

BONANZA ORES OF THE COMSTOCK LODGE, VIRGINIA CITY, NEVADA.

By **EDSON S. BASTIN.**

INTRODUCTION.

At certain periods in the long and diversified history of mining on the Comstock lode the engineering problems of handling the treacherous floods of hot mine waters and the problems involved in the struggles for financial control of the mines have seemed to outweigh all others in influencing the progress of deep mining. Yet more fundamental than these or other problems has been the geologic problem of persistence of ores in depth. If the rich silver ores were wholly or largely deposited from solutions ascending from deep-seated sources this fact should encourage deep exploration. If the bonanzas owed their richness to the action of waters of surface origin on ores that originally were comparatively poor in gold and silver, then little encouragement to deep mining is offered. With the steady progress in the metallurgical treatment of low-grade gold and silver ores the probable persistence in depth of ores of this class also assumes practical importance. No serious observer expects a revival of the golden (and silver) age of Comstock mining, for fracturing on a tremendous scale created the channels that made ore deposition possible, and this fracturing was more extensive near the surface than at great depths. Nevertheless, the "roots" of an ore deposit of such magnitude are of no mean proportions, and the confidence of the Comstock operators in the existence of large deep-lying bodies of workable ore has been demonstrated by the drainage in recent years of a large part of the lode to and below the 2,900-foot level. It is the purpose of this paper, by reporting the first detailed microscopic studies on Comstock ores, to offer additional encouragement to deep exploration and not merely to illuminate the already brilliant achievements of the past.

In spite of the very detailed studies that have been made of Comstock geology, very little concrete and tangible evidence has been presented concerning the variations in tenor or composition of the ores in depth, and little basis has been available for weighing the relative importance of primary processes versus downward enrichment in the formation of the richer ores. Yet because of the recog-

nized potency of downward enrichment in many silver deposits a tacit belief in its importance at the Comstock seems to have become current among many geologists and mining engineers.

The early work of King¹ and Becker² was done before the development of the concept of enrichment of ores through the agency of descending surface waters. Later observers have made only brief examinations under conditions most trying because of the high mine temperatures. Finally, the ores themselves being as a rule fine grained, it has been impossible to determine the mutual relations of their different minerals by observation with the unaided eye.

The writer visited the Comstock in 1913 for the purpose of collecting representative ore specimens from various depths on the lode for study, after polishing, through the metallographic reflecting microscope. His visit was only partly successful, for it was possible to procure in Virginia City only a few specimens from depths near the surface and from the older shallow bonanzas. Many specimens from the deeper workings were obtained, however, and through the courtesy of Dr. George P. Merrill, of the United States National Museum, these were supplemented by the original collections of Dr. Becker containing many ore specimens collected near the surface and at moderate depths. The writer is greatly indebted to Mr. Thomas McCormick, superintendent of the C. & C. mine, for a number of specimens of the richer ores, and to Mr. W. G. Hellier, superintendent of the Union Consolidated mine, for other specimens and for the careful collection of a sample of the deep mine waters for analysis. The publication of the results has been delayed by professional work in South America and later by work incident to the war.

EARLIER INVESTIGATIONS.

Baron Von Richthofen, who made the first noteworthy geologic study of the Comstock, in 1865, plainly considered that the ores had been deposited by ascending hot solutions, in part gaseous and in part liquid, and concludes with the words: "As it has been shown that the vein was filled from a deep-seated source, it is certain that it is continuous in depth."³

Clarence King⁴ also considered that the bulk of the ores had been deposited by hot ascending solutions, which he believed to be connected with volcanic activity, and concluded that geologic indications were at least not unfavorable to the finding of valuable ore bodies at considerable depths.

¹ King, Clarence, The Comstock lode, in Hague, J. D., Mining industry: U. S. Geol. Explor. 40th Par. Rept., vol. 3, pp. 11-96, 1870.

² Becker, G. F., Geology of the Comstock lode and the Washoe district: U. S. Geol. Survey Mon. 3, 1882.

³ Becker, G. F., op. cit., p. 21.

⁴ Op. cit., p. 21.

Both King and Von Richthofen deemed it unlikely that the "magnificent expansion of bonanzas" that characterized the upper levels would be repeated below.

Becker,⁵ like his predecessors, believed that the ores were deposited by ascending thermal solutions but thought that the metal content of these solutions had been leached from the altered rocks adjacent to the lode, a conception which has now been generally abandoned by students of ore genesis for deposits of this type.

Thus none of the earlier students of Comstock geology attached any great importance to descending solutions in the formation of the ores beyond recognizing the familiar change wrought by oxidation in the shallow zone, 300 to 500 feet deep, between the surface and the original ground-water level.

The only important later contribution to the geology of the Comstock is that by Reid in 1905.⁶ Although partly devoted to the structure of the lode this paper shows that the hot ascending Comstock waters carry both gold and silver and are very probably now depositing metals in the deeper parts of the lode. In the upper parts of the lode acid waters descending through it are depositing certain minerals, and an assay of the waters revealed both gold and silver. Apparently Reid does not believe that descending solutions have produced any of the bonanza ores, for he says:⁷

Also there is considerable concentration of ore taking place from above by the surface, or vadose waters. These ores will occur on or near the footwalls of numerous branches of the lode which outcrop on the surface, within a few hundred feet of the outcrops. *Such material is low grade, however, and in the main not yet available.*

Particularly indicative of the deposition of rich silver ores by ascending solutions is the occurrence of such ores at depths of 1,800 to 2,250 feet in a blind vein in the hanging wall of the main lode, a vein which does not appear at the surface even as a barren fracture.⁸

Before passing to the microscopic characters of the ores, the mineral composition as recorded by King should be noted. He says that the main ore mass of the bonanzas is composed of quartz (several generations), pyrite, sphalerite, galena, chalcopyrite, argentite, polybasite, stephanite, and calcite. Polybasite and stephanite occur in all the bonanzas, but rarely in well-defined crystals. Gypsum occurring locally and the oxidation products of the upper parts of the veins complete the list.

⁵ Op. cit., pp. 285-287.

⁶ Reid, J. A., The structure and genesis of the Comstock lode: California Univ. Pub., vol. 4, pp. 177-199, 1905.

⁷ Idem, p. 197. (*Italics are mine.*—E. S. B.)

⁸ Idem, p. 183.

SUMMARY OF MICROSCOPIC ORE CHARACTERS.

The salient results of the microscopic studies are recorded here for the benefit of those who are not concerned with the full details.

The ores of the Comstock lode are characteristically fine grained, the grains of the metallic minerals being commonly less than 1 millimeter in diameter and only rarely attaining diameters of 5 to 10 millimeters. Because of this fineness microscopic study is necessary in order to determine fully the mutual relations of the minerals. The texture is usually granular; banding is rare and where present is of the somewhat ill-defined type developed in ores formed by replacement. Well-defined crustification developed by deposition on the walls of fissures or irregular open spaces is very rare.

The ores studied came from depths ranging from a few hundred to 2,900 feet.

The abundant minerals in nearly all the ore specimens are quartz, sphalerite, galena, chalcopryrite, and pyrite. Calcite may occur sparsely or abundantly. These minerals are intercrystallized in a fashion indicating that all were deposited essentially contemporaneously during a single period of mineralization. No one of this group characteristically replaces or fills fractures in any of the others or shows any other evidences of having been deposited at a different period.⁹ Inclusions of each of these minerals were noted in essentially all the others.

The textural relations typical of these common ore minerals are shown in figures 5 to 8. As will be noted from these figures, the galena and chalcopryrite, as well as argentite, gold, and polybasite, commonly occupy a matrix-like or interstitial position between the crystals of quartz and sphalerite. This position does not indicate that the interstitial minerals belong to a younger period of mineralization, for inclusions of quartz and sphalerite may be noted in all of them; it shows, however, that quartz and sphalerite crystallized most abundantly early in the mineralization period.

The common ore minerals, quartz, calcite, and the base-metal sulphides listed above, are present in all the ores, from those close to the surface to those at depths of 2,900 feet, and throughout this range in depth show similar mutual relationships. Because this mineral association ranges unchanged through this noteworthy vertical interval in apparently complete independence of any processes originating at the surface and because hot mineral-bearing waters are even now rising along the lode this group of minerals is interpreted as a primary deposit from hot mineral-bearing waters rising from great depths toward the surface. The waters at present ascending

⁹ An exception is to be noted in occasional white quartz or calcite traversing sulphide-rich ore and clearly younger.

along the lode carry small amounts of the precious metals and though not analyzed for base metals probably carry these as well. The conclusion that the bulk of the ore minerals were deposited by ascending solutions is in harmony with the conclusions reached by King, Von Richthofen, and Becker.

Inasmuch as the Comstock ores are worked as a source of gold and silver, chief interest attaches to the mode of occurrence of minerals carrying these metals. If it can be shown that the precious-metal minerals are wholly or in large part of the same age as the commoner ore minerals they also are to be interpreted as a deposit from ascending solutions. If this is true, then there would seem to be no reason why bodies of rich ore should not be found at great depths.

In the great majority of the specimens studied, coming from depths ranging from 2,500 feet to a few hundred feet of the surface and including samples of some of the richest bonanza ores, the only precious-metal minerals present in notable amounts are argentite and gold. The gold is invariably very pale yellow and therefore is probably highly argentiferous. All the gold in these ores and nearly all the argentite occur in exactly the same textural relation to sphalerite and quartz that is characteristic of galena and chalcopyrite—that is, argentite, gold, galena, and chalcopyrite occur side by side as a matrix between areas of quartz and sphalerite. Neither gold nor the larger areas of argentite show any evidence of having replaced other minerals or filled fractures in them. These relations, characteristically shown in figures 5, 6, and 7, are interpreted as showing that all the gold and the larger areas of argentite are primary and were deposited contemporaneously with galena and chalcopyrite. As shown on a later page, minor amounts of argentite are secondary. Many argentite areas are of the same order of size as galena areas. Areas of gold 1 millimeter across were noted. In one specimen numerous minute round or oval inclusions of argentite were noted irregularly distributed through both galena and sphalerite. These show no evidence of having been formed by replacement, neither their form nor their distribution being related to cleavage directions of the galena. In another specimen occasional small inclusions of argentite were noted in gold and in chalcopyrite. All these inclusions are believed to be primary.

In a few specimens, as illustrated in figure 8, polybasite occurs in relations similar to those characteristic of argentite and gold and is interpreted as a primary mineral. It is rare, compared with argentite. In other specimens tarnishing of the galena with hydrogen peroxide reveals scattered inclusions of rounded outline that were too small for identification but are very possibly a silver mineral.

In most of the specimens studied secondary minerals, to be discussed later, were either absent or present only in amounts too small

to have any great influence on the tenor of the ore. The conclusion is therefore reached that essentially all the gold of the Comstock ores is primary and that the silver content of some of the richest bonanza ores is also in primary minerals—argentite and rarely polybasite.

If the gold and silver of the Comstock ores are in the main in primary minerals, as the observations recorded above seem to show, are there any evidences that the precious-metal value has been anywhere increased through the enriching action of descending solutions of surface origin? This query must be answered in the affirmative. Minerals deposited by descending solutions may occur in two ways—as replacements of primary minerals or as fillings of cracks or cavities in the primary ores. Replacement in the sense here used means the dissolving of an older mineral and the immediate deposition in its place of another mineral without the intervening formation of open spaces.

Replacement on a scale capable of materially influencing the tenor of the ores was noted only in ores obtained within a few hundred feet of the surface. This is considered valid evidence that such replacement was accomplished by descending solutions. The replacement was of several kinds.

Replacement of chalcopyrite by covellite and by chalcocite was noted in ore from the 300-foot level of the Hale & Norcross mine, and replacement of chalcopyrite by covellite was noted in ore from the 350-foot level of the Andes mine. The covellite or chalcocite formed replacement borders around the chalcopyrite or penetrated it as replacement veinlets. No such replacement was observed in ores from greater depths.

Replacement of argentite by native silver was noted in ore from the Belcher bonanza obtained probably from depths of less than 350 feet. This replacement is shown in figures 9 and 10. In small pores in this ore minute wires and “teeth” of silver were also noted on argentite. In ore from a depth of probably less than 425 feet in the Gould & Curry mine silver also replaces argentite. In both these specimens the argentite is primary, for it occurs in the same textural relationships as galena.

In the specimen from the Belcher mine noted above argentite which is probably primary is peripherally replaced by polybasite in the fashion shown in figure 11. No such replacement was noted in deeper ores.

In ore from the 350-foot level of the Andes mine galena was replaced peripherally and along fractures by lead sulphate (anglesite).

In ore collected from the Hale & Norcross mine soon after mining operations were begun nearly every area of galena has been replaced peripherally by argentite or by a galena-like mineral, probably a lead-silver sulphide, as described in more detail on pages 55–56. These

replacement deposits are conspicuously shown when the galena is tarnished brown by hydrogen peroxide. Argentite that is probably primary is also present in this specimen, but it is probable that 50 per cent or more of the silver content is in secondary minerals. Tarnishing with hydrogen peroxide reveals occasional replacement of galena by other minerals, probably silver minerals, in ores from depths as great as 1,950 feet, but these replacement minerals form exceedingly narrow bands and are not sufficiently large or numerous to affect the tenor of the ore materially.

Enrichment on a scale sufficient to exert any notable influence on the tenor of the ore was therefore noted only in ores obtained less than 500 feet below the surface, and some ores from these slight depths showed no enrichment phenomena.

MICROSCOPIC DETAILS.

ORES FROM DEPTHS OF 1,000 TO 2,500 FEET.

1. Bonanza ore, main lode, C. & C. mine; depth, 1,650 feet. This ore is typical of much of the ore from moderate depths in the lode and will be described before some of the ores from lesser depths, in which the relations are similar but are less clearly exhibited. The ore consists in the main of a fine-grained granular aggregate of the following minerals, named in approximate order of abundance: Quartz, chalcopyrite, sphalerite, galena, argentite, pyrite, and light-colored gold. The argentite and gold are not recognizable to the unaided eye, but the microscope shows that they are fairly abundant. The relation of the argentite to the other ore minerals is shown in figure 5, from which it will be seen that argentite bears identically the same relation to quartz and sphalerite that galena does, and the two are interpreted as of the same age and as primary (hypogene). There are no evidences of replacement of galena by argentite along fractures or cleavages or along contacts with other minerals. Figure 6, drawn from the same specimen, shows light-colored gold in similar relations to quartz and sphalerite to those shown by argentite and galena.

2. Bonanza ore, Hale & Norcross mine, 1,100-foot level; collection of G. F. Becker. This is a heavy sulphide ore, carrying in approximate order of abundance chalcopyrite, quartz, galena, sphalerite, calcite, pyrite, argentite, and pale-yellow gold, all of which are primary, their characteristic relations being the same as observed in ores from the C. & C. mine illustrated in figures 5 to 7. Gold is present in unusual abundance, and some gold areas are 1 millimeter across. Argentite not only forms areas comparable with the galena in size and relations but occurs also in the form of occasional small inclusions in chalcopyrite and in gold.

3. Bonanza ore, Belcher mine, depth between 800 and 1,200 feet; collections of G. F. Becker. Highly quartzose ore ranging in color from white where free from sulphides to gray where there is an abundance of small sulphide grains. The ore is exceptionally rich in calcite, which occupies interstices between quartz crystals. Through the quartz and calcite the usual suite of base-metal sulphides as well as argentite and gold are scattered as isolated grains or small aggregates. The textural relations of argentite and gold are identical with those of the base-metal sulphides, and all the minerals

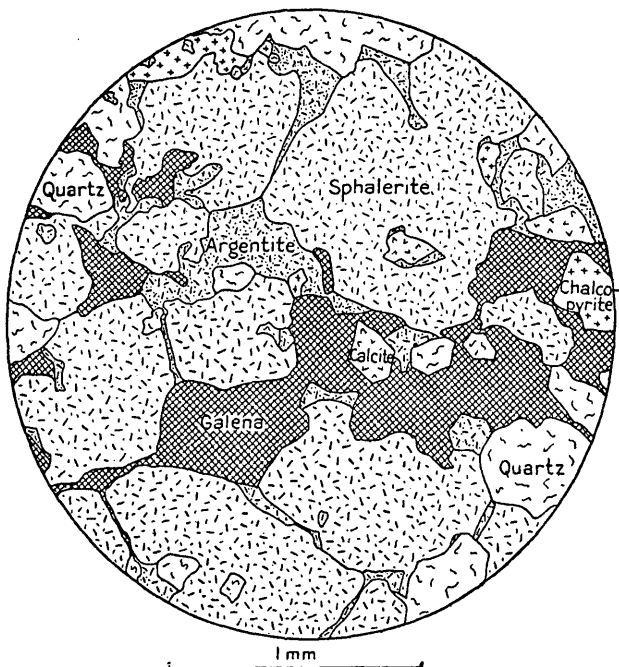


FIGURE 5.—Argentite occupying a similar interstitial position to galena with respect to quartz and sphalerite, in bonanza ore from 1,650-foot level of C. & C. mine, Comstock lode, Nev. All are believed to belong to the same period of mineralization and to be primary (hypogene). Camera lucida drawing from same specimen as figure 6.

appear to belong to a single period of primary mineralization. No replacement phenomena are shown.

4. Fairly rich ore, Alta mine, 200 feet south of Benton line, depth 1,950 feet; collections of G. F. Becker. This ore carries galena in unusually coarse crystals as much as 1 centimeter across in a matrix of much finer grained sulphides. A slightly later $\frac{1}{8}$ -inch veinlet of white calcite traverses the quartz-sulphide ore. Ore from which this sample was taken assayed 55 ounces of silver and 0.27 ounce of gold to the ton. The microscope shows in approximate order of abundance quartz, pyrite, galena, sphalerite, and chalcopyrite. Argentite or other silver minerals were not noted in grains comparable in size

with the base-metal sulphides, but when the galena was tarnished with hydrogen peroxide numerous rounded inclusions of the order of 0.01 millimeter in diameter became visible in the galena. These are too small for certain identification but are "peppered" very abundantly through some of the galena crystals and are probably a silver-bearing mineral. The only secondary minerals present are extremely narrow replacement bands, probably of polybasite, between galena crystals, but these are too few and too narrow to affect the silver tenor of the ore materially. They appear only upon tarnishing the galena with hydrogen peroxide.

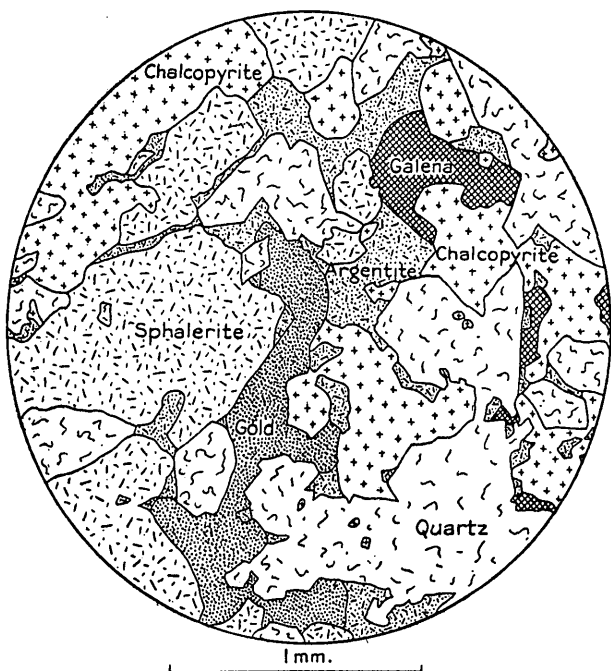


FIGURE 6.—Primary argentite and gold (electrum?) in bonanza ore from 1,650-foot level of C. & C. mine, Comstock lode. Camera lucida drawing from same specimen as figure 5.

5. Bonanza ore, East vein, C. & C. mine, depth 2,000 to 2,050 feet. This specimen was a fragment of a large piece in the collections of Mr. T. F. McCormick. The large piece showed fine-grained ore rich in sulphides traversed by a veinlet consisting mainly of gray quartz with which a few flat hexagonal crystals of polybasite or stephanite were intercrystallized. No clearly secondary minerals were recognized in the large specimen. The microscopic appearance of the portions richest in metallic minerals is shown in figure 7, from which it will be seen that, as in the specimens previously described, argentite, gold, and galena all bear identical textural relations to quartz and sphalerite. This figure shows the somewhat rounded outlines

characteristic of much of the sphalerite, in contrast to the crystalline outlines usually assumed by the quartz. Such rounded outlines are not interpreted in this case as indicative of resorption of sphalerite prior to the deposition of galena, argentite, and gold but as expressive merely of some difference in the forces of crystallization of sphalerite and quartz by virtue of which the quartz more readily develops crystal faces. In parts of this same specimen, however, the sphalerite develops crystal faces. Rounded outlines in sphalerite are common in the somewhat similar ores of Tonopah.¹⁰ The fine-grained

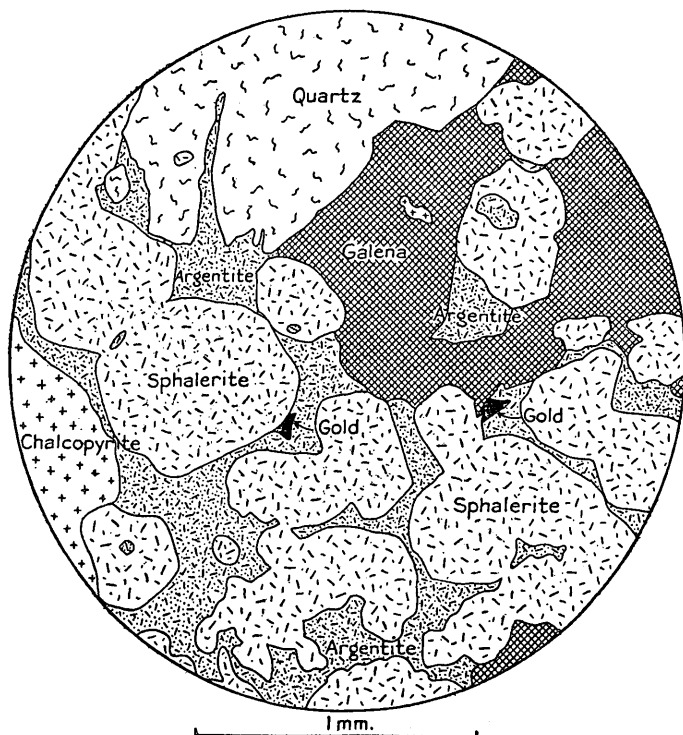


FIGURE 7.—Bonanza ore from C. & C. mine, Comstock lode, East vein, between 2,000 and 2,050 foot levels, carrying abundant primary argentite associated with galena, sphalerite, chalcopyrite, quartz, and gold. Camera lucida drawing.

sulphide-rich portions of this ore from which figure 7 was sketched are traversed by coarser, highly quartzose portions, which appear to represent the latest phase of the mineralization though belonging to the same general period. On and between the coarse quartz occur argentite, polybasite, and some galena in relatively large crystals.

6. Bonanza ore, C. & C. mine, East vein, depth 2,200 feet. This ore shows gradual transitions from fine-grained ore rich in sulphides to coarse-grained ore rich in white quartz and carrying sulphides

¹⁰ Bastin, E. S., and Laney, F. B., The genesis of the ores at Tonopah, Nev.: U. S. Geol. Survey Prof. Paper 104, fig. 10, p. 22, 1918.

sparsely but in relatively large crystals as much as 5 millimeters in diameter. The coarse portions are vuggy and obviously represent the last phases of mineralization. In these coarse-grained portions, usually between large quartz crystals but interlocking irregularly with smaller ones, occurs argentite intercrystallized locally with chalcopyrite, galena, and light-yellow gold. Polybasite in characteristic flat hexagonal prisms occurred in one vug. In the finer-grained portions of the ore the microscope reveals argentite in the same relations to the commoner ore minerals as in the specimens already described (figs. 5-7) though less abundant. Polybasite is abundant, however, and, as shown in figure 8, it bears the same relation to quartz and sphalerite as galena does. The contacts between polybasite and galena are sharp and regular and bear no relation to cracks and cleavages in the galena or to the contacts of polybasite with other minerals. The polybasite appears not to replace galena but to be contemporary with it and primary. The only replacement phenomenon observed in this specimen was a slight replacement of argentite by chalcocite along its contacts with other minerals.

7. Bonanza ore, East vein, Mexican mine, 2,500-foot level. In this ore pyrite was the earliest metallic mineral, and fractures traversing it

are occupied by an association of sphalerite, galena, quartz, chalcopyrite, argentite, and gold. Some of the argentite occurs in the same manner as in the specimens illustrated in figures 5 to 7, but much also forms minute inclusions in galena and especially in sphalerite. Most of the argentite inclusions in galena are round or oval in outline and show no definite relation either in form or in distribution to the cleavage direction of the galena. Tarnishing the galena with hydrogen peroxide reveals a few very narrow replacement "rims" of probable polybasite between galena and other minerals and along contacts between two galena crystals. Minor peripheral replacement

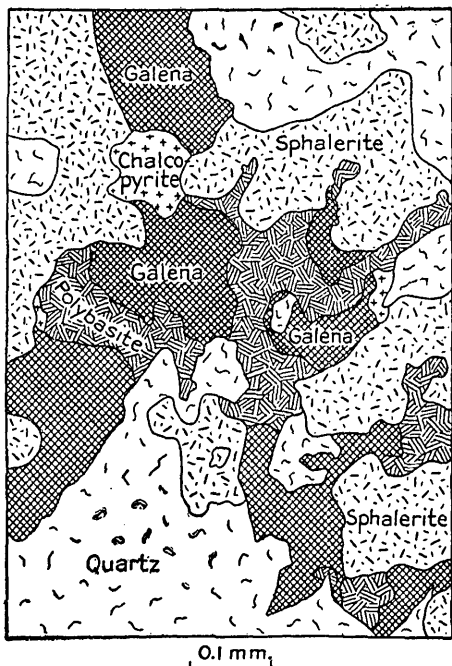


FIGURE 8.—Polybasite, probably primary, intergrown with galena, sphalerite, chalcopyrite, and quartz in ore from C. & C. mine, Comstock lode, East vein, 2,200-foot level. Camera lucida drawing.

of argentite by chalcopyrite was also noted. In vugs occur small mosslike masses of argentite and a few crystals of either polybasite or pearceite.

8. Rich ore, Sierra Nevada mine, depth 2,500 feet. Quartz-lined vugs contain crystals as much as 2 millimeters across of chalcopyrite, pyrite, and pearceite intergrown and obviously contemporaneous. On them and on the quartz later crystals of calcite have been deposited.

9. Ophir mine, Hardy vein, depth 2,100 feet. This specimen is one of the few that show a banded structure. On fine-grained sulphide-rich ore of the usual character a layer of comb quartz about 1½ inches thick has been deposited. This quartz layer is nearly barren of sulphides, but a small branch from it cutting the sulphide ore carries scattered crystals of chalcopyrite and pearceite. On the coarse quartz crystals of this specimen later crystals of calcite have been deposited. Ore from a depth of about 2,200 feet in this same vein showed pale gold in unusual abundance and argentite in fair abundance, and the texture was similar to those shown in figure 6.

Other bonanza ores from depths between 1,000 and 2,500 feet show characters similar to those which have been described.

LOW-GRADE ORES FROM DEPTHS OF 2,500 FEET OR MORE.

With these bonanza ores may next be compared certain ores collected personally by the writer from depths of 2,500 feet or more, and for the most part of low grade.

Ore from South drift No. 3 on the 2,500-foot level of the Mexican mine does not differ notably in general appearance from the rich ores, but the microscope shows an ore composed essentially of quartz, sphalerite, and galena, with minute amounts of chalcopyrite and pyrite. No silver minerals were recognized, even under high power.

Ore from East crosscut No. 1 on the 2,700-foot level of the Mexican mine, said to average about \$25 a ton, consists mainly of chalcopyrite, quartz, sphalerite, and galena, with rare pyrite. In a very few places minute amounts of argentite were noted intergrown with galena or as inclusions in sphalerite, but they are exceedingly rare.

Ore collected from the Union mine, on the 2,600-foot level, shows quartz, sphalerite, galena, pyrite, and rare chalcopyrite intergrown in the same manner as in the rich ores, but no silver minerals could be recognized.

SHALLOW BONANZA ORES.

Ores from the upper portions of the Comstock lode are now very difficult to procure, but the collections of G. F. Becker afforded several specimens of such ores for study.

1. Belcher bonanza. Through the courtesy of Mr. Herbert Hidden, of Virginia City, a small specimen from the Belcher bonanza, very

rich in both gold and silver, was obtained for study. According to Becker's longitudinal projections of the lode¹¹ the Belcher bonanza extended from a depth of about 75 feet to a depth of about 350 feet. The exact place of origin of the specimen is uncertain, but it presumably came from this ore body or was obtained at no great distance below it.

The small specimen, 1 inch across, though not stained with iron oxides is very porous in places, evidently as an effect of the solvent action of descending mine waters. The ore minerals are quartz, pyrite, chalcopyrite, sphalerite, galena, argentite, gold (light colored), native silver, and polybasite. There is a transition from fine-grained ore rich in sulphides to coarser ore rich in quartz, but both types show all the minerals listed above except polybasite, which is present only in the coarser portions. With the exception of native silver and polybasite the ore minerals are inter-crystallized in the same manner noted in the deeper bonanza ores and illustrated in figures 5 to 7. Argentite is abundant even in

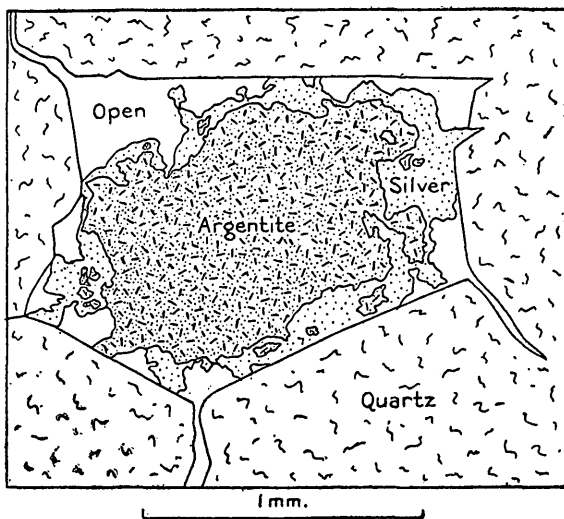


FIGURE 9.—Primary (?) argentite in small quartz-lined vug peripherally replaced by native silver, in shallow ore from Belcher bonanza, Comstock lode. The silver is believed to be a deposit from descending solutions. Camera lucida drawing.

the finer-grained portions of the ore, is related to the other minerals in identically the same fashion as galena, and is believed to be primary (hypogene).

In the more porous portions of the specimen, particularly the coarse-grained portions, native silver occurs associated exclusively with argentite and bearing the relations to it illustrated in figures 9 and 10. Where sparsely developed the silver lies mainly along the contacts between argentite and quartz which borders it, or adjacent to open spaces developed along such contacts, as is shown in figure 9. The contacts between argentite and silver, in marked contrast to those between argentite and galena, are exceedingly irregular, as shown in figure 9 and on a larger scale in figure 10. Such relations clearly indi-

¹¹ Becker, G. F., op. cit., atlas sheet 11.

cate that most of the silver was developed by the replacement of argentite. A hand lens shows, however, that some of the silver in the larger pores assumes the form of wires or teeth. As native silver is found only in ores from shallow depths in the Comstock and is usually in ore that is porous or oxidized or both, it is believed to be a secondary mineral deposited by descending solutions.

In the coarser parts of the specimen some argentite areas show a periphery of polybasite, as illustrated in figure 11. This relationship indicates that the polybasite was developed by the replacement of argentite, spreading inward from contacts between argentite and quartz. Such occurrences were not noted in the deeper ores and are believed to be due to downward enrichment.

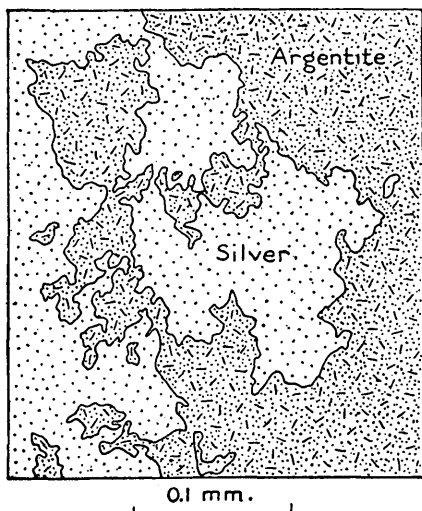


FIGURE 10.—Detail, under higher magnification, of the exceedingly irregular replacement boundary between native silver and argentite in the specimen from which figure 9 was drawn.

This is a heavy ore in which the siliceous minerals are dominant over quartz. A few new minerals are present, but most of the mineral grains are less than 1 millimeter across. Broken surfaces favor the abundance of native silver. The ore minerals, in approximate order of abundance, are sphalerite, galena, pyrite, pyrrhotite, argentite, native silver, calcite, and quartz. All these minerals except native silver are clearly hypogene, and the relations of argentite and gold to the base-metal sulphides are identical with those shown in figures 5 to 7. Therefore, all the gold and a considerable part of the silver of this ore are primary.

2. Gould & Curry mine; Becker collection. The original position of this specimen in depth is not given, but it was marked as collected in 1866. Up to 1864 the deepest working was a tunnel cutting the ore body at a depth of 425 feet. In 1864 the sinking of the deep shaft was begun, but prior to the date of King's report¹² (about 1869) no important ore bodies had been found below a depth of 600 feet, and all the ore produced in the late sixties was obtained by reworking old ground or from newly discovered deposits at upper levels. It is certain, therefore, that this specimen was collected from

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¹² King, Clarence, op. cit., pp. 170, 171.

In many parts of the specimen the primary argentite has been replaced partly or wholly by native silver, the silver masses forming minute replacement veinlets or larger and more irregular masses in the argentite. Where best developed the replacement by silver has involved no change in volume, and no pores are visible, even under high powers of the microscope. No mineral other than argentite has been replaced by the silver. Tarnishing the galena by hydrogen peroxide reveals no replacement of galena by other minerals.

3. Rich ore, Hale & Norcross mine; Becker collections. The depth from which this specimen came was not recorded, but it was marked as collected in 1860. This date may be in error, for according to King¹³ operations at this mine were begun in 1861 or 1862. At any

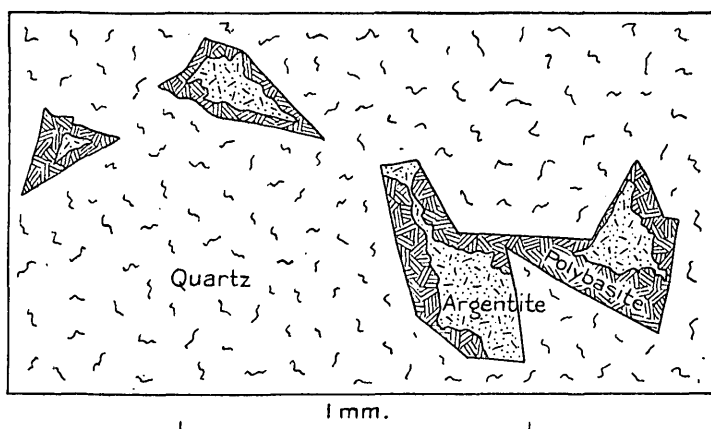


FIGURE 11.—Polybasite peripherally replacing primary argentite in shallow ore from the Belcher bonanza, Comstock lode. The polybasite is believed to be a deposit from descending enriching solutions. Camera lucida drawing.

rate the specimen was probably collected early in the history of the mine and from slight depth.

The ore is fairly rich in sulphides in grains mostly under 1 millimeter in diameter. The primary minerals, named in the approximate order of abundance, are quartz, sphalerite, chalcopryrite, galena, calcite, and argentite. Some of the argentite occurs in relations similar to those shown in figures 5 to 7—that is, in areas comparable in size to the galena areas and bearing similar textural relations to the other minerals. In view of the presence in this specimen of argentite that has replaced galena, as described below, the primary nature of the larger argentite areas can not be demonstrated but is regarded as probable.

Nearly every area of galena shows peripheral replacement by argentite. This relation is brought out more clearly by tarnishing

¹³ Op. cit., p. 174.

the galena brown with hydrogen peroxide, which makes visible also a relation not seen before tarnishing, namely, the invariable presence between argentite and tarnished galena of an untarnished band identical with galena in color and possessing the same perfect cubical cleavage, as shown by the occurrence in it of triangular pits identical with those that characterize galena. The band between galena and argentite evidently represents an intermediate product in the replacement of galena by argentite. The same phenomenon was recognized by the writer in the silver ores of Tonopah,¹⁴ and the conclusion then reached may here be quoted:

The nature of the intermediate replacement product revealed by the microscope between galena and argentite still remains in doubt; it may be a solid solution of galena and argentite or a double sulphide of lead and silver.

Nissen and Hoyt¹⁵ from a study of a series of melts of galena and silver sulphide conclude that "the limit of solid solution at atmospheric temperatures is below 0.2 per cent Ag_2S ." The apparent homogeneity of the transition mineral and the extreme sharpness of the boundaries between it and both galena and argentite seem to favor its interpretation as a double sulphide of lead and silver.

The replacement borders of argentite and the unknown mineral occur along nearly all contacts between galena and quartz or calcite but almost nowhere between galena and sphalerite or chalcopyrite. This means apparently that the contacts between galena and metallic minerals were less permeable to the replacing solutions than the contacts between galena and nonmetallic minerals.

It is clear that in this specimen a very considerable part of the silver content, probably over 50 per cent, is in secondary argentite and perhaps lead-silver sulphide developed by the replacement of galena. As replacement on this scale is observed only in the shallow ores of the lode it is reasonable to conclude that it is an effect of descending solutions—that is, of downward enrichment.

4. Low-grade ore, Hale & Norcross mine, 300-foot level; Becker collections. Highly quartzose ore, nearly white where free from sulphides but dark gray where crowded with microscopic grains of sulphides. Parts of the hand specimens are stained brown with limonite. The primary ore minerals, named in the approximate order of abundance, are quartz, sphalerite, chalcopyrite, pyrite, and galena. Some isolated and relatively large areas of argentite in quartz lie adjacent to areas of unaltered chalcopyrite and appear to be primary. The secondary minerals are chalcocite and covellite replacing a few small areas of chalcopyrite peripherally or extending into them as replacement veinlets.

¹⁴ Bastin, E. S., and Laney, F. B., The genesis of the ores at Tonopah, Nev.: U. S. Geol. Survey Prof. Paper 104, pp. 21-23, fig. 12, 1918.

¹⁵ Nissen, A. E., and Hoyt, S. L., On the occurrence of silver in argentiferous galena ores: Econ. Geology, vol. 10, p. 179, 1915.

5. North bonanza and Flowery mine, 600-foot level; Becker collections. This ore is relatively coarse, showing chalcopyrite areas 5 to 10 millimeters across. It shows the usual base-metal sulphides in a white quartz gangue. No argentite or gold was noted. On tarnishing the galena with hydrogen peroxide very narrow replacement bands, probably of a silver mineral, became visible about the peripheries of some galena areas and between galena crystals. Such replacement bands are a minor feature and can represent only a slight enrichment in silver.

6. Andes mine, north drift on 350-foot level; Becker collections. This specimen carries in approximate order of abundance quartz, sphalerite, chalcopyrite, and galena as primary ore minerals. Secondary covellite forms replacement rims around chalcopyrite and also traverses the chalcopyrite as replacement veinlets. Galena is replaced peripherally and traversed by replacement veinlets of a mineral which in reflected light is slightly darker gray than the associated sphalerite but which when scratched is found to yield a white nonmetallic powder. This mineral, whose hardness is about the same as that of galena, was identified chemically from the hand specimen as anglesite (PbSO_4). In its replacement of galena it locally follows with remarkable regularity the cleavage directions of the galena.

7. Gould & Curry mine; Becker collections. This specimen was marked as collected in 1863. The maximum depth attained up to that time did not exceed 425 feet. The ore is fine grained and rich in sulphides. The microscope shows, in approximate order of abundance, quartz, chalcopyrite, sphalerite, galena, and pyrite, with small amounts of argentite and gold.

The argentite and gold are primary, their relations to the other minerals being similar to those shown in figures 5 to 7. Tarnishing the galena with hydrogen peroxide reveals no replacement by other minerals. In spite of its shallow source the precious-metal content of this ore appears to be wholly primary.

MINE WATERS OF THE COMSTOCK LODE.

The mine waters of the Comstock lode have always been of more than usual practical as well as scientific interest, for they have constituted one of the chief obstacles to mining operations. The water pumped from the lode in one year, 1880, about 7,000,000 tons, equaled in weight the total quantity of ore mined from the lode up to that year, and between 1886 and 1898, because of the large influx of water, deep mining was virtually abandoned. In 1898, through a consolidation of operations and the installation of more modern pumps, the contest with the waters was finally won and mining on the deep levels resumed.

Trouble with mine waters was experienced even near the surface, for the water-tight clay seams so common along lines of faulting within the lode impounded the shallow waters in numerous separate reservoirs. Reaching any particular level in mining gave no assurance that all the region above that level had been drained.¹⁶ Thus at a depth of 313 feet below the surface in the Ophir mine great quantities of water were let loose when a clay seam was penetrated and flooded the mine to a depth of about 21 feet. Similar incidents are recorded as occurring in other mines. From the data afforded by such occurrences and from the depth of oxidation as recorded by King it appears that the ground-water level stood originally at depths below the surface ranging from slightly less than 300 feet to about 500 feet.

According to King¹⁷ the waters encountered above the 700-foot level ranged in temperature between 70° and 75° F., this being also the temperature of the rocky material of the lode.

On the 1,040-foot level of the Crown Point mine the waters, apparently ascending, had a temperature of 102° F. At depths of 2,000 feet the temperatures of the rock and of the mine waters were originally 120° to 130° F.¹⁸ In 1877 the Savage shaft encountered not far below the 2,000-foot station a flow of water with a temperature of 157° F. In 1880 to 1882 water at a depth of 3,080 feet from a drill hole at the bottom of the Yellow Jacket shaft had a temperature of 170° F.¹⁹ Becker says that on the lower levels the waters, when first tapped by the drill, were frequently under pressures equivalent to a head of several hundred feet.

With continued operations in the deeper levels the mine waters have, as might be expected, become cooler than when first encountered, and the sample collected in 1915 from the 2,650-foot level of the Union Consolidated mine had a temperature of 130° F. Water from the Mexican-Ophir winze on the 2,700-foot level was observed by the writer in 1915 to have a temperature of 149° F.; tested at the point of issuance it was neutral in reaction toward phenolphthalein.

The chemical qualities of the deep waters of the lode have been determined by two trustworthy analyses, which will next be considered.

At the writer's request and in conformity with his detailed suggestions, Mr. W. G. Hellier, superintendent of the Union Consolidated mine in 1915, kindly collected a sample of water from the 2,650-foot level of the mine. This sample was analyzed by Chase Palmer, of

¹⁶ King, Clarence, *op. cit.*, p. 50.

¹⁷ *Op. cit.*, p. 86.

¹⁸ Symmes, Whitman, *Decline and revival of Comstock mining: Min. and Sci. Press*, vol. 97, p. 496, 1908.

¹⁹ Becker, G. F., *op. cit.*, p. 230.

the United States Geological Survey, and the analysis is recorded in the following table and diagrammatically in figure 12.

Analyses of mine waters from Comstock lode.

Hot water from 2,650-foot level, Union Consolidated mine.

[Temperature 130° F. Analyst, Chase Palmer, U. S. Geol. Survey.]

| Radicle. | Parts per million. | Reacting value. | | Adjusted reacting value (per cent). |
|------------------------|--------------------|-----------------|-----------|-------------------------------------|
| | | By weight. | Per cent. | |
| Na..... | 145.0 | 6.3075 | 18.7 | 19.2 |
| K..... | 8.4 | .2150 | .6 | |
| Ca..... | 204.0 | 10.1796 | 30.2 | 30.8 |
| Mg..... | 4.0 | .3288 | 1.0 | |
| Mn and Fe..... | None. | | | 47.8 |
| SO ₄ | 752.0 | 15.6416 | 46.3 | |
| Cl..... | 12.0 | .3384 | 1.0 | .9 |
| CO ₃ | 9.3 | .3097 | .9 | |
| HCO ₃ | None. | | | 1.3 |
| OH..... | 7.5 | .4410 | 1.3 | |
| SiO ₂ | 61.0 | | | |
| | 1,203.2 | | 100.0 | 100.0 |

| | Per cent. |
|----------------------------|-----------|
| Alkalies+strong acids..... | 38.4 |
| Earths+strong acids..... | 57.2 |
| Earths+weak acids..... | 1.8 |
| Earths+hydroxyl..... | 2.6 |
| | 100.0 |

Hot water from 2,250-foot level, C. & C. shaft.

[Analyst, Prof. N. E. Wilson, University of Nevada.]

| As reported (grams per liter). | | As recalculated. | | | |
|--------------------------------------|--------|------------------------|--------------------|-----------------|-----------|
| | | Radicle. | Parts per million. | Reacting value. | |
| | | | | By weight. | Per cent. |
| Na ₂ O..... | 0.1765 | Na..... | 131.0 | 5.70 | 27.4 |
| K ₂ O..... | .0643 | K..... | 53.4 | 1.37 | |
| CaO..... | .1404 | Ca..... | 100.3 | 5.00 | 21.2 |
| MgO..... | .0097 | Mg..... | 5.9 | .48 | |
| Al ₂ O ₃ | .0025 | Al..... | 1.3 | .14 | 1.4 |
| Fe ₂ O ₃ | .0091 | Fe..... | 6.4 | .23 | |
| SO ₃ | .3957 | SO ₄ | 542.6 | 11.29 | 47.3 |
| Cl..... | .0190 | Cl..... | 19.0 | .54 | |
| CO ₂ | .0150 | CO ₃ | 20.5 | .68 | 2.7 |
| SiO ₂ | .1334 | SiO ₂ | 133.4 | | |
| | .9656 | | 1,013.8 | | 100.0 |

| | Per cent. |
|----------------------------|-----------|
| Alkalies+strong acids..... | 54.8 |
| Earths+strong acids..... | 39.8 |
| Earths+weak acids..... | 2.6 |
| Metals+weak acids..... | 2.8 |
| | 100.0 |

NOTE.—Residue from evaporation of 10 liters assayed silver, 2.92 milligrams per ton of solution; gold, 0.298 milligrams per ton of solution.

Analyses of mine waters from Comstock lode—Continued.

Descending water, Central tunnel.

[Analyst, Prof. N. E. Wilson, University of Nevada.]

| As reported (grams per liter). | As recalculated. | | | | |
|--------------------------------------|------------------|------------------------|-----------------|-----------|--------|
| | Radicle. | Parts per million. | Reacting value. | | |
| | | | By weight. | Per cent. | |
| Na ₂ O..... | 0. 7209 | Na..... | 534. 9 | 23. 3 | 0. 3 |
| CaO..... | 1. 7400 | Ca..... | 1, 243. 4 | 62. 0 | |
| MgO..... | 10. 8108 | Mg..... | 6, 520. 8 | 536. 0 | 6. 5 |
| Al ₂ O ₃ | 18. 2140 | Al..... | 9, 659. 6 | 1, 069. 3 | |
| Fe ₂ O ₃ | 7. 1786 | Fe..... | 5, 020. 8 | 269. 6 | 15. 2 |
| Mn ₂ O ₄ | 1. 2500 | Mn..... | 900. 3 | 32. 8 | |
| CuO..... | 0. 1850 | Cu..... | 147. 8 | 4. 7 | 28. 0 |
| | | H (by difference). | | | |
| SO ₃ | 70. 1154 | }SO ₄ | 218, 645. 0 | 4, 547. 8 | 50. 0 |
| H ₂ SO ₄ | 125. 0804 | | | | |
| Cl..... | 0. 1276 | Cl..... | 127. 6 | 3. 6 | |
| SiO ₂ | . 6160 | SiO ₂ | 616. 0 | | |
| | 236. 0387 | | 243, 416. 2 | 6, 549. 1 | 100. 0 |

| | Per cent. |
|----------------------------|-----------|
| Alkalies+strong acids..... | 0.6 |
| Earths+strong acids..... | 13.0 |
| Metals+strong acids..... | 30.4 |
| Free strong acids..... | 56.0 |
| | 100.0 |

The perusal of a water analysis as reported by the analyst affords slight indication of the chemical properties of the water. In order to visualize these properties and to facilitate comparison with other water it is necessary to recalculate the analyses and to express the results graphically. The method of study adopted is that developed by Palmer²⁰ and expounded in its geologic applications by Rogers.²¹ Its details need not be repeated here, but briefly it consists in expressing the several radicles present in the water in terms not of weight but of their capacity to react with one another. The radicles are then balanced against one another (or assumed to combine) in the order of their general chemical combining power, alkalies being first balanced against strong acids, remaining alkalies against weak acids, and remaining strong acids against alkali earths, etc. The balancing thus accomplished may readily be expressed graphically, as shown in figures 12 and 13, and by eliminating the factor of concentration and considering only the components other than water in the solutions different solutions may be instructively compared.

In figures 12 and 13 the reacting values of the positive radicles are entered above each diagram and those of the negative radicles are entered below; each group adds to 50 per cent, and combined they make 100 per cent.

²⁰ Palmer, Chase, The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, 1911.

²¹ Rogers, G. S., The interpretation of water analyses by the geologist: Econ. Geology, vol. 12, pp. 56-88, 1917.

The two analyses of Comstock deep hot waters are in general very similar, and the noteworthy features they show are these:

1. The abundance of alkalis (Na and K), as compared with cool descending waters.

2. The abundance of strong acid radicles (mainly SO_4), as compared with weak acid radicles (CO_3). The small proportion of carbonate radicles present accords with the scarcity of carbonates as gangue minerals in the ores and in the wall rocks altered ("propy-

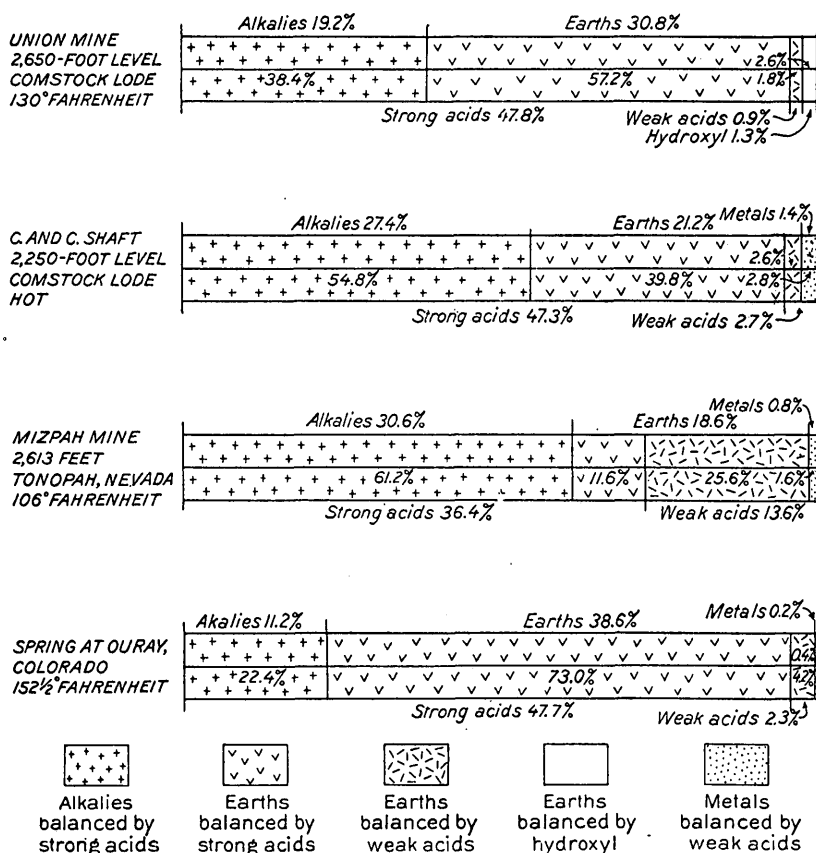


FIGURE 12.—Composition diagrams of hot ascending waters from Comstock lode and Tonopah, Nev., and from Ouray, Colo.

litized") by solutions that were presumably somewhat similar to those analyzed.

3. The small amounts of heavy metal radicles present, as contrasted, for example, with the descending mine waters shown in figure 13.

The Comstock deep waters belong to the same general type as the deep hot mine waters of Tonopah, Nev., and the thermal springs at Ouray, Colo., and may profitably be compared with them. (See

fig. 8.) At Tonopah carbonates are abundant as gangue minerals and as alteration products in the wall rocks, and it is therefore natural that the weak acid radicles (CO_3 and HCO_3) should be more abundant in the waters than at the Comstock. The Tonopah water resembles that of the Comstock, however, in the abundance of alkali radicles and the paucity of metal radicles. The thermal spring waters of Ouray resemble those of the Comstock in the great dominance of strong acid radicles (mainly SO_4), but the alkali radicles are less abundant.

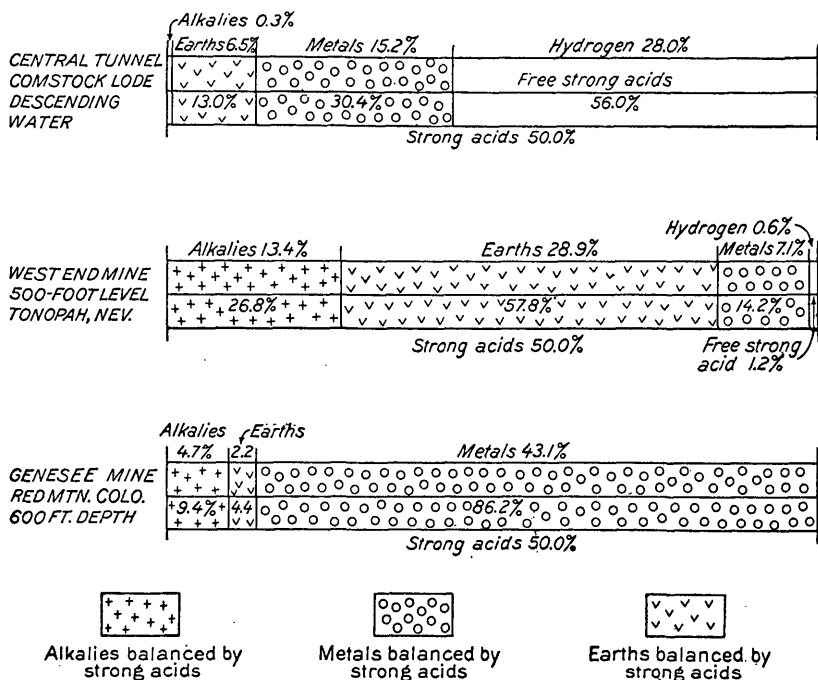


FIGURE 13.—Composition diagrams of cool descending mine waters from Comstock lode and Tonopah, Nev., and from Red Mountain, Colo.

At the time of visit in 1915 there were no favorable opportunities for collecting mine waters from the upper levels in the Comstock lode, but about 1904 John A. Reid²² collected a sample of cold water descending through the lode from a point about 100 feet below the surface in the Central tunnel. This analysis is shown in the table on page 60 and in figure 13. Its chemical characters are in marked contrast to those of the hot deep waters, especially in its poverty in alkalies and the abundance of metals and of free acids.

The quantity of free acid, mostly H_2SO_4 , present is remarkable but becomes understandable when it is recalled that carbonates that would neutralize free acid are exceedingly rare both in the ores and in the altered wall rocks. This water belongs to the same general class

²² Op. cit., p. 192.

as the descending water at Tonopah²³ shown diagrammatically in figure 13, but in the Tonopah water free acid is much less abundant, as might be expected from the prevalence of carbonates as gangue minerals. The sample collected by Reid also belongs to the same general class as a water collected by Chase Palmer and the writer from the Genesee mine, at Red Mountain, Colo. The analysis of this water has not yet been published, but the quality of the water is shown diagrammatically in figure 13. This water was dripping from limonite stalactites in the roof of workings in ore body No. 3, about 600 feet below the surface. It is proportionately much richer in metals than the Comstock or Tonopah waters, but it carries no free acid.

In the above comparisons of Comstock waters the factor of concentration has been purposely eliminated. It is important to note, however, that the cool descending water is more than 200 times as concentrated a solution as the hot ascending waters.

CONCLUSIONS.

The application of detailed methods of microscopic study to a considerable number of specimens from the Comstock lode obtained at depths ranging from a few hundred feet to 2,900 feet shows with a reasonable degree of conclusiveness that in ores from depths greater than 500 feet, including the bulk of the bonanza ores of the lode, the silver is essentially all in primary minerals. Descending solutions of surface origin produced an important increase in the silver content of certain ores within 500 feet or less of the surface, yet even in such situations a part of the silver content is in primary minerals, and some rich ores from slight depths showed no secondary silver minerals.

Gold, so far as observed, is primary in all the ores.

Although the occurrence in the deep portions of the lode of ore bodies comparable in size and richness to the great bonanzas of the past is not to be expected, yet the primary origin of some of the rich ores offers encouragement for deep development.

The hot ascending mine waters of the Comstock lode are essentially sodium and calcium sulphate solutions. Similar waters are characteristic of certain sedimentary formations, but the association of these waters with igneous rocks and the fact that they carry measurable quantities of the precious metals suggest that they may be related to the solutions that deposited the primary ores. The hot waters of the Comstock resemble somewhat the deep hot mine waters at Tonopah but are poorer in carbonates.

²³ For occurrence and analysis see Bastin, E. S., and Laney, F. B., *op. cit.*, pp. 29, 44.

