ORIGIN OF CERTAIN RICH SILVER ORES NEAR CHLORIDE AND KINGMAN, ARIZONA.

By Edson S. Bastin.

INTRODUCTION.

The mineral deposits of the Cerbat Mountains between Kingman and Chloride, in northwestern Arizona, were described by Schrader[1] in 1909. The writer visited some of the silver mines and prospects of the Cerbat Mountains in 1913, in the course of a study of silver enrichment undertaken by the United States Geological Survey in many mining camps of the western United States. The work of preparing the results for publication has been delayed by the war and other causes.

The practical application of the results lies in the determination of the extent to which the several silver minerals of the ore are secondary or primary and hence to what extent they are likely to play out at moderate depths or to persist below the reach of surface processes of alteration. The results are summarized at the end of the report.

The mines described were reached from Kingman, on the main line of the Atchison, Topeka & Santa Fe Railway, and from Chloride, the terminus of a short railroad line from Kingman.

GENERAL FEATURES OF THE AREA.

The area here considered is arid, with hot summers and mild winters. The annual precipitation is about 5 inches, almost never in the form of snow. The area is for the most part treeless, and its vegetation is of desert types.

The Cerbat Mountains constitute one of the numerous desert ranges of nearly north-south trend that form a characteristic feature of the Great Basin topography. In the parts of the range under discussion the altitude ranges between 4,000 and 6,000 feet.

The Cerbat Mountains consist in the main of pre-Cambrian igneous and metamorphic rocks, and these form the wall rocks at all the mines

[1] Schrader, F. C., Mineral deposits of the Cerbat Range, Black Mountains, and Grand Wash Cliffs, Mohave County, Ariz.: U. S. Geol. Survey Bull. 397, 1909.

visited. Near Kingman and along the western flank of the range occur rhyolite, andesite, and other volcanic rocks of Tertiary age. The familiar desert wash occupies the valleys that flank the mountains.

The ore deposits of the Cerbat Mountains are veins of prevailingly northerly or northwesterly strike and steep dip. All those studied have been worked mainly for their silver content, although minor amounts of gold were present in some. A few veins worked mainly for their base metals were not included in this investigation. The veins are believed by Schrader to have been formed in Tertiary time and to be connected in origin with the granite porphyry of the area.

The bulk of the silver produced in this area in the seventies and eighties came from oxidized ores extending from the surface to depths varying from 50 to 300 feet. Cerargyrite (horn silver) and native silver were the dominant silver minerals of these ores. In the lower part of the oxidized zone ruby silver (proustite) was commonly present, in places so abundantly as to constitute very rich ore. Most of the silver veins were worked to depths of only a few hundred feet and in 1913 had been idle for many years. Few workings could be entered, and samples of the ores were obtained mainly from the dumps or were generously donated by former operators from their personal collections. Specimens of the rich oxidized ores were not available, and these studies therefore relate almost wholly to the sulphide ores.

The reasons for the suspension of mining on most of the silver veins were probably complex. Foremost, perhaps, was the rapid decline in the price of silver between 1885 and 1895. To this was added the fact that the sulphide ores were in general not as rich as the oxidized ores and were more costly to mine. Resumption of mining during the recent period of high silver prices has perhaps been hindered by a fear that the best of the ruby silver ores also owed their richness to enrichment by waters of surface origin, but as indicated on pages 36–39 this belief appears to have no justification in fact.

CHLORINE IN SURFACE WATERS.

The abundant development of silver chloride in the oxidation of the ores of this desert area suggested the testing of the surface waters for chlorine by neutralization with silver nitrate tablets of known weight in the presence of an indicator. Because most of the streams are intermittent only one good opportunity presented itself for such a test. The water of a stream in Tennessee Wash, a quarter of a mile east of the Elkhorn shaft, was collected at a point where it emerged from a dry wash. This water carried about 80 parts per million of chlorine, a large content as contrasted, for example, with the average chlorine content of surface waters close to the New England coast, which is about 6 parts per million.[2] For comparison may be cited the chlorine content of 65 parts per million[3] in descending mine waters in the West End mine (500-foot level) at Tonopah, Nev., and of 127 parts per million[4] in similar waters of the Comstock lode, Nev. Both these Nevada waters occur in regions climatically much like the Chloride-Kingman area.

DETAILED DESCRIPTIONS.

DISTAFF MINE.

The Distaff mine is about three-quarters of a mile east of Chloride. The shaft is on the southwest slope of a small hill, and the shaft collar is about 250 feet above the level of the plain on which the town is situated.

The wall rock is somewhat gneissic granite, and the vein, 2 to 3 feet in width, is nearly vertical and strikes nearly north, about parallel to the foliation in the granite. The vein has been traced for about a mile. The principal surface indications of the presence of a vein are several bands of white quartz 1 to 3 inches in width. When this quartz from the surface is broken it is occasionally found to inclose pyrite, but commonly small limonite-stained cavities mark the original position of the pyrite grains; in addition there is staining with limonite along fractures traversing the vein and the granite. There is no heavily iron-stained gossan or "iron hat."

The Distaff shaft was reported to be 265 feet deep, with short levels at 100, 200, and 250 feet. At the time of visit the mine was idle and the water stood about 220 feet below the collar of the shaft—that is, close to the level of the flats bordering the hill on which the mine is situated.

All ore above the 250-foot level is reported to have shown oxidation. Horn silver (cerargyrite) was the principal silver mineral from the surface to depths of 100 to 150 feet. Native silver was most abundant somewhat deeper; some occurred on the 100-foot level, but most of it between the 200 and 250 foot levels. Schrader[5] mentions the occurrence of slabs of native silver many pounds in weight. A specimen in the collection of Jack Lane at Kingman showed a slablike mass of native silver one-eighth of an inch thick along a fracture in sulphide ore. Wire silver occurred in small vugs in this ore.

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[2] Jackson, D. D., The normal distribution of chlorine in the natural waters of New York and New England: U. S. Geol. Survey Water-Supply Paper 144, 1905.

[3] Bastin, E. S., and Laney, F. B., Genesis of the ores at Tonopah, Nev.: U. S. Geol. Survey Prof. Paper 104, p. 29, 1918.

[4] Bastin, E. S., Bonanza ores of the Comstock lode, Virginia City, Nev.: U. S. Geol. Survey Bull. 735, p. 60, 1922.

[5] Op. cit., p. 60.

In ore from the bins argentite was noted in two associations—(1) in scattered thin fungus-like patches along fractures in unoxidized ore, and (2) intimately associated with proustite and pearceite in quartz-lined vugs in unoxidized ore; some of this argentite is well crystallized. In one specimen from the 250-foot level small octahedral crystals of argentite show quartz crystals coating them or implanted on them. Minute amounts of chalcopyrite and sphalerite are intercrystallized in places with this argentite, and all three minerals should apparently be interpreted as primary (hypogene), whereas the argentite occurring in fungus-like patches along fractures is probably secondary (supergene).

Proustite was noted in ore from the 250-foot level in irregular masses as large as the end of a man's thumb, in places well crystallized. It is intimately intercrystallized with quartz, sphalerite, and pyrite and has every appearance of being contemporary with them and primary.

A small specimen from the ore bins shows a very fine intergrowth of proustite, pearceite, and chalcopyrite bordering an association of base-metal sulphides, mainly sphalerite and pyrite. The silver minerals and chalcopyrite were clearly the latest to crystallize; they interlock, however, with the base-metal sulphides and are believed to be late primary (hypogene). The primary origin of the proustite is confirmed by the microscopic study of a specimen from the ore bins. The main portion of a 3-inch veinlet shown by this specimen is a granular aggregate of galena, sphalerite, and pyrite; but next one wall is a quarter to half an inch of gray quartz carrying scattered grains or crystals of chalcopyrite, proustite, and pearceite. In the polished specimen some areas of galena lie within 1 millimeter of areas of pure proustite, but tarnishing of the galena with hydrogen peroxide shows that it has not been replaced even incipiently by proustite or other minerals. In places proustite is intercrystallized with chalcopyrite very intimately. The contacts between these two minerals are crystal faces and not the ragged contacts usually developed by the replacement of one metallic mineral by another. Furthermore, the chalcopyrite areas in one place show a radiating arrangement. Neither mineral forms veinlets in the other. The two minerals are interpreted as contemporary and primary (hypogene).

To summarize the evidence obtained at this mine bearing on the origin of the rich silver ores: The zone of oxidation is 200 to 250 feet deep. Within this zone oxidation of sulphides has been only partial, and no heavily iron-stained gossan has been developed. From the surface to depths of 100 to 150 feet the dominant silver mineral appears to have been horn silver (cerargyrite). This mineral, here as everywhere else, is a product of weathering. Lower down, from depths of 100 to 250 feet, native silver was abundant. It occurred as plates in fractures and as wires and teeth in vugs. Its disappearance in depth shows that it also was a product of near-surface oxidation. Some argentite occurring along fractures is also probably a result of alteration near the surface.

Primary (hypogene) minerals noted are quartz, pyrite, sphalerite, galena, chalcopyrite, proustite, pearceite, and probably argentite. Evidence of the primary origin of the silver minerals is found in the entire absence of replacement phenomena in ores in which these minerals are abundant. The silver minerals can not reasonably be regarded as having completely replaced older minerals, inasmuch as galena adjacent to them is wholly unreplaced. Galena is one of the minerals most readily replaced by silver minerals in the process of downward enrichment. Primary origin is also indicated by the intimate contemporaneous intergrowth of proustite with chalcopyrite, a mineral formed only rarely in processes of downward enrichment.

EMPIRE MINE.

The Empire mine, about 2 miles north-northeast of Chloride, was not visited by the writer, but a specimen of rich silver ore from a depth of 150 feet on the vein was presented by the owner, Mr. E. F. Thompson, and was studied in detail.

The specimen is unoxidized and carries pyrite, arsenopyrite, quartz, sphalerite, galena, tennantite, and proustite. It shows the entire width of a 1½-inch vein. In the median portion of this vein tennantite, proustite, and quartz are the dominant minerals, but there is complete gradation from the silver-rich central portions to the border portions carrying mainly the base-metal sulphides.

Microscopic study shows that the proustite and tennantite are commonly intergrown and that the proustite-tennantite contact shows the crystal outlines characteristic of tennantite, as is shown in Figure 2. The proustite can not therefore have replaced tennantite, nor is there any evidence of replacement of any sort in the polished specimens. The galena when tarnished with hydrogen peroxide shows absolutely no replacement by other minerals. Evidence of the primary (hypogene) character of the proustite in this specimen appears to be conclusive.

GEORGE WASHINGTON CLAIMS.

The George Washington group of claims, in Mineral Park, about 3 miles southeast of Chloride, was in 1913 being developed through a tunnel then 300 feet long. The vein exposed in this tunnel was nearly vertical and had a strike of N. 40° W. Widths up to 3½ feet were noted. The dominant vein minerals are quartz and pyrite, but silver minerals are present in fair abundance in about 1 foot of the vein thickness next the southwest wall. The vein walls, which are granite, show alteration of the feldspars and carry disseminated small crystals of pyrite.

The workings are all shallow, even the face of the tunnel attaining a vertical depth of only about 80 feet below the surface. Even at these slight depths, however, much of the ore, because of its dense, fine-grained texture, is unoxidized. Oxidation is limited to the immediate vicinity of fractures traversing the ore and commonly does not extend more than 1 or 2 centimeters from such fractures.

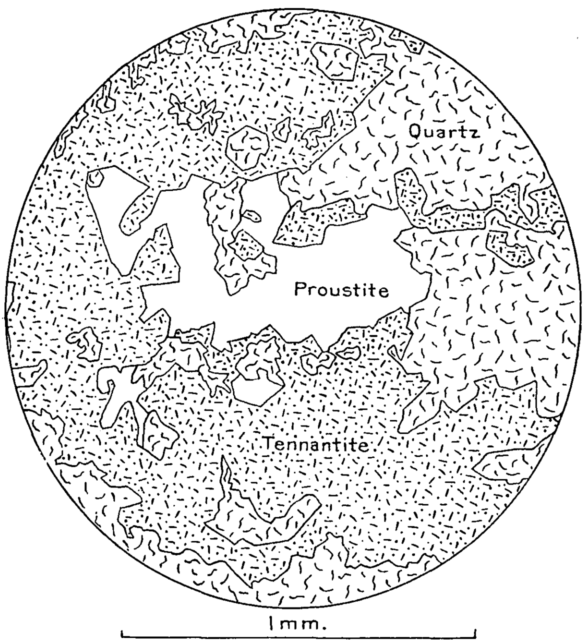

FIGURE 2.—Primary (hypogene) intergrowth of proustite with tennantite and quartz, Empire No. 2 mine, Chloride, Ariz.

Ore obtained near the face of the main tunnel is reported by the operators to have assayed $175 to the ton, mainly in silver. Assays of $240 a ton were reported from lesser depths on the vein.

Three specimens of the richest ore were collected for detailed study; one came from a depth of 56 feet and the others from depths of about 80 feet. In most respects these samples are similar. All are fine-grained grayish aggregates of quartz carrying scattered sulphides in grains that rarely exceed 1 millimeter in diameter. Oxidation is confined to fractures and to the 1 or 2 centimeters of ore adjacent to them. Vugs are rare in the unoxidized ore, but a few as much as 5 millimeters across were noted.

The primary ore minerals identified, in the approximate order of abundance, are quartz, pyrite, proustite, chalcopyrite, arsenopyrite, polybasite, and sphalerite. The secondary minerals noted are native silver and covellite.

Evidence of the primary (hypogene) origin of the silver minerals, proustite and polybasite, though negative is convincing. It consists in the absence of any suggestion that these silver minerals have replaced older minerals. The relatively large unmixed areas of proustite or polybastite must either be primary or the results of complete replacement of older minerals. In places, however, they occur adjacent to chalcopyrite that has been peripherally replaced by covellite. Complete replacement of some older mineral by proustite and

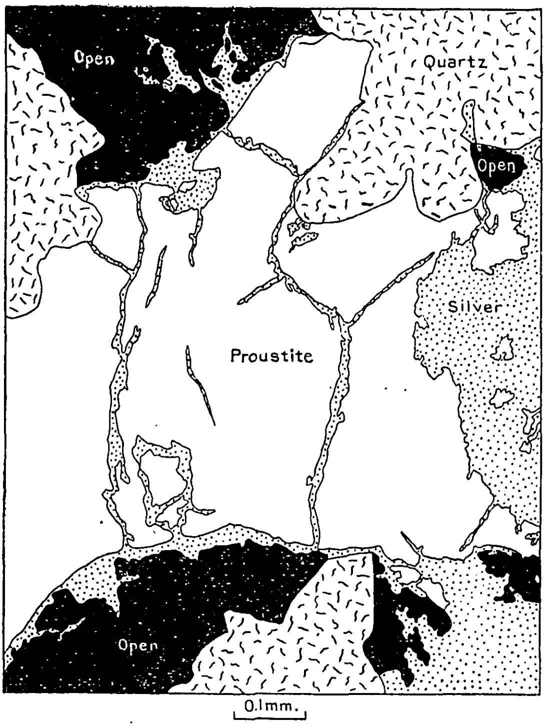

FIGURE 3.—Replacement of proustite by native silver, George Washington claim, Mineral Park, Ariz.

polybasite is hardly compatible with the incipient replacement of chalcopyrite by covellite close by; it is much more probable that the sulphosalts of silver are a primary deposit from the same solutions that deposited pyrite, chalcopyrite, quartz, and the other undoubtedly primary minerals.

Added indication that the proustite and polybasite are primary is found in their replacement near small open spaces in the ore by native silver, after the fashion shown in Figure 3. These replacement deposits are confined to porous and somewhat oxidized portions of the ore and are clearly the result of alteration by waters of surface origin. In degree the replacement of proustite by silver is compatible with that of chalcopyrite by covellite in the same specimen, and both are attributed to descending oxidizing solutions.

The silver content in the specimens examined is therefore in part primary, in proustite and polybasite, and in part secondary, as native silver. The primary silver content is high—sufficient in itself to produce a rich silver ore. Such abundance of primary sulphosalts of silver in ores from depths of only 50 to 80 feet is unusual but is due to the dense, highly quartzose, fine-grained nature of the ore, which narrowly limits oxidation and enrichment to the immediate vicinity of fractures.

RURAL AND BUCKEYE MINES.

The Rural and Buckeye mines are about 1½ miles northeast of Mineral Park and are a few hundred feet apart on the same vein. The wall rocks are granite gneiss and schist of pre-Cambrian age, intruded by dikes of much younger granite porphyry. The vein is nearly vertical and from 2 to 8 feet wide. All workings were inaccessible in 1913, the mines having been idle for many years. Ground water stood at a depth of about 50 feet below the collar in the Rural shaft.

Ores seen on the dumps showed pyrite, arsenopyrite, and quartz as the dominant minerals, with chalcopyrite, sphalerite, and galena subordinate. No silver minerals were seen on the dump, but native silver is abundant in specimens from this mine seen at Kingman. One specimen in the collection of E. F. Thompson shows a mass of nearly solid native silver 1½ inches across.

The following records show the tenor of the richer ores:

Tenor of smelting ores shipped from Rural and Buckeye mines in 1886–87.

Net weight (pounds).	Silver (ounces per ton).	Gold (ounces per ton).	Net weight (pounds).	Silver (ounces per ton).	Gold (ounces per ton).
9,033	722	6.13	29,862	266	5.85
8,024	440	2.66	21,106	249	4.00
13,089	200	2.55	72,680	480	8.25
28,376	479	9.46	10,212	442	8.16
23,575	119	4.90	27,142	172	4.70
30,999	196	6.05	87	4,467	4.80
9,898	109	5.12	167	4,024	5.35
20,314	73	7.29			

QUEEN BEE MINE.

The Queen Bee mine is in the northwestern part of the Mineral Park district, close to the cut-off trail to Chloride. The mine is owned by James B. Uncopher, of Mineral Park, to whom the writer is indebted for valuable information and specimens. The property when visited in 1913 had been idle for many years, and none of the workings could be entered. The main shaft, 225 feet deep, was filled with water within 60 feet of the surface.

The wall rock at the mine is mica schist of pre-Cambrian age. The ore is said to be somewhat oxidized to a depth of about 70 feet. The following minerals were noted in specimens from the mine dump and from Mr. Uncopher's collections:

Primary (hypogene): Quartz, pyrite, arsenopyrite, manganiferous siderite, calcite (white), sphalerite, galena, tennantite, chalcopyrite, proustite, pearceite (probably primary), argentite (probably in part primary).

Secondary (supergene): Argentite, native silver, cerargyrite (reported by Schrader[6]).

The proustite abundant in many of the ores from this mine appears clearly to be a primary (hypogene) mineral deposited from the same mineralizing solutions that deposited the common base-metal sulphides; the evidence for this conclusion is given below.

In one specimen studied a piece of proustite three-fourths by three-eighths by one-half inch in dimensions was intercrystallized with quartz and ferruginous calcite, all three minerals interlocking and having apparently been deposited contemporaneously. In one specimen in Mr. Uncopher's collection proustite in vugs is wholly inclosed by calcite. Other well-formed crystals of proustite are coated with calcite.

A particularly rich specimen of unoxidized ore donated by Mr. Uncopher shows the entire width of a 2½-inch veinlet carrying abundant proustite. Microscopic examination shows that in general the proustite has not replaced other ore minerals. The galena when tarnished brown with hydrogen peroxide (which does not tarnish the silver minerals) usually shows no evidences of replacement. Figure 4 shows a contact between galena and an intergrowth of proustite and sphalerite. The galena can not have been replaced by proustite alone, because there are no sphalerite areas in the galena corresponding to those so abundant in the proustite. Simultaneous replacement of galena by an intergrowth of proustite and sphalerite is highly improbable and if it occurred would probably be a part of the process of primary (hypogene) mineralization, for the deposition of sphalerite in the downward enrichment of ore deposits is extremely rare. The proustite is interpreted as hypogene and broadly contemporaneous with galena and sphalerite.

Additional evidence that most of the proustite is not the result of a replacement of galena is found in the fact that in many places minute inclusions of chalcopyrite are abundant in the proustite but are absent from the adjacent galena.

[6] Op. cit., p. 86.

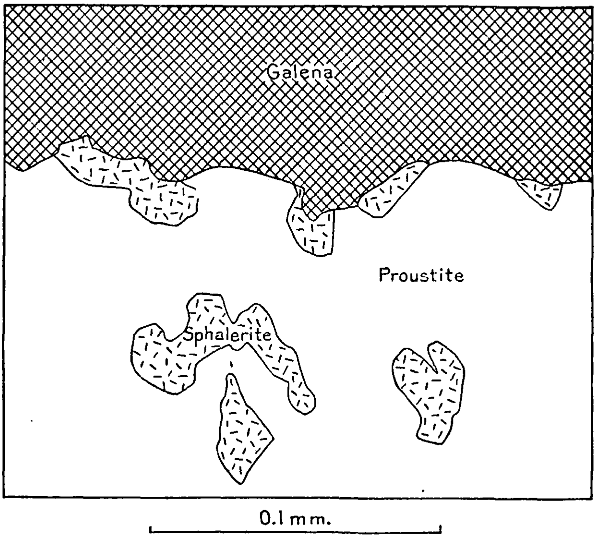

FIGURE 4.—Contact relations of proustite and sphalerite with galena, Queen Bee mine, Mineral Park, Ariz.

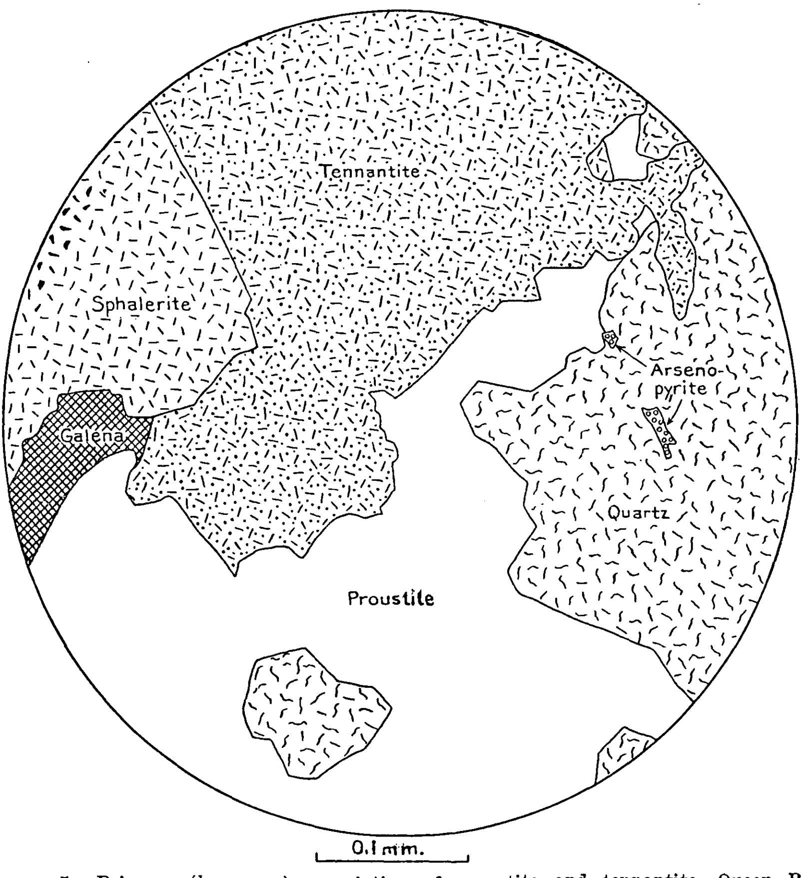

FIGURE 5.—Primary (hypogene) association of proustite and tennantite, Queen Bee mine, Mineral Park, Ariz.

Throughout the mine the proustite is intimately intergrown with tennantite and for this reason appears to the unaided eye somewhat darker than most proustite. It is clear that the two sulpharsenides—of silver and of copper, respectively—crystallized at essentially the same time. When their intergrowths are examined in detail it is found that the tennantite shows its own characteristic crystal faces against proustite, as illustrated in Figure 5. If the proustite had replaced tennantite, crystal faces of the tennantite should have been destroyed. The proustite is therefore interpreted as a primary (hypogene) deposit.

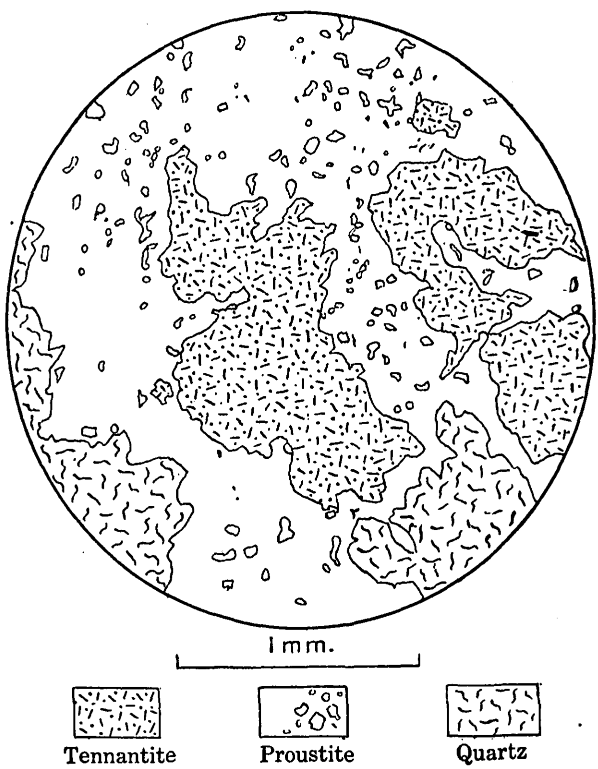

FIGURE 6.—Proustite crowded with inclusions of sphalerite and chalcopyrite and bordering tennantite essentially free from such inclusions, Queen Bee mine, Mineral Park, Ariz.

Additional evidence that proustite has not replaced tennantite is furnished by the fact that many areas of tennantite carry few and small inclusions of sphalerite, whereas immediately adjacent areas of proustite carry numerous and relatively large sphalerite inclusions, as is shown in Figure 6.

The presence of inclusions of sphalerite and chalcopyrite in both proustite and tennantite is itself an indication of the primary (hypogene) origin of the proustite, as chalcopyrite, sphalerite, and tennantite are rarely products of enrichment.

In a few places inclusions of proustite occur in galena in the manner illustrated in Figure 7. The inclusions have straight crystal outlines, but these bear no definite relation to the crystallographic directions of the inclosing galena. Replacement of galena by a silver mineral is usually controlled by the galena cleavages or by its contact planes with other minerals; absence of such control indicates that replacement has probably not been operative. The proustite inclusions are interpreted as primary (hypogene).

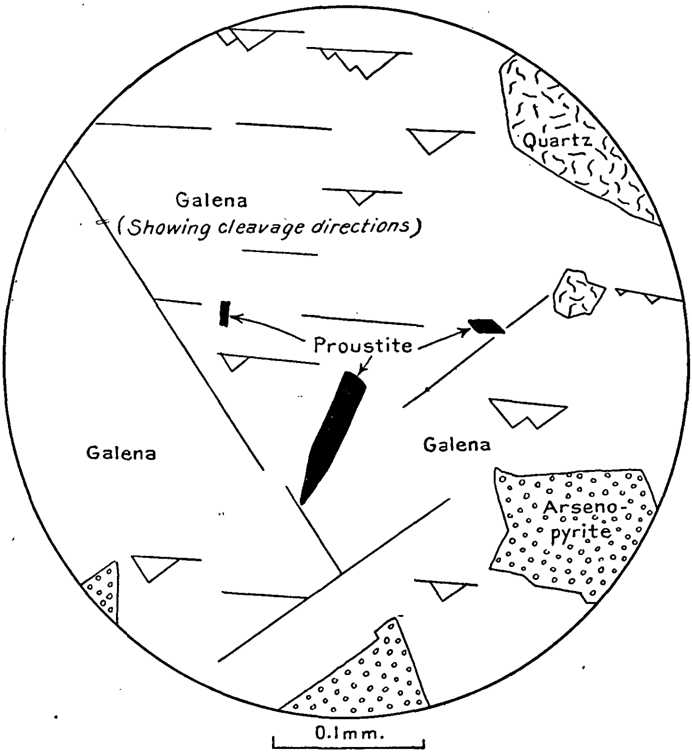

FIGURE 7.—Inclusions of primary proustite in galena, Queen Bee mine, Mineral Park, Ariz.

A possible partial exception to the rule that the proustite has not replaced other minerals is illustrated in Figure 8. The minute veinlets of proustite shown in this figure parallel cleavage directions in the galena and are interpreted as formed mainly by fracture filling, combined possibly with slight replacement. These veinlets of proustite are rare and are interpreted as of late primary (hypogene) origin rather than products of downward (supergene) enrichment.

Argentite occurs here and there. A specimen in Mr. Uncopher's collection shows calcite, argentite, and wires of silver in vugs. One octahedron of argentite is a quarter of an inch in diameter, and in places argentite is so intimately intercrystallized with calcite as to leave little doubt that it is primary (hypogene). In other specimens argentite forms patches or fungus-like growths along fractures cutting primary sulphides. Such argentite is very probably secondary (supergene).

Pearceite is also of local occurrence. One specimen shows tabular hexagonal crystals of pearceite in vugs. On some of these small

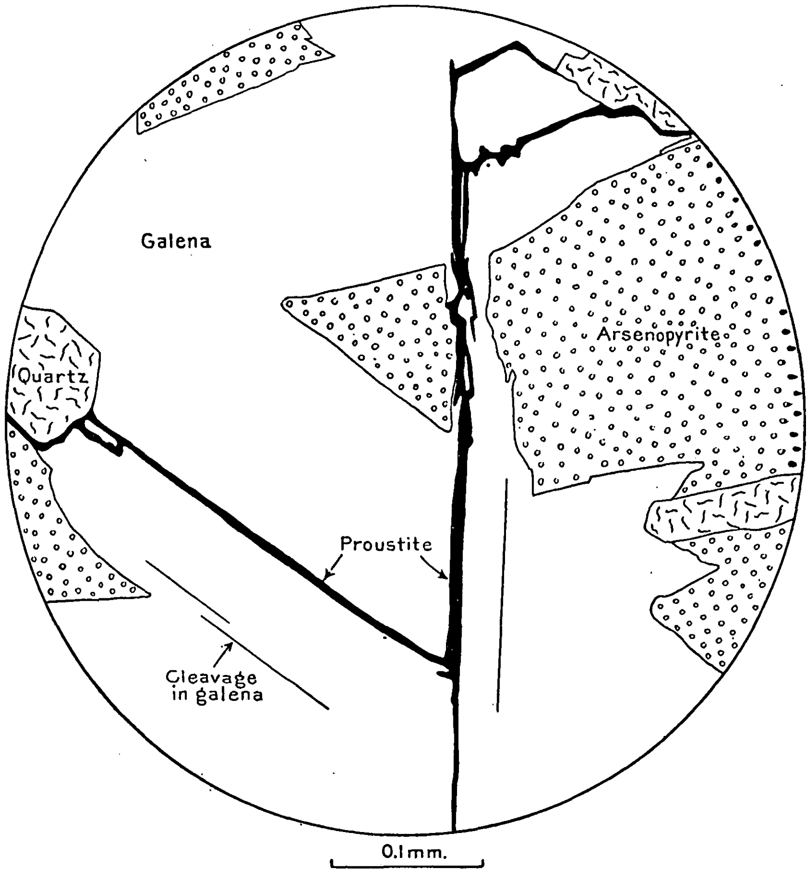

FIGURE 8.—Veinlets of proustite following cleavage planes in galena and contacts between galena and quartz, Queen Bee mine, Mineral Park, Ariz.

crystals of chalcopyrite have later been deposited. As chalcopyrite is rarely a product of downward enrichment, this pearceite is probably though not demonstrably primary.

Native silver is clearly secondary (supergene). It occurs as wires and teeth attached to argentite, proustite, and pearceite in vugs and is manifestly formed by their alteration. Native silver also occurs in matted masses of wires and teeth along fractures in sulphide ore.

Here it is associated with remnants of argentite, from which it was probably derived. In a number of places the silver is in contact with unetched crystals of calcite or of manganiferous siderite, an association which indicates that it was not deposited from solutions that were notably acid.

KAY CLAIM.

The Kay claim is about half a mile northwest of the settlement of Mineral Park. A steeply dipping vein striking nearly due east is developed by a shallow shaft and a short tunnel, neither of which was accessible in 1913. The shaft is near the bottom of a small gulch, and ground water stood only 25 feet below its collar. The vein traverses medium-grained granite. Proustite is reported to have occurred within a few feet of the surface in this vein. Specimens of ores were collected from the dump, and two were obtained from Mrs. Kay.

The minerals recognized in the ore, in the approximate order of abundance, are as follows:

Primary (hypogene): Quartz, pyrite, sphalerite, tennantite, pearceite, proustite, galena, chalcopyrite.

Secondary (supergene): Chalcocite, native silver, copper pitch ore, malachite.

Of the primary minerals quartz, pyrite, sphalerite, and galena were the oldest; after their deposition some brecciation occurred, and additional quartz and chalcopyrite, tennantite, pearceite, and proustite were deposited in the fractures so produced. The pearceite and proustite are most abundant and occur in the largest masses near small vugs. The later quartz is white; the earlier is dark gray.

In the granite of the wall disseminated grains of pyrite are abundant.

Evidence that the silver minerals pearceite and proustite are primary is found (1) in the absence of any indication that they have replaced earlier minerals and (2) in the intimate penetration of tennantite by crystals of these silver minerals, as sketched in Figure 9. In this figure proustite and pearceite are not differentiated by separate symbols, but both show similar relations, with characteristically sharp crystal outlines against tennantite. The narrow lathlike white areas in the tennantite of this figure are mostly pearceite; the larger white areas are mostly proustite. There is no evidence that the proustite of this specimen replaces either tennantite or pearceite.

In some vugs in the same specimen from which Figure 9 was sketched wires and teeth of native silver have been developed by the alteration of proustite and pearceite.

KING CLAIM.

The King claim, at Mineral Park, was located to develop a vein striking nearly east and dipping steeply south. Prior to 1913 two shafts, 35 and 50 feet deep, had been sunk on the vein, and two short tunnels had been run.

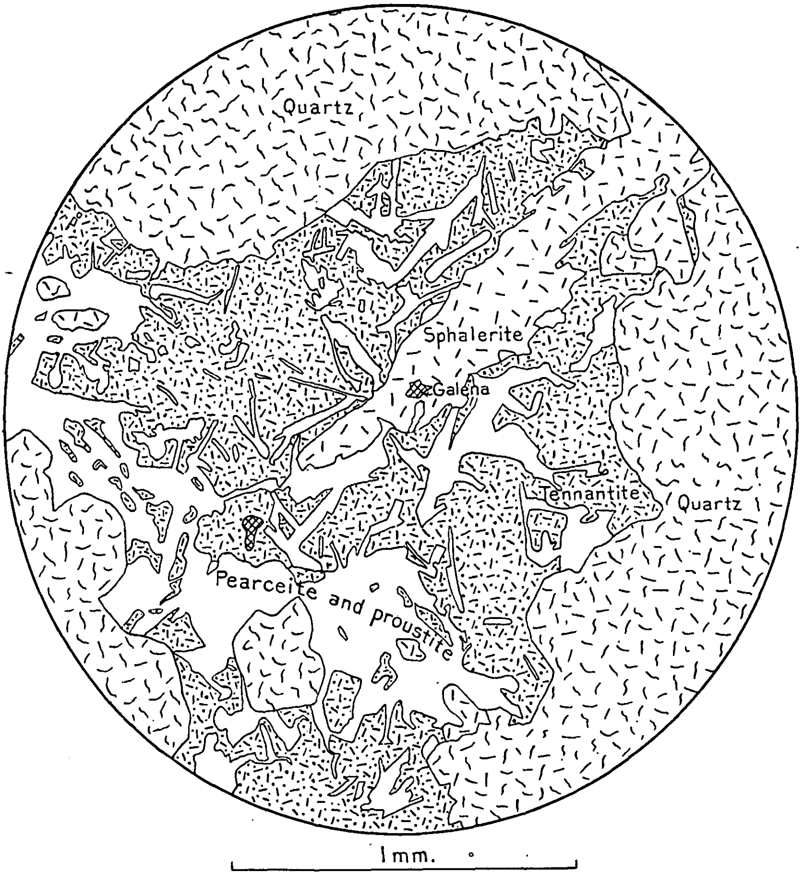

FIGURE 9.—Primary intergrowth of proustite and pearceite with tennantite, Kay mine, Mineral Park, Ariz.

The vein as exposed in the tunnels is 6 inches to 2 feet wide and shows gray quartz carrying scattered pyrite. Ore seen on the dump carried the following minerals:

Primary (hypogene): Quartz, pyrite, sphalerite, galena, chalcopyrite.
Secondary (supergene): Covellite, chalcocite, native copper.

A specimen from the mine dump when polished showed peripheral replacement of chalcopyrite and sphalerite by covellite. Ore from a depth of 12 feet shows dendritic growths of native copper along small fractures in flinty-looking quartz. Another specimen obtained within a few feet of the surface at this mine shows chalcocite developed along and close to small fractures in granite. The chalcocite appears to replace pyrite, remnants of which remain within some of the chalcocite. In places native copper in thin platelike masses is associated with the chalcocite and appears to be an alteration product from it.

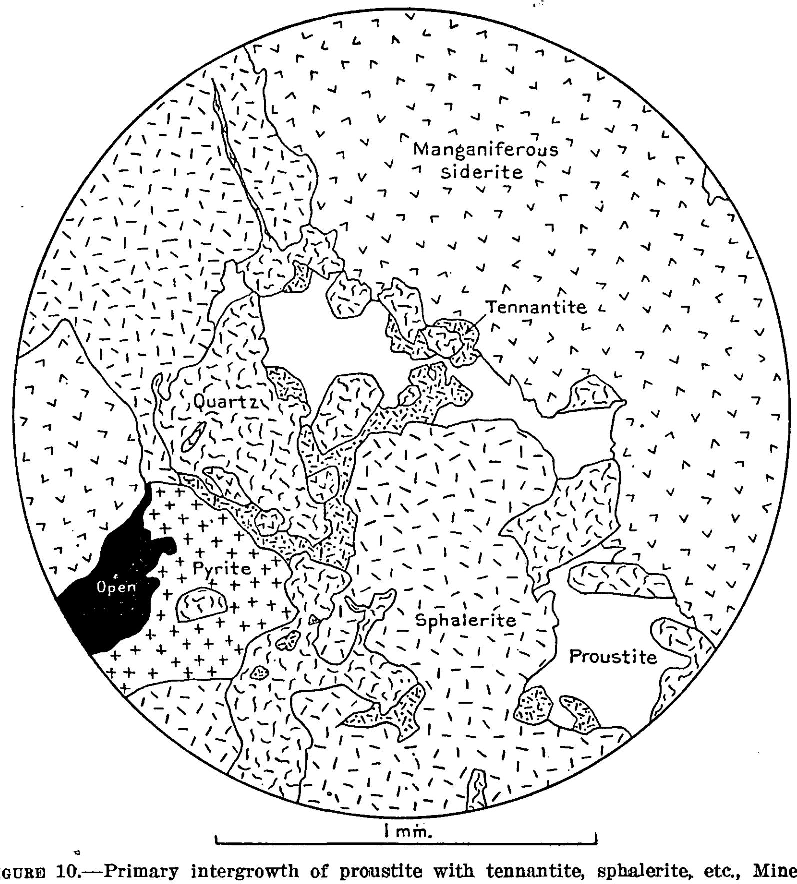

FIGURE 10.—Primary intergrowth of proustite with tennantite, sphalerite, etc., Mineral Park, Ariz.

UNSPECIFIED ORES FROM MINERAL PARK.

A very fine specimen of rich proustite ore from Mineral Park was presented by Mrs. Kay, of that place, but she was unable to specify more closely the exact source of the material. The minerals recognized in this ore, all primary (hypogene), are quartz, pyrite, galena, sphalerite, manganiferous siderite, tennantite, and proustite.

All these minerals appear to have been deposited during a single period of primary mineralization, but pyrite appears to have been the first mineral deposited, and some fracturing of it occurred prior to the deposition of the other ore minerals. As in most of the ores of Mineral Park the proustite is clearly associated with tennantite, a relation which suggests that it may replace tennantite. Close examination, however, shows that the tennantite nearly everywhere has sharp crystal faces next to proustite, as shown in Figure 10 and on a larger scale in Figure 11. The proustite can not have replaced tennantite and is interpreted as primary (hypogene). The galena when tarnished brown with hydrogen peroxide, a reagent that does not tarnish silver minerals, shows no evidence of replacement by other minerals to more than the most incipient degree. The proustite is never found along galena contacts or cleavages.

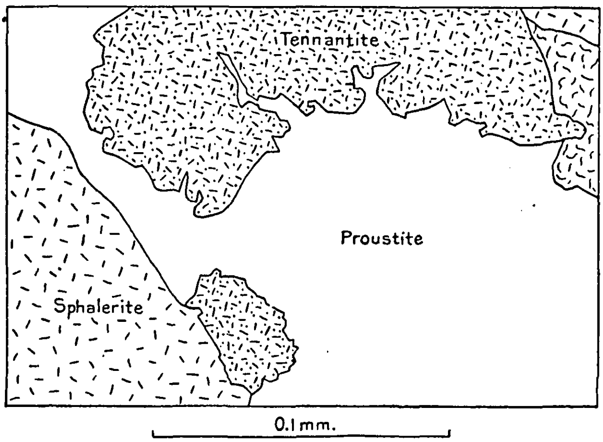

FIGURE 11.—Primary association of proustite and tennantite, Mineral Park, Ariz.

MINES NEAR STOCKTON HILL.

The mining camp of Stockton Hill is about 9 miles north-northwest of Kingman, near the south end of the Cerbat Range and on its east slope. It lies within the area of pre-Cambrian gneiss and schist. In 1913 all the mines had been idle for many years, but some old mine dumps were examined. According to Schrader[7] the district was noted for its rich minerals—cerargyrite, native silver, argentite, and proustite—found in the upper portions of its mines. The water level stood commonly at a depth of about 100 feet.

At the Cupel mine the dump is very old, and the workings are caved, operations having ceased in 1891. The output of the mine is variously estimated at $500,000 to $1,500,000, chiefly in silver. According to Schrader[8] some of the ruby silver ore averaged 3,000

[7] Op. cit., p. 108.

[8] Op. cit., p. 111.

ounces of silver to the ton. Cerargyrite and argentite were found in some of the ore.

Specimens collected by the writer from the old dumps and one especially rich specimen of unoxidized ore presented by Mr. H. H. Watkins, of Kingman, showed the following minerals:

Primary (hypogene): Quartz (usually gray and fine grained), pyrite, arsenopyrite, galena, sphalerite, siderite, chalcopyrite, tennantite, proustite, pearceite.

Secondary (supergene): Proustite and argentite, both very rare.

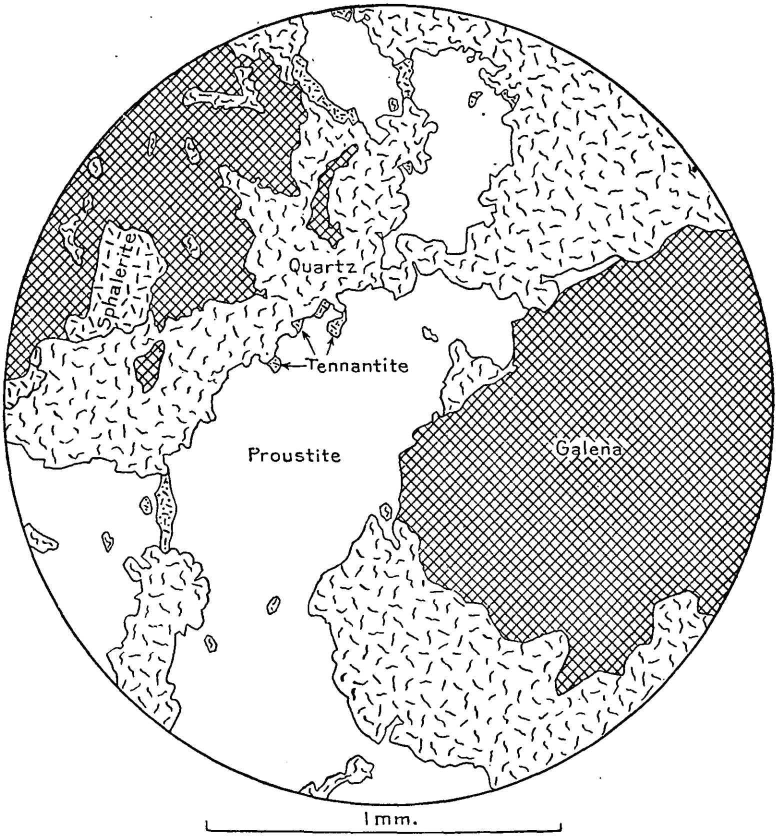

FIGURE 12.—Primary proustite in association with galena, tennantite, and quartz, Cupel mine, Stockton Hill, Ariz.

In the specimen presented by Mr. Watkins proustite constitutes fully half of the volume of the ore throughout an ill-defined band $1\frac{1}{2}$ inches wide. Microscopic study of this specimen fails to disclose any evidence that the proustite either fills fractures in older minerals or has replaced them. The mineral commonly most susceptible to replacement by silver minerals in downward enrichment is galena. In this ore, however, there is no indication that galena has been replaced by proustite. On the contrary, the two minerals occur side by side in areas of comparable size, as shown in Figure 12.

Tennantite is present in small amounts and here, as in the ores of Mineral Park and Chloride, is particularly intimately associated with proustite, usually forming small patches within the proustite. These patches of tennantite are not, however, replacement remnants, because they are as likely to occur at the border of proustite areas as in their interior and because they commonly show crystal outlines characteristic of tennantite. If tennantite had been replaced by proustite the original crystal outlines would have been destroyed. Added evidence that proustite has not replaced tennantite is found in the localization of some tennantite crystals along the contact between two crystals of proustite; such a relation is not explainable on the assumption that proustite has replaced tennantite but is readily understood if the two minerals crystallized at about the same time. In places proustite carries abundant inclusions of quartz and of chalcopyrite, both of which show crystal outlines.

Though nearly all the proustite in the ores of the Cupel mine is interpreted as primary (hypogene), one specimen of partly oxidized ore from the dump showed very thin films of argentite and of proustite, with dendritic outlines, along a small fracture. These minerals are very probably secondary (supergene), but they are quantitatively of almost negligible importance. This mode of occurrence of proustite is in marked contrast to that of the proustite which is intercrystallized with the primary ore minerals.

SUMMARY AND CONCLUSIONS.

The minerals noted in the silver ores of the Cerbat Mountains, between Kingman and Chloride, Ariz., are listed below. Those marked with an asterisk (*) are rare under the conditions indicated.

Oxidation products: Cerargyrite (horn silver), native silver, *copper pitch ore, *malachite, *native copper.

Products of downward sulphide enrichment: Argentite, *proustite (very rare), *covellite, *chalcocite.

Primary (hypogene) minerals: Quartz (usually gray and finely crystalline), manganiferous siderite, *calcite (white), pyrite, arsenopyrite, sphalerite, galena, chalcopyrite, tennantite, *argentite, proustite, pearceite, *polybasite.

It is noteworthy that the ores are prevailingly arsenical, with four arsenic minerals, arsenopyrite, tennantite, proustite, and pearceite. Only in one specimen were small amounts of an antimony mineral (polybasite) noted.

The unoxidized ores are in general fine grained and compact. Vugs are few and small. Because of this compactness oxidation above the ground-water level is very commonly incomplete, being confined to the vicinity of fractures that traverse the ore. Ore specimens several inches across essentially unoxidized may in places be found within a few feet of the outcrop. Heavily limonite-stained gossans or "iron caps" are not characteristic.

The ground-water level stood at depths of 25 to 250 feet in the mines studied. A test of stream water near Chloride showed the high chlorine content (80 parts per million) usual in desert regions.

According to Schrader the dominant silver mineral in the ores found close to the surface was usually cerargyrite. No specimens of these ores were obtainable for study. In this area, as elsewhere, cerargyrite is confined to the oxidized zone.

Native silver appears to have been most abundant at slightly greater depths than those at which cerargyrite was dominant—that is, close to the surface native silver is dissolved and partly reprecipitated as cerargyrite by chloride-bearing waters. Native silver appears to have been confined mainly to the oxidized zone in the vicinity of vugs and fractures. A little may have been deposited a short distance below the ground-water level. Some of the silver has replaced proustite, as shown in Figure 3. It was also noted replacing polybasite, pearceite, and argentite. In places the silver forms tapering and curling " teeth " attached to these minerals and obviously formed by their alteration. Some such silver " teeth " are in contact with older crystals of calcite that are unetched, indicating that the silver was not deposited from acid solutions. The manganiferous siderite and calcite present in most of the veins would insure the prompt neutralization of acidity developed in solutions descending through the oxidized zone. Schrader [9] mentions the occurrence in the Distaff mine of slabs of native silver many pounds in weight.

Chalcocite is not abundant, but it was noted along fractures in granite near the King vein, in Mineral Park. It contained remnants of pyrite and was evidently formed by the replacement of pyrite. In places a little native copper is associated with this chalcocite and probably represents a residuum after the oxidation of the sulphur of the chalcocite.

Argentite, though not abundant, occurs in two contrasting ways—in scattered, thin fungus-like scales or patches along fractures in unoxidized or only slightly oxidized ore and in small but well-formed octahedral crystals occurring side by side with crystals of proustite and pearceite in small vugs in unoxidized ore. Some of this argentite is intercrystallized with small amounts of chalcopyrite and sphalerite, and on some of the argentite small crystals of later quartz are implanted. It is probable that the argentite occurring in octahedral crystals is primary (hypogene); that occurring in scales or patches is very probably supergene, a product of downward enrichment.

Downward (supergene) sulphide enrichment, or the deposition of sulphides below the ground-water level by solutions descending from

[9] Op. cit., p. 60.

the oxidized zone, appears to have been of nearly negligible importance in these ores. The supposedly supergene argentite mentioned above is present in only small amounts. In one specimen of ore from the Cupel mine, at Stockton Hill, very thin films of argentite and of proustite, dendritic in form, occurring along small fractures cutting primary ore, are believed to be secondary (supergene). Quantitatively such occurrences are negligible, and most of the proustite, for reasons enumerated below, is believed to be primary (hypogene). Very slight downward enrichment in copper was shown in some specimens by peripheral replacement of pyrite by chalcocite and of chalcopyrite and sphalerite by covellite.

Proustite, or light ruby silver, is the only abundant silver mineral of the unoxidized ore, although pearceite, polybasite, and argentite also occur. In some specimens studied masses 1 or 2 inches across are mainly proustite, and masses of pure proustite as large as the end of a man's thumb were noted. Such proustite is believed to be primary (hypogene), and the evidence for this opinion will next be summarized.

1. Masses of proustite as large as the end of a thumb and with well-developed crystal faces were noted intercrystallized with the undoubtedly primary minerals quartz, sphalerite, pyrite, and ferruginous calcite—all having apparently been deposited at about the same time.

2. In one specimen studied small areas of proustite are wholly inclosed by calcite that forms the lining of vugs. Elsewhere well-formed crystals of proustite are coated with calcite. There is no evidence that this calcite has been deposited by descending (supergene) solutions.

3. Relatively large unmixed areas of proustite in a granular aggregate of ore minerals must either be primary (hypogene) or the product of complete replacement of older minerals. In places, however, such proustite areas are adjacent to chalcopyrite and sphalerite that show only incipient peripheral replacement by covellite. Such incipient replacement by covellite would hardly be expected to occur side by side with complete replacement of relatively large masses of some hypothetical mineral by proustite. It is more probable that the proustite was formed not by replacement but by primary crystallization.

4. In all the ores studied proustite is more intimately associated with tennantite than with any other mineral. Proustite is the sulpharsenide of silver; tennantite is the sulpharsenide of copper. The proustite has not, however, replaced tennantite, for the tennantite nearly everywhere has its own characteristic crystal outlines, as shown in Figures 2, 5, 9, and 10. Added evidence that proustite has not replaced tennantite is furnished by the fact that certain

areas of tennantite carry only scattered small inclusions of sphalerite, whereas bordering areas of proustite are crowded with relatively large sphalerite inclusions.

5. The presence of inclusions of sphalerite and chalcopyrite in both tennantite and proustite is itself suggestive of a primary origin for the proustite, because sphalerite, chalcopyrite, and tennantite are exceedingly rare as products of secondary (supergene) enrichment.

6. Galena, fairly abundant in these ores, is a mineral that is usually particularly susceptible to replacement by silver minerals in the processes of downward enrichment. Where galena and proustite are found together in these ores they commonly occur side by side without evidence of replacement. Figure 4 shows an association of sphalerite and proustite in contact with galena. The smooth galena contacts extending from proustite to sphalerite indicate either simultaneous replacement of galena by proustite and sphalerite or an absence of replacement, the three minerals all being essentially of the same age and primary. Simultaneous replacement of galena by an intergrowth of proustite and sphalerite is highly improbable and if it occurred would almost certainly be a part of the process of primary (hypogene) mineralization, for the deposition of sphalerite in the downward enrichment of ore deposits is exceedingly rare. In Figure 7 are shown small areas of proustite inclosed by galena. If these were formed by replacement of the galena, they should be related to the galena cleavages, but they show no such relation and are interpreted as inclusions of primary proustite in galena. A single possible exception to the general rule that proustite has not replaced galena is illustrated in Figure 8. This figure was drawn from a specimen which in most places shows the relations illustrated in Figures 4 and 7. The veinlets are interpreted as fillings of a fracture in galena by primary proustite, possibly combined with very slight primary replacement of the galena by the proustite. Such relations are very exceptional. Additional evidence that proustite has not replaced galena is found in the common presence of many small inclusions of sphalerite and chalcopyrite in proustite and the absence of such inclusions from adjacent galena. It can not be assumed that the proustite has replaced galena unless sphalerite and chalcopyrite have replaced it simultaneously.

7. In some ores proustite and pearceite intergrown with tennantite possess regular crystal outlines, as shown in Figure 9. The narrow white areas in this figure are pearceite showing its own characteristic tabular crystal forms (lath-shaped in cross section); the larger white areas are mostly pearceite. Sulphides occasionally develop their own crystal form in replacing other sulphides, but the relation seems to be rare. In ores from the Mowry mine, in the Patagonia district, Ariz.,

the writer has observed radiating groups of tabular crystals of covellite replacing galena. The development of the covellite was, however, clearly controlled by cleavage planes of the galena or by contacts of galena with other minerals. In the association of pearceite and tennantite under description there is no such relation of the pearceite to tennantite contacts or partings, but the pearceite appears to be fairly evenly distributed through the tennantite. The two are interpreted as in primary intergrowth. There is no evidence that the proustite of this specimen is the result of a replacement of pearceite; it appears rather to be contemporaneous. On theoretical grounds the supergene replacement of pearceite ($9Ag_2S.As_2S_3$), a rich silver mineral, by proustite ($3Ag_2S.As_2S_3$), a mineral poorer in silver, is unlikely, for it would involve a reversal of the progression to richer silver minerals characteristic of the process of downward silver enrichment.

Although some of the relations outlined above taken singly would not form conclusive evidence that the proustite was primary, taken collectively their significance is unescapable.

The possibility of profitable operation of any particular deposit in this area is dependent upon many considerations, among which may be mentioned the price of silver, costs of transportation and labor, milling and smelting facilities, the width and horizontal extent of the ore body, the primary distribution of silver minerals within the vein, and the nature and extent of downward enrichment in silver.

Some of the richest silver ores of the area, carrying cerargyrite and native silver, were unquestionably products of oxidation and downward enrichment, and the playing out of these ores in depth was certainly an important factor in the closing down of many of the mines. The decline in the price of silver from 1872 to 1916 was unquestionably an added discouraging factor.

The conclusion that the rich ruby silver ores of the region are in the main primary offers encouragement to further exploration of the ore bodies, although this work should be undertaken only with due regard to the many other and perhaps unfavorable factors involved. A general decrease in the primary silver content of veins of this type with increase in depth is probable, but such primary changes are likely to be much less abrupt than those due to downward enrichment and to be recognizable only through vertical intervals measured in many hundreds rather than a few hundreds of feet. The depth of most of the mines is too small to afford any valid test of this factor, even had the workings been accessible for study. Underground studies, had they been possible, would have aided in determining whether the rich primary proustite ores were of spotty or patchy distribution, or of fairly regular distribution within the veins, a question of fundamental practical importance.