are intimately associated with carminite and scorodite in cavities of the scorodite blocks. Thometzekite is the Cu-analog of tsumcorite; the habit and color of this material are distinctly different from the blue-green to green tabular crystals from Tsumeb, Nambia, the type locality. The X-ray powder pattern matches well with that of the type material.

Figure 13. Olivenite crystals to 1.1 mm. Dan Behnke specimen and photo.

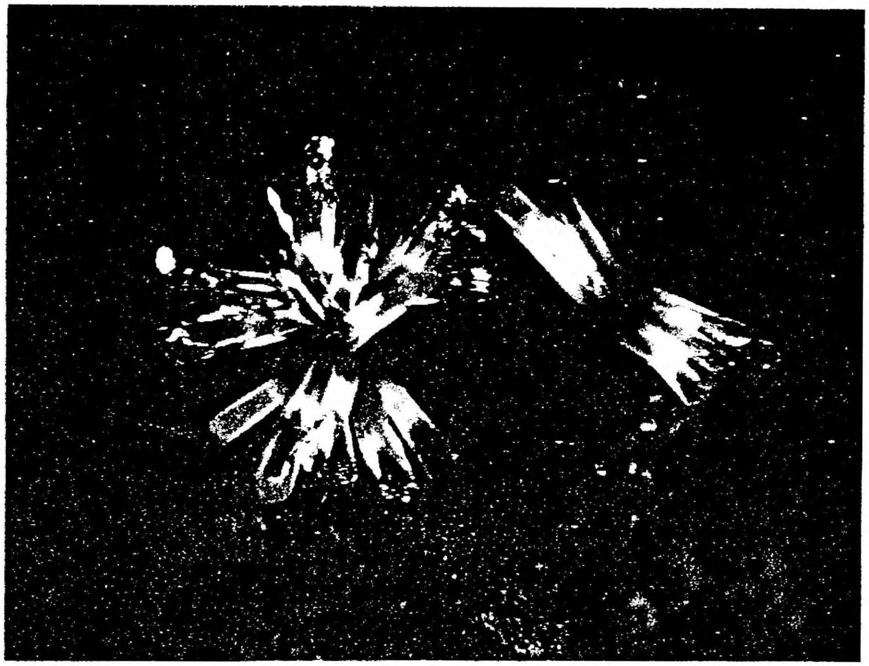

Figure 14. Austinite on cuprian austinite from the Red dump. Width of view: 3 mm. Wise specimen and photo.

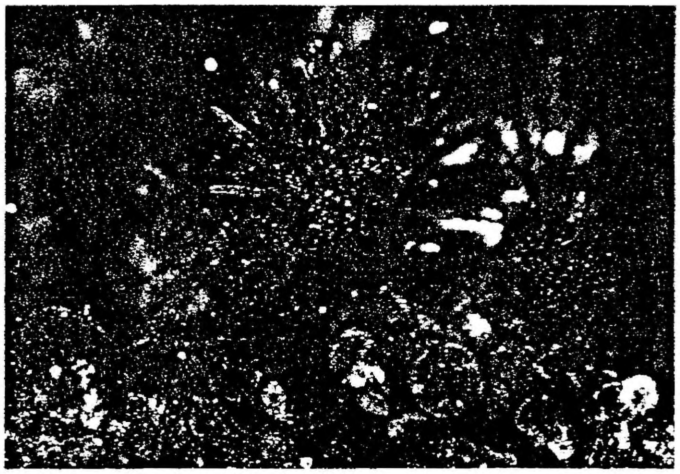

Figure 15. Cuprian austinite on conichalcite; the center spray is 0.9 mm across. Dan Behnke specimen and photo.

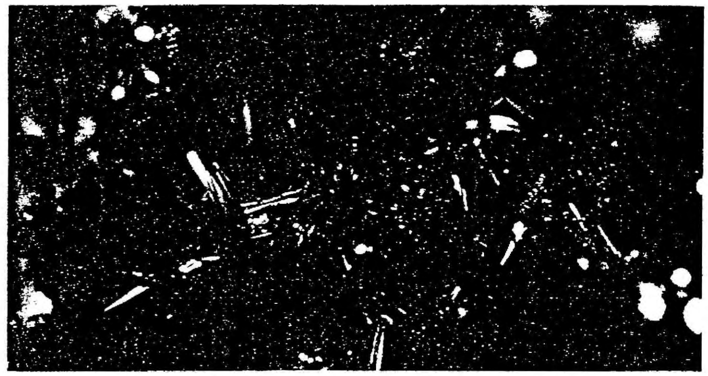

Figure 16. Carminite and beudantite from blocks along the haulage tram. Width of view: 4.5 mm. Kokinos specimen; Wise photo.

Figure 17. Talmessite on limonite from the Glory Hole. Width of view: 3.5 mm. Wise specimen and photo.

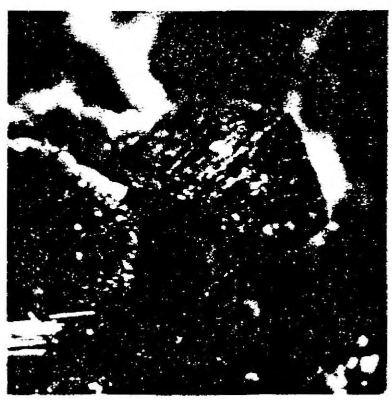

Figure 18. Sodium pharmacosiderite on olivinite; the crystal is about 1 mm across. S. White specimen and photo.

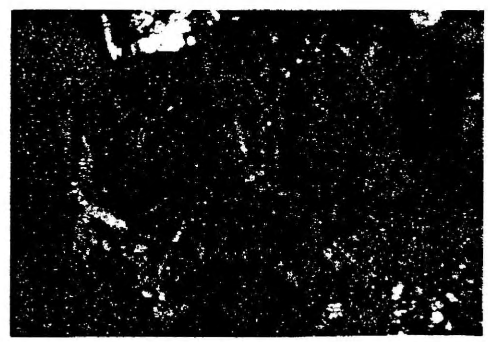

Figure 19. Thometzekite with beudantite and scorodite from the Red dump. Length of crystals: 0.5 mm. S. White specimen and photo.

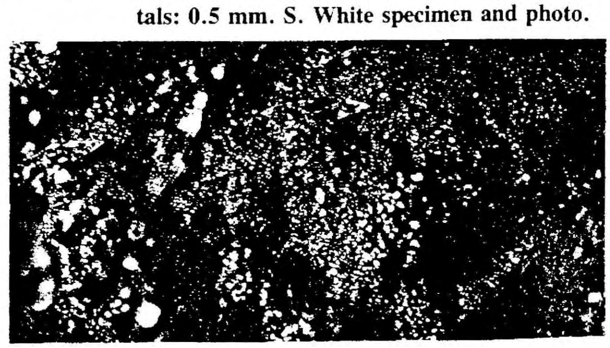

Figure 20. Steeply pyramidal wulfenite from the Glory Hole. Curtis specimen and photo.

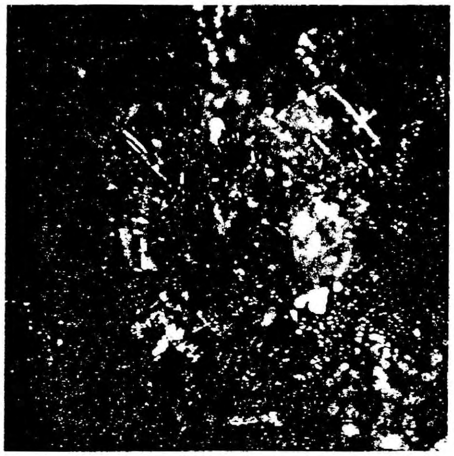

Figure 21. Atacamite crystal cluster, 1 mm across, from the South dump. Kokinos specimen; Wise photo.

Figure 22. Brochantite and malachite from the South dump. Width of view: 7 mm. Wise specimen and photo.

Figure 23. Cornubite crystals, up to 0.4 mm long, from the South dump. S. White specimen and photo.

Figure 24. Connellite on vein quartz with cornwallite from the South pit. Width of view: 9 mm. Wise specimen and photo.

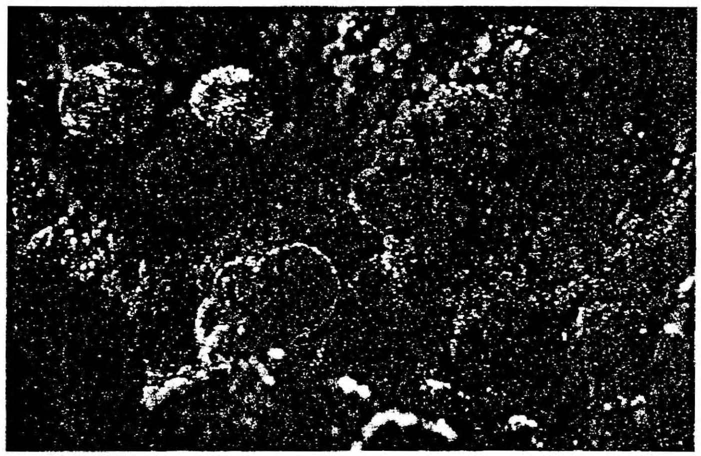

Figure 25. Cornwallite and conichalcite from the South dump. Width of view: 7 mm. Kokinos specimen; Wise photo.

Figure 26. Lavendulan and strashimirite from the South dump. Width of view: 5 mm. Kokinos specimen; Wise photo.

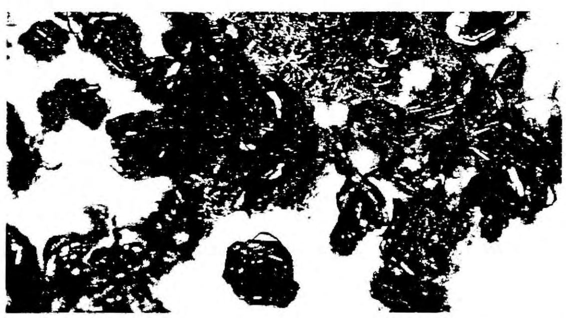

Figure 27. Philipsburgite from the Middle pit. Width of each cluster: about 1 mm. J. Marty specimen and photo.

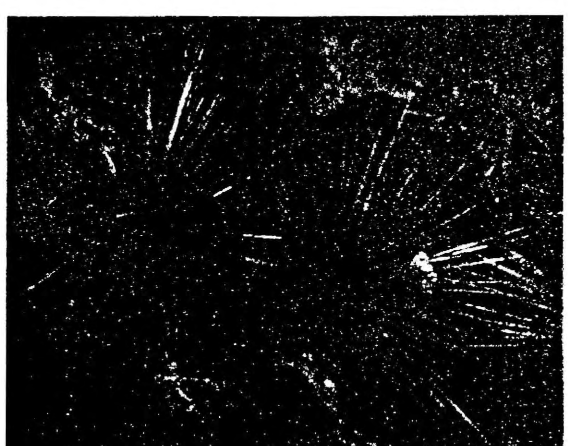

Figure 28. Mixite from the 30 level. Width of view: 5 mm. S. White specimen and photo.

Figure 29. Strashimirite sprays from the South dump. Width of view: 3 mm. S. White specimen and photo.

However, the analysis by microprobe gives the composition, $Pb_{.98}(Cu_{1.14}Fe_{.80}Zn_{.02})(AsO_4)_{2.00}\cdot 2H_2O$. The oxidation state of the iron was not determined, but is probably ferric judging from the highly oxidized environment. The content of apparent ferric iron suggests that this mineral is chemically intermediate between thometzekite and mawbyite, and could also account for the unusual color for a copper mineral.

Wulfenite $PbMoO_4$

We are aware of only two 0.3-mm pale yellow crystals of wulfenite being found at the Gold Hill mine; both were collected in the Glory Hole. One is pseudocubic octahedron, modified by prism and basal faces. The other is prismatic with pyramidal terminations.

Copper Arsenate and Sulfate Assemblage

The late-stage replacement veins, which contained mostly quartz, chalcopyrite, tennantite and pyrite, were emplaced along fractures in the skarn and limestone. Oxidation has altered much of the tennantite, chalcopyrite and pyrite, but some remains sealed in vein quartz. Many of the secondary minerals grew in the original cavities of the veins, but in the vicinity of carbonate host rocks massive limonitic gossan was formed by the acidic fluid migration. Excellent specimens of the secondary copper minerals can be found in both environments.

Atacamite $Cu_2Cl(OH)_3$

Atacamite occurs as radiating clusters of bright green, transparent, very thin tabular (010) crystals 0.05 to 0.3 mm long. Only a few specimens have been found on the upper portion of the South pit dump, where it is associated with malachite and connellite in limonite-lined cavities in gossan impregnated with grains of cuprite and copper.

Azurite $Cu_3(CO_3)_2(OH)_2$

Sharp plates and acicular crystals of deep blue azurite 0.5 to 1 mm are associated with malachite, mixite and colorless barite and calcite from the 150 level.

Barite $BaSO_4$

Massive material and fine crystals of colorless to white barite occur in the 150 level. The transparent, colorless plates 0.5 to 2 mm in size are associated with azurite, malachite, mixite and calcite.

Bayldonite $PbCu(AsO_4)_2(OH)_2\cdot H_2O$

Bayldonite in the few specimens that have been found occurs as yellow-green, adamantine clusters of thin, platy crystals 0.05 to 0.2 mm long. These specimens were found on the upper portion of the South dump. Bayldonite is associated with cornwallite and malachite.

Brochantite $Cu_4(SO_4)(OH)_6$

Emerald-green, wedge-shaped brochantite crystals in clusters, sheaves or botryoidal crusts are fairly common in the copper assemblage. It is commonly associated with malachite, conichalcite and connellite. The crystals are distinctive and easy to recognize, but crustiform material is nearly indistinguishable from cornwallite.

Carbonate-fluorapatite $Ca_5(PO_4,CO_3)_3F$

A single 0.5-mm, botryoidal, pale blue mass of apatite was found on quartz in the South pit.

Chrysocolla $(Cu,Al)_2H_2Si_2O_5(OH)_4\cdot nH_2O$

Chrysocolla is a common late-stage mineral in the cavities and fractures of the quartz veins, occurring as blue and blue-green masses. Exceptional chrysocolla pseudomorphs after mixite, olivenite and possibly azurite have been collected form the South pit.

Clinoclase $Cu_3(AsO_4)(OH)_3$

Small amounts of clinoclase have been found in the South pit occurring with olivenite and malachite in cavities in the quartz veins, with chrysocolla in limonitic gossan in the 150 level, and with philipsburgite in the Middle pit. The clinoclase occurs as dark blue, prismatic to bladed single crystals and clusters up to 1.3 mm in length. It is visually distinguished from azurite and connellite by its crystal form and high luster.

Connellite $Cu_{19}Cl_4(SO_4)(OH)_{32}\cdot 3H_2O$

A number of excellent connellite specimens have been collected in recent years from two different localities. In the South pit sprays of dark blue, acicular crystals up to 2 mm are found associated with atacamite, malachite and lavendulan in cavities in quartz veins. Similar specimens, although with smaller crystals, have been found in copper/cuprite-impregnated limonitic blocks from the South dump. Recently, stout hexagonal prisms with basal pinacoids have been found in clusters and as single crystals up to 0.5 mm long on quartz from the 150 level. Here it is associated with malachite, an unnamed Cu-Bi arsenate, parnauite, chrysocolla and tyrolite.

Copper Cu, and **Cuprite** Cu_2O

A few samples of jasperoid and limonitic gossan impregnated with masses of cuprite and copper have been found on the South dump with atacamite and malachite.

Cornubite $Cu_5(AsO_4)_2(OH)_4$

A few specimens containing cornubite were found in the South pit and the associated dump. It occurs as clusters of thin, transparent green plates up to 0.2 mm in length, and is associated with cornwallite, malachite and bayldonite. The mineral also occurs as dark green spherical aggregates that are indistinguishable from brochantite.

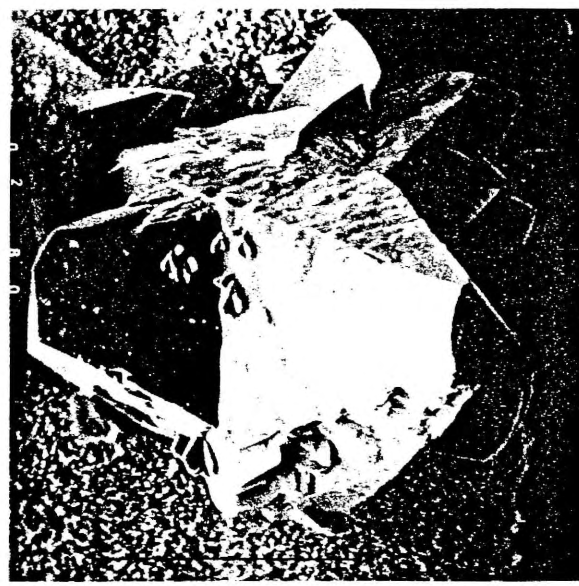

Figure 30. **Scanning electron micrograph of cornwallite crystals. The common form is {211}.**

Cornwallite $Cu_5(AsO_4)_2(OH)_4\cdot H_2O$

Cornwallite is fairly widespread in cavities in the quartz veins from the South pit and gossan blocks of the South dump. Generally it forms dark green, spherical, crystalline aggregates and masses with a porcelaneous to waxy luster. It is commonly associated with the other copper arsenates olivenite, clinoclase, strashimirite and lavendulan. It is difficult to visually distinguish cornwallite from botryoidal malachite or brochantite.

A single specimen with single crystals of cornwallite has been found at the boundary between the Middle and South pits. The identity of these crystals has been verified by X-ray powder diffraction and microprobe analysis. Crystal shapes on SEM photographs suggest that the form {211} is present. To our knowledge these are the first single crystals of cornwallite to be found.

Gold Au

Rounded, 0.2-mm droplets of gold occur on quartz with mixite and conichalcite at the entrance to the 30 level adit and on its dump.

Lavendulan $NaCaCu_5(AsO_4)_4Cl \cdot 5H_2O$

Thirty to 40 years ago magnificent specimens of lavendulan were found in limonitic gossan blocks on the South dump. This lavendulan is in the form of blue aggregates of translucent blades up to 4 mm long and is associated with strashimirite, olivenite, cornwallite, conichalcite and chrysocolla. More recently lavendulan has been found as small (about 1 mm), blue, waxy-lustered balls of radiating blades in quartz vein cavities in the South pit.

Malachite $Cu_2(CO_3)(OH)_2$

Pale to medium green, fibrous malachite clusters up to 2 mm are common in cavities in the quartz veins of the South pit and blocks of gossan on the South dump. It most commonly occurs with azurite, brochantite, cornwallite and chrysocolla. Its appearance is similar to some mixite sprays, but the individual fibers are thin blades.

Metazeunerite $Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$

A single 0.2-mm translucent green metazeunerite crystal associated with olivenite on jasperoid was collected from the South pit dump.

Mixite $Cu_6Bi(AsO_4)_3(OH)_6 \cdot 3H_2O$

Two somewhat different varieties of mixite occur at Gold Hill. In cavities in the quartz veins exposed in the South pit, sprays of very thin, pale green needles of mixite occur with olivenite and conichalcite. From the 30 level larger sprays of emerald-green to bluish green mixite occur along fractures in altered skarn, where it is associated with conichalcite, an unnamed Cu-Bi arsenate, tryolite and gold. These crystals of mixite are up to 3 mm long and as much as 25 microns in diameter.

Microprobe analyses have detected no elements other than Cu, Bi, As and Ca. Using conichalcite and bismutite as standards, and comparing with mixite from the Tintic district, quantitative analyses show that the large 30-level crystals are relatively high in Ca and low in Bi and Cu. The thinner crystals from the South pit contain less Ca, and are closer to the ideal composition. The 30-level crystals warrant further investigation.

Parnauite $Cu_9(AsO_4)_2(SO_4)(OH)_{10} \cdot 7H_2O$

Clusters of pale blue parnauite laths (0.1 to 0.3 mm) were collected from the South pit; and drusy cavity coatings of green, platy crystals were found in the 150 level. The square terminations on the blades are characteristic of this mineral, especially at Gold Hill.

Philipsburgite $Cu_6(AsO_4)_2(OH)_6 \cdot H_2O$

Emerald-green philipsburgite plates and blades as singles and rosettes up to 1 mm across and 0.05 mm thick occur with mixite, cornwallite, olivenite and chrysocolla from the southwest wall of the Middle pit. The plates are dominated by the (100) form and bounded by {010}, {001} and {111}.

Quartz SiO_2

Quartz occurs in two notable types of specimens: (1) primary quartz in veins near the southwest end of the Middle pit that form Japan-law twins, and (2) secondary quartz that has crystallized with and after many of the secondary copper minerals, especially chrysocolla. Most notably it occurs as sharp single crystals on mixite needles and as crusts on malachite and chrysocolla from the South pit.

Silver Ag, and **Chlorargyrite** AgCl

A few specimens of silver and several of chlorargyrite have been found in the South pit and South dump. The silver occurs as thin, irregular sheets up to 3 mm within conichalcite; the chlorargyrite forms honey-yellow octahedra and irregularly shaped masses 1 to 2 mm on conichalcite, cornwallite and mixite.

Strashimirite $Cu_8(AsO_4)_4(OH)_4 \cdot 5H_2O$

Strashimirite was found only in limonitic blocks from the South dump, most often associated with lavendulan and olivenite. It occurs as pale yellow-green to green, very thin pointed blades in radiating clusters up to 4 mm high.

Tyrolite $CaCu_5(AsO_4)_2(CO_3)(OH)_4 \cdot 6H_2O$

Dark green to blue-green, platy tyrolite crystals and cleavable masses up to 1 mm in length have been found in altered skarn from the 30 level and in quartz vein cavities of the 150 level. In both cases tyrolite is associated with conichalcite, mixite, connellite and the unnamed Cu-Bi arsenate.

Unnamed Cu-Bi arsenate

This mineral was originally found in the gossan of the 30 level, associated with conichalcite and Ca-rich mixite, but has recently turned up in quartz vein cavities on the 150 level, where it is associated with connellite, tyrolite and azurite. The unnamed Cu-Bi arsenate forms tiny (0.25 mm), square, yellow-green to brown-green plates and clusters which commonly coat surfaces or fill thin fractures.

Unnamed Ca-arsenate

Several specimens of an unnamed mineral were collected from the 80 level. It occurs as very pale blue to colorless, very thin plates in a drusy coating on fracture surfaces, especially on chrysocolla. The mineral is a hydrated Ca arsenate, with prominent X-ray diffraction peaks at 22.8 (10), 11.4 (5), 7.56 (1), 5.00 (1), 3.35 (2), 3.00 (2), and 2.50 (1) Å.

PARAGENESIS

As explained above, the secondary minerals generally occur in suites controlled by the varying mineralogies of different sulfide-bearing deposits at Gold Hill. Oxidation of the sulfide minerals may have been initiated in the late stages of hydrothermal activity, but much of it occurred following uplift of the Deep Creek Range. As sulfide minerals were oxidized and metal ions entered the local groundwater, the precipitation of secondary minerals removed these ions before extensive migration took place. For example, oxidation of the late-stage copper-bearing veins of the upper levels (30 and 80 levels and the South pit) yielded abundant copper ions to local fluids, but none migrated into the zinc arsenate assemblage area of the Glory Hole, only a few meters away. However, there are examples of minor amounts of mixing, such as cuprian austinite and zincian adamite from various localities within the Glory Hole and Middle pit. Restricted migration occurred where local fluids did not become highly acidic, for example because of the buffering by adjacent calcite-bearing wall rocks.

The zinc arsenate assemblage occurs where primary arsenopyrite and sphalerite replaced dolomitic limestone. Oxidation must have affected the sphalerite first, because the earliest secondary mineral was smithsonite. Fluids apparently became much more acidic, because the smithsonite and some of the host limestone were dissolved as adamite, austinite and köttigite/symplesite were precipitated. Abundant arsenate ions reacted with dolomite to form talmessite, and with calcium and iron to form arseniosiderite.

Galena and arsenopyrite were also deposited together in those portions of the orebody that were exploited by the 300 level. Fluids from the oxidation of this deposit must have contained abundant arsenate and sulfate anions, allowing the massive crystallization of scorodite and beudantite. Because these ions so completely dominated the system, or perhaps because there was very little MoO_4, wulfenite is exceedingly rare at Gold Hill.

The richest assemblage of minerals is certainly that which resulted from the alteration of the tennantite and chalcopyrite-bearing veins. Many secondary minerals crystallized in the cavities remaining in the quartz veins, because there were insufficient amounts of sulfide minerals to affect the much more abundant skarn and limestone minerals. Gossan formed from the alteration of sulfides in place. Anions include carbonate from the groundwater (atmospheric CO_2) and the limestone, sulfate and arsenate from the tennantite and chalcopyrite, and chloride from the groundwater. Many specimens show pseudomorphs of early-formed minerals such as azurite that precipitated from neutral or slightly alkaline waters. As these fluids became richer in cations, they also became more acidic and precipitated many of the arsenates. Bismuth in the mixite and the unnamed Cu-Bi arsenate presumably came from bismuth-bearing tennantite. The great abundance of conichalcite in these rocks attests to the interaction of these fluids with the surrounding limestones. We regard the specific associations, such as olivenite-cornwallite-strashimirite-lavendulan or brochantite-connellite-atacamite or mixite-conichalcite-unnamed Cu-Bi arsenate, to be reflections of unique local cation and/or anion concentrations. Different host rocks, ranging from altered skarn to limestone, buffered the pH of local waters to varying degrees, allowing different assemblages of minerals to occur within short distances.

CONCLUSIONS

Much of the interest in the minerals from Gold Hill comes from the rich variety and rarity in each of the principal assemblages. The area should continue to provide interesting collecting for years to come, if it does not fall prey to open-pit mining and leaching.

Permission should be obtained to collect, because the mine is the private property of ASARCO (American Smelting and Refining Company). We strongly recommend against collecting in any of the underground workings. With minor exceptions the dumps and open pits will yield excellent micromount material of all the species listed here. Comments concerning collecting in the four levels of underground workings are provided as explanatory notes for the material found on the associated dumps.

ACKNOWLEDGMENTS

This study developed over many more years than we care to admit, and during this time a great number of people shared specimens with us. To mention a few will necessarily omit many. We therefore gratefully acknowledge the help, the specimens, the data, and the discussions of all the micromounters from the western U.S., and the visitors from elsewhere in the country as well as abroad, who have visited Gold Hill. However, we need to mention the specific assistance of Dave Pierce who provided much of the electron microprobe data and the scanning electron micrographs, Cecil Woodman who was particularly helpful in providing access to the mine and information about early-day activity, Robert Winchell for mineralogical help in the initial stages of the work, and Richard Thomssen whose careful review of the paper helped sharpen our thinking concerning the mineralogy and paragenesis.

REFERENCES

CLARKSON, J. F., ROBERTS, W. L., and LINGARD, A. L. (1971) Hidalgoite from Gold Hill, Utah. *Mineralogical Record*, **2**, 212–213.

EL-SHATOURY, H. M. and WHELAN, J. A. (1970). Mineralization in the Gold Hill mining district, Tooele County, Utah. *Utah Geological and Mining Survey, Bulletin* **83**, 37 p.

KEMP, J. F. and BILLINGSLEY, P. (1918) Notes on Gold Hill and vicinity, Tooele County, Utah. *Economic Geology*, **13**, 247–274.

NOLAN, T. B. (1935) The Gold Hill mining district, Utah. *U.S. Geological Survey, Professional Paper* **177**, 172 p.

STAPLES, L. (1935) Austinite, a new arsenate mineral, from Gold Hill, Utah. *American Mineralogist*, **25**, 112–119.

WILLIAMS, S. A. and DE AZEVEDO, J. (1967) Austinite from Gold Hill, Utah. *American Mineralogist*, **52**, 1224–1226.

WILSON, S. R. (1959) Gold Hill, Utah (Clifton District, Tooele County). *Bulletin, Mineralogical Society of Utah*, **9**, 5–12.