SILVER ENRICHMENT IN THE SAN JUAN MOUNTAINS, COLORADO.

By Edson S. Bastin.

INTRODUCTION.

The following report forms part of a topical study of the enrichment of silver ores begun by the writer under the auspices of the United States Geological Survey in 1913. Two reports embodying the results obtained at Tonopah, Nev.,[1] and at the Comstock lode, Virginia City, Nev.,[2] have previously been published.

It was recognized in advance that a topical study carried on by a single investigator in many districts must of necessity be less comprehensive than the results gleaned more slowly by many investigators in the course of regional surveys of the usual types; on the other hand the advances made in the study of a particular topic in one district would aid in the study of the same topic in the next. In particular it was desired to apply methods of microscopic study of polished specimens to the ores of many camps that had been rich silver producers but had not been studied geologically since such methods of study were perfected.

If the results here reported appear to be fragmentary and to lack completeness according to the standards of a regional report, it must be remembered that for each district only such information could be used as was readily obtainable in the course of a very brief field visit. The results in so far as they show a primary origin for the silver minerals in many ores appear amply to justify the work in the encouragement which they offer to deep mining, irrespective of more purely scientific results.

The work in the San Juan Mountains occupied about a month in the fall of 1913. The office study of the results, involving a large amount of microscopic work, was delayed until the summer of 1920, first because of the writer's absence from the country on professional work and later through duties incident to the war.

In the work near Ouray the writer was accompanied by Chase Palmer, chemist, of the United States Geological Survey, who con-

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[1] Bastin, E. S., and Laney, F. B., The genesis of the ores at Tonopah, Nev.: U. S. Geol. Survey Prof. Paper 104, 1918.

[2] Bastin, E. S., Bonanza ores of the Comstock lode, Virginia City, Nev.: U. S. Geol. Survey Bull. 735, pp. 41–63, 1922 (Bull. 735–C).

tributed valuable advice and assistance in the testing and collection and later in the analysis of the waters of mines and hot springs.

The writer is indebted to Mr. William Rathmell, of Ouray, for many excellent specimens of rich silver ores; to Mr. Fred Carroll, of the Atlas mine, Ouray; Mr. F. G. Farish, of the Humboldt mine, near Telluride; Mr. L. F. S. Holland, then in charge of the Smuggler-Union mine, at Telluride, and many others for valuable aid and generous hospitality.

REGION NEAR OURAY AND TELLURIDE.

GENERAL GEOLOGIC FEATURES.

Few regions in the United States have had a geologic history of such fascinating complexity as the San Juan region. In the following paragraphs only those outstanding features of this history which are essential as a background for the writer's studies will be given. The reader is referred to earlier Survey reports[3] for further details.

The bedrocks of the Ouray-Telluride region include sediments of Algonkian, Devonian, Carboniferous, Triassic, Jurassic, Cretaceous, and Tertiary age, Tertiary extrusive rocks in great variety, and Tertiary intrusive rocks of several kinds. The Algonkian sediments are highly tilted, but the younger sediments and the extrusive rocks are nearly flat or gently folded except where disturbed by igneous intrusions. In Quaternary time deposits of glacial till and of fluviatile and landslide material have been formed.

The major part of the surface in the area between Ouray and Telluride is occupied by the Tertiary volcanic rocks. The sedimentary bedrocks crop out mainly in the walls and floors of the valleys, and the Quaternary deposits are also confined mainly to the valleys.

The dominant types among the Tertiary volcanic rocks are the San Juan tuff and the overlying Silverton and Potosi volcanic series. The San Juan tuff consists of bedded tuffs and volcanic breccias and agglomerates of andesitic composition. The Silverton volcanic series consists of andesite and rhyolite flows, tuffs, and breccias. The Potosi volcanic series consists of flows and tuffs of general rhyolitic composition. The Tertiary intrusive rocks range in composition from quartz monzonite to diorite and gabbro.

The region is characterized by very rugged topography and a relief amounting to about 6,000 feet. Ouray has an altitude of about 7,800 feet, Telluride of about 8,700 feet, and neighboring high peaks rise to heights around 13,800 feet.

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[3] Cross, Whitman, and Purington, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), 1899. Cross, Whitman; Howe, Ernest; and Irving, J. D., idem, Ouray folio (No. 153), 1907. Cross, Whitman; Howe, Ernest; and Ransome, F. L., idem, Silverton folio (No. 120), 1905.

The ore deposits comprise fissure veins, replacement deposits in quartzite, and replacement deposits in limestone. The fissure veins cut all the bedrock formations. The observations on which this report is based relate principally to the fissure veins, but the ores of the Newsboy mine (see p. 73) exemplify the replacement deposits in limestone. The ore deposits have been attributed by previous students of these districts to deposition from ascending thermal solutions that were an after effect of the Tertiary volcanic activity, followed in some places by enrichment through the agency of descending waters of surface origin. The ores have been mined mainly for their gold and silver content, though some copper, lead, and recently zinc have been recovered from them.

The productive portions of most of the fissure veins are within the San Juan tuff and the Silverton series, though certain productive veins like the Bachelor traverse the underlying sediments, and some replacement deposits occur in limestone. Purington[4] long ago called attention to the marked decline in the metal content of certain veins near Telluride in passing upward from the San Juan tuff and the Silverton series, which are prevailingly andesitic and fragmental, into the overlying Potosi series, which is prevailingly rhyolitic and more massive. This change he attributed mainly to the mechanical influence of rock texture and structure upon the degree of fracturing prior to mineralization, but he believed that rock composition also exerted some control upon the kind and abundance of ore minerals that were deposited.

The long and varied physiographic history of the region—that is, the steps by which the surface has been shaped to its present rugged and diversified form—has been summarized by Atwood and Mather.[5] Obviously this history has an important bearing upon the problems of the enrichment of the ores, but at present it is not possible to correlate the phenomena of enrichment with particular stages in the erosion of the region.

HOT SPRINGS NEAR OURAY.

Within the limits of the town of Ouray are a number of hot springs that apparently issue from Carboniferous limestone of the Hermosa formation. The primary mineralization in this ancient volcanic district is generally attributed to thermal solutions coming from the same deep sources that yielded the lava flows. Hot springs in such districts are also interpreted usually as an after effect of volcanism.

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[4] Purington, C. W., Ore horizons in veins of the San Juan Mountains, Colo: Econ. Geology, vol. 1, pp. 129–133, 1905.

[5] Atwood, W. W., and Mather, K. F., Geographic history of the San Juan Mountains since the close of the Mesozoic era (abstract): Geol. Soc. America Bull., vol. 27, pp. 38–39, 1916.

Although these springs are unconnected with the problem of silver enrichment it seemed that the opportunity to collect samples of their waters should not be neglected, because the analysis of these waters might throw light upon the chemistry of the deposition of the primary ores. The samples were collected and analyzed by Chase Palmer, and the results are given in the following table. The waters are clear and are depositing gypsum.

Analyses of hot-spring waters from Ouray, Colo.

[Chase Palmer, analyst. Parts per million except as otherwise indicated.]

Radicle.	1	2	3	4				
				Parts per million.	Reacting value.			
					By weight.	Per cent.		
Na	121.0	114.0	106.0	119.0	5.1765	10.4	11.2	50.00
K	18.0	18.0	18.0	15.3	.3917	.8		
Ca	375.0	357.0	366.0	370.0	18.4630	37.1	38.6	
Mg	11.0	11.0	9.9	9.3	.7645	1.5		
Mn	.4	Trace.	Trace.	.4	[a] .0145	.03	.2	
Fe	1.9	1.3	4.2	2.1	[a] .0752	.15		
SO_4	1,133.0	1,059.0	1,076.0	1,084.0	22.5472	45.3	47.7	50.00
Cl	41.0	42.0	41.0	42.0	1.1844	2.4		
HCO_3	40.0	60.0	46.0	70.0	1.1480	2.3	2.3	
SiO_2	13.0	35.0	33.0	11.4	....	......	......	......
	1,754.3	1,697.3	1,700.1	1,723.5	49.7650	99.98	100.0	100.00

[a] Assumed as bivalent.

1. Just back of zinc concentrator, 65 feet from No. 4. Temperature, 132° F.
2. About 300 feet east of No. 4. Temperature, 134° F.
3. 40 feet above and 75 feet east of No. 2. Temperature, 142° F.
4. About 150 feet northwest of zinc concentrator. Temperature, 152½° F.

No. 4.	Alkalies balanced by strong acids	22.4
	Earths balanced by strong acids	73.0
	Earths balanced by weak acids	4.2
	Metals balanced by weak acids	.4
		100.0

In reaction these waters are neither acid toward litmus nor alkaline toward phenolphthalein. As shown by the analyses they are dominantly sodium and calcium sulphate waters, and they are depositing somewhat porous masses of finely crystalline gypsum.

The four waters are so similar in composition that only one of the analyses has been recalculated into terms of the reacting values of the components in accordance with the methods proposed by Palmer.[6]

These analyses fail to indicate conclusively the origin of the waters. Waters carrying calcium and sodium sulphates as their principal components are common in sedimentary formations that contain gypsum and salt. The Hermosa limestone, from which these waters issue, is known to be gypsiferous, as are some of the younger

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[6] Palmer, Chase, The geochemical interpretation of water analyses: U. S. Geol. Survey Bull. 479, 1911. See also Rogers, G. S., The interpretation of water analyses by the geologist: Econ. Geology, vol. 7, pp. 56–88, 1917.

sediments. Waters of meteoric origin descending through such sediments may have become heated by contact with igneous rocks or by the friction of movements within the rocks.

On the other hand, thermal waters approximating the composition of those of the Ouray springs occur in association with ore deposits where contributions to their mineral content from sedimentary sources are improbable. One of the best examples of such waters is the water from the 2,650-foot level of the Union shaft, at the Comstock lode, which is essentially a calcium and sodium sulphate water. The Ouray waters also bear some resemblance to the deep thermal waters at Tonopah, which are dominantly sulphate waters, but in which sodium is present in much greater abundance than calcium.

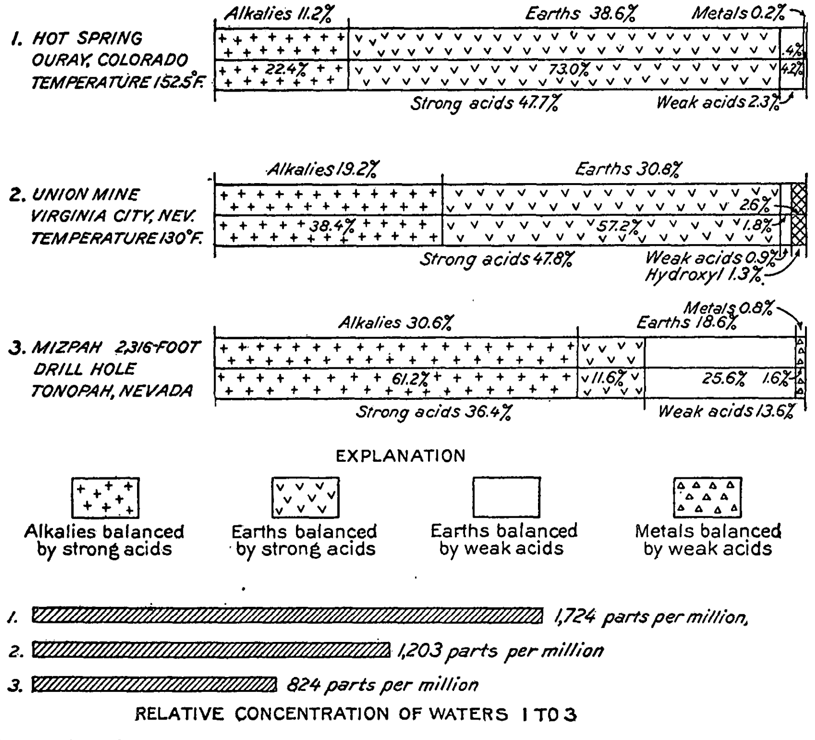

FIGURE 14.—Composition diagrams of thermal spring waters from Ouray, Colo., and somewhat similar mine waters from Virginia City and Tonopah, Nev.

Final judgment as to the origin of the Ouray spring waters must apparently be held in abeyance for the present. Composition diagrams of these waters are shown in figure 14. The close similarity of the four waters from Ouray, both in respect to quality and to concentration, is perhaps an added argument in favor of a deep-seated origin.

BACHELOR AND WEDGE MINES.

The Bachelor and Wedge mines are about 2 miles north of Ouray.[7] The Bachelor vein, which has been opened in the Bachelor, Wedge, and Neodesha mines, is in general of easterly trend and nearly vertical and traverses rather flat-lying Jurassic and Cretaceous sediments. At one horizon movement along the bedding of these sediments prior to mineralization shifted the vein fissure so that for a short space the vein lies almost flat. Owing to the slight amount of faulting involved in the formation of the vein fissure the vein does not crop out but terminates upward in a mere distortion of the black shales that form its cap.

The part of the vein first examined by the writer was on a level about 180 feet above the Bachelor tunnel, near the middle of the part of the vein that belongs to the Bachelor mine. It is in this part of the mine that the vein is nearly horizontal. The primary ore minerals noted here were galena, sphalerite, chalcopyrite, tetrahedrite, pearceite, quartz, barite, and manganiferous calcite. Irving[8] states that the galena is argentiferous. Pearceite and tetrahedrite, identified with certainty by microchemical tests, are intimately intergrown in the fashion shown in figure 15. They are clearly contemporaneous with each other and with galena, sphalerite, and chalcopyrite and are therefore primary. To the unaided eye the intimate intergrowth of pearceite and tetrahedrite has the appearance of ordinary tetrahedrite, though reacting strongly for silver. In one specimen this "gray copper" forms fully half of a veinlet about 1 inch in width. An assay of this veinlet made in the Geological Survey laboratories showed 2,190 ounces of silver to the ton and 6.4% of copper. In the specimen assayed no secondary silver minerals were recognizable by the unaided eye.

The absence of outcrop in the Bachelor vein is a feature unfavorable to extensive oxidation and hence unfavorable to downward enrichment. That downward enrichment in both silver and copper has taken place, however, is clearly demonstrated. Some of the ore from the above-mentioned locality shows bornite and chalcocite tarnishes along fractures in chalcopyrite, and in vugs the chalcopyrite is coated by sooty chalcocite. In the same polished specimens that show primary pearceite (see fig. 15) tarnishing of the galena with hydrogen peroxide shows that it has been replaced peripherally in places by a mineral of exactly the whiteness of galena. This mineral could not be certainly identified. It is unaffected by HCl, KCN, $HgCl_2$, and KOH, but is tarnished by HNO_3 and $FeCl_3$. It therefore does not correspond to any of the minerals listed by

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[7] Irving, J. D., U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 153), p. 17, 1907.

[8] Idem, p. 17.

Davy and Farnham.[9] It is certainly not pearceite or polybasite. Even if argentiferous at all it is present in too small amounts to have any great influence on the tenor of the ore.

Other specimens show primary ore traversed by narrow, clean-cut fractures along which pearceite (antimony-bearing), calcite, and chalcopyrite have been deposited. The pearceite rarely shows crystal faces; it can be cleanly stripped from the walls of the fractures. The calcite is not everywhere present but is intimately intergrown with the pearceite and plainly contemporary with it. The chalcopyrite occurs in very small amounts and is finely crystalline. Slight staining with iron oxide is characteristic of most portions of the fractures that carry these minerals but does not penetrate the primary ore bordering the fractures.

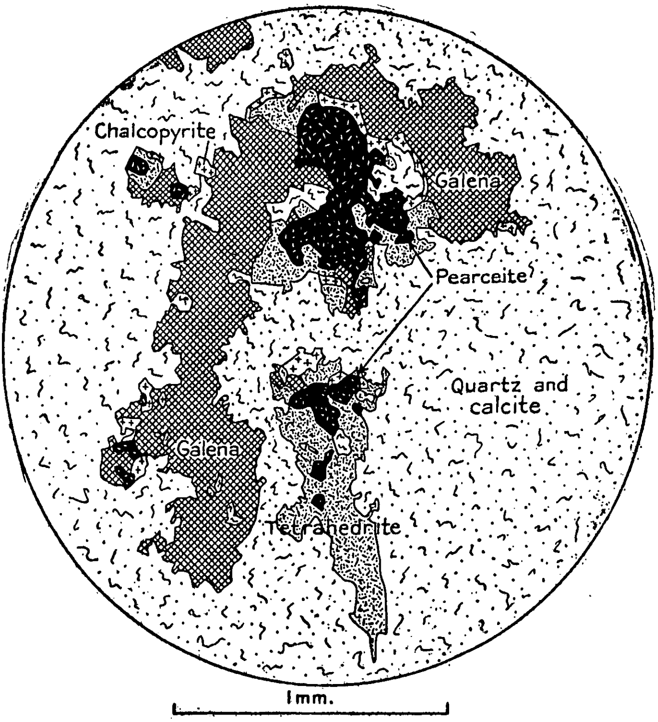

FIGURE 15.—Ore showing primary pearceite intergrown with tetrahedrite, chalcopyrite, and galena, Bachelor mine, Ouray, Colo. Camera lucida drawing.

It is clear from these relations that a period of fracturing intervened between the formation of the undoubted primary pearceite-bearing ore and the deposition of more pearceite accompanied by chalcopyrite and calcite. These later minerals may possibly represent a second stage of primary mineralization, but it seems more

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[9] Davy, W. M., and Farnham, C. M., Microscopic examination of the ore minerals, pp. 93, 99, New York, 1920.

probable that they are products of enrichment through the agency of descending surface waters. The presence of sooty chalcocite in the same part of the mine as evidence of alteration of chalcopyrite by descending waters supports this interpretation, as do also the occurrences of native silver next to be described. The presence of calcite shows that the solutions which deposited the younger pearceite were not acid.

The second locality at which the ores were studied was in the Wedge mine on a level about 60 feet below the Bachelor tunnel and 650 feet below the surface. The ores studied were taken from the north branch of the Bachelor vein at a point where it traverses a gray sandstone. Here occur numerous small veinlets a few millimeters across, whose walls are lined with comb quartz and whose medial portions are in part open. There is slight local oxidation. Usually occupying the medial portions of these veinlets, though interlocking with the quartz of the walls, occur scattered patches of galena, of chalcopyrite, rarely of sphalerite and ferruginous calcite. Sheetlike masses of chalcopyrite 1 to 2 millimeters thick in some of these veinlets show bornite tarnishes along fractures and have been altered next to the quartz walls to a somewhat porous mass of chalcocite. On this chalcocite in places native silver has been deposited. From these beginnings of chalcocite and silver deposition all transitions are traceable to chalcocite with only small remnants of chalcopyrite bordered on both sides by a thin deposit of native silver and in places traversed along fractures by thin veinlets (probably replacement veinlets) of the same metal. Finally in some specimens the chalcocite has been altered to black impure chrysocolla (copper pitch ore), which is still bordered on each side by silver. A little argentite is irregularly associated with the native silver. Calcite, probably primary, remains in many of the specimens that carry abundant silver, so that it may be inferred that the silver-depositing solutions were neutral or at most not strongly acid.

From these relations it appears that solutions carrying both silver and copper effected a gradual alteration of chalcopyrite to chalcocite and then to copper pitch ore and that the chalcocite served as an agent for the precipitation of native silver, probably in accordance with the reaction $Cu_2S+2Ag_2SO_4 \rightarrow 2CuSO_4+Ag_2S+2Ag$ set forth by Palmer and the writer in an earlier paper.[10] It should be noted that the silver sulphate solution used in working out this reaction was neutral. To test further the applicability of this reaction to the ore under study, fragments of the chalcocite associated with the native silver were immersed in a dilute neutral solution of silver sulphate. Silver crystals immediately began to develop in the chalcocite.

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[10] Palmer, Chase, and Bastin, E. S., Metallic minerals as precipitants of silver and gold: Econ. Geology, vol. 8, p. 155, 1913.

The presence of copper pitch ore, which always requires oxidizing conditions for its development, is conclusive evidence that descending meteoric waters deposited the associated silver and chalcocite. The minerals known or believed to be products of downward enrichment in this vein may, therefore, be listed as chalcocite, copper pitch ore, native silver, argentite, pearceite, chalcopyrite (finely crystalline), and calcite.

In general, therefore, these observations, though based on only brief field studies, show conclusively that the ores of the Bachelor vein carry primary pearceite, as well as tetrahedrite that may be argentiferous, in sufficient abundance to constitute in places rich silver ores, small specimens assaying as much as 2,190 ounces of silver to the ton. Much of the ore has subsequently been enriched in silver through the deposition by descending meteoric waters of native silver, argentite, and probably pearceite. Such enrichment extends in at least one place to a depth of 650 feet. The waters at the time these minerals were deposited were neutral or at most very weakly acid.

NEWSBOY MINE.

A few specimens were collected from the ore bins at the Newsboy mine, but the mine itself was not accessible. The mine is on the east slope of the Uncompahgre Valley about 3½ miles north of Ouray.

According to Irving,[11] the ores of this mine are representative of a group of broad, flat deposits that replace limestone adjacent to vertical or nearly vertical fissures along which the mineralizing solutions circulated. He says:

> At the Newsboy mine the limestone which carries the ore is bluish black in color and is overlain by clay shale and sandstone and underlain by thin-bedded black shales and a heavy gray sandstone. It is about 5 to 7 feet in total thickness. The shoots of ore here are flat masses and as a rule fill the entire space between roof and floor. Laterally the valuable portions of the ore material extend from 5 to 30 feet from the fissure, although the silicification goes much farther. The shoots run nearly east and west, parallel to the direction of the fissure, for distances of 300 feet or more in places. Most of the shoots lie north of the vein.

Specimens from the ore bins showed the following minerals: Primary, dominant, barite, argentiferous tetrahedrite, galena, and pyrite; subordinate, quartz, sphalerite, and chalcopyrite. Secondary, covellite, chrysocolla (?), azurite, malachite, and limonite.

The tetrahedrite, which is notably argentiferous, is associated with galena, sphalerite, and chalcopyrite and to the unaided eye has every appearance of being primary. The microscopic examination of a polished specimen confirms the primary nature of the argentiferous tetrahedrite by showing that it is irregularly intercrystallized with the unquestionably primary minerals. Secondary copper min-

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[11] Irving, J. D., U. S. Geol. Survey Geol. Atlas, Ouray folio (No. 153), p. 18, 1907.

erals, covellite, malachite, and azurite, have replaced chalcopyrite and tetrahedrite, the covellite developing first and then one or the other of the copper carbonates. Although no secondary silver minerals were noted in the specimens available for study, the fact that copper enrichment has occurred makes it probable that enrichment in silver has also been operative in certain parts of the ore body. It is certain, however, that the silver content of the ore is in considerable part if not mainly in primary argentiferous tetrahedrite.

ATLAS MINE.

The Atlas mine is near Sneffels, in the upper part of the valley of Canyon Creek, and may be reached most readily from Ouray. In 1913 mining was confined to the Klondike vein, which was seen by the writer at several places at depths ranging from 850 to 1,500 feet. Oxidation was noted throughout this range, but no evidences of downward sulphide enrichment were found. Mine waters descending through the vein were tested with methyl orange at three places and were uniformly neutral in reaction.

A typical specimen of ore from stopes above the G or Atlas tunnel level consisted of white quartz, galena, sphalerite, pyrite, chalcopyrite, and tennantite. Wet chemical tests showed the tennantite to be notably argentiferous. Microscopic examination of a polished specimen shows that all the minerals named are irregularly intergrown and are clearly primary. Tarnishing of the galena with hydrogen peroxide failed to show the slightest replacement of that mineral by other minerals; secondary minerals appear to be absent from this specimen.

Another specimen from the Klondike vein, taken from the ore bins, showed the same minerals as that just described, including the argentiferous tennantite, but in addition showed in small vugs in the most quartzose parts of the vein pearceite in small orthorhombic-appearing crystals. The pearceite is intercrystallized with quartz and calcite, crystals of clear quartz in places completely inclosing pearceite.

In another Klondike specimen from the ore bins rhodonite was present with quartz as a gangue mineral.

Ore from the J level on the Klondike vein showed well-formed crystals of sphalerite, chalcopyrite, and pearceite in vugs lined by hexagonal crystals of clear white quartz. The pearceite and chalcopyrite are to a large extent intergrown, and though in the main they crystallized later than the quartz, in places they are inclosed within the tips of transparent quartz crystals.

The quartz and coarsely crystalline chalcopyrite with which the pearceite is intergrown can not reasonably be regarded as a secondary deposit from descending solutions, for their crystals interlock at their bases with undoubted primary minerals. It follows that the pearceite is a primary mineral, and its restriction to the median, more quartzose part of the vein indicates that it was one of the last of the primary minerals to form.

VIRGINIUS VEIN IN REVENUE TUNNEL.

The Virginius vein crops out near the San Miguel-Ouray county line in the extreme northeastern part of the Telluride quadrangle.[12] It strikes about N. 46° W. and dips 60° SW. The older and higher workings on this vein in the Virginius Basin were inaccessible, but the vein was seen where intersected by the Revenue tunnel. This adit tunnel starts near Sneffels, in the northwest corner of the Silverton quadrangle, and intersects the Virginius vein at a depth of about 2,100 feet. Because of caving only a short segment of the vein was exposed, even at this locality.

From the Virginius shaft, which descends on the Virginius vein from the level of the Revenue tunnel, warm water was rising and flowing out along the floor of the tunnel. This water had a marked odor of hydrogen sulphide. Because of the caving of the shaft it was not possible to get a sample of this water before it had become mixed with surface waters coming down through the vein. The mixed water was neutral in reaction toward methyl orange and was not alkaline toward phenolphthalein.

Ore samples from the Virginius vein close to the Revenue tunnel were stained with iron oxide along fractures and in vugs. These specimens when carefully examined with the binocular microscope showed white quartz, sphalerite, galena, tennantite, chalcopyrite, and siderite intimately intergrown as primary minerals. Seemingly pure pieces of the tennantite were found by wet tests to be highly argentiferous. Along some fractures the tennantite showed slight alteration to covellite and chalcocite, and chalcopyrite had altered similarly. It is clear that the silver content of this ore is mainly in tennantite, but some silver is in secondary ruby silver (proustite) that forms small thin patches on sharp fractures that cut the primary ore. This silver was probably deposited from descending solutions. The abundance of perfect crystals of siderite in vugs indicates that the enriching solutions that deposited chalcocite, covellite, and proustite were not notably acid.

In view of the presence of thermal waters ascending along the vein close to the place where the ores described above were collected,

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[12] Purington, C. W., Preliminary report on the mining industries of the Telluride quadrangle, Colo.: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 836–838, 1898. Cross, Whitman, and Purington, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), economic-geology map, 1899.

it seems possible that such waters may have occupied all cavities in this portion of the vein prior to its intersection by the Revenue tunnel, about 1893 or 1894, and may have prevented both oxidation and downward sulphide enrichment. If this was the case, the observed slight oxidation and enrichment have occurred after the draining of the vein through the tunnel. Data for deciding this point are lacking.

YANKEE BOY MINE.

The Yankee Boy mine is about 4½ miles northeast of Telluride, near the head of Canyon Creek.[13] It is more easily reached from Ouray than from Telluride. The vein strikes about N. 35° W. and is nearly vertical. The mine has long been idle, and most of the workings were inaccessible in 1913. In past years it produced modest amounts of rich ore carrying ruby silver. At the one exposure where the vein was visible it was a shattered zone 4 to 5 feet wide sparsely mineralized along certain bands with finely divided sulphides.

The proximity of the outcrop of the vein to Canyon Creek, which at one place cuts across the course of the vein, offers a serious though possibly not insuperable obstacle to deep mining.

A number of ore specimens were obtained from the mine dump, and several were obtained from private collections in Ouray; these showed quartz, calcite, siderite, barite, galena, sphalerite, pyrite, arsenopyrite, chalcopyrite, pearceite, and proustite. In the specimens collected from the dump proustite occurs in well-formed crystals between the quartz crystals of vugs and apparently is slightly younger than the quartz. From these specimens alone the primary origin of the proustite could not be affirmed, but two specimens richer in proustite, obtained from collections in Ouray, were studied under the microscope and show clearly that the proustite is primary. One specimen obtained from the collections in the Miners and Merchants Bank at Ouray carried quartz, galena, sphalerite, chalcopyrite, tennantite, and proustite very intimately and irregularly intergrown in the fashion shown in figure 16. Tarnishing of the galena with hydrogen peroxide failed to show any replacement of it by proustite or any other mineral.

Another specimen from the Yankee Boy mine, obtained through the courtesy of Mr. William Rathmell, is unusual in showing two generations of ore minerals. Minerals of the first generation are quartz, siderite, sphalerite, galena, pyrite, and arsenopyrite. The ore containing these minerals was fractured, and in the fractures, as well as in vugs in the older ore, were deposited an association of

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[13] Cross, Whitman, and Purington, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), economic-geology map, 1899.

quartz, siderite, sphalerite, galena, pyrite, and arsenopyrite. The sphalerite, pyrite, arsenopyrite, and pearceite. The minerals of this second generation are irregularly intercrystallized, replacement phenomena appear to be lacking, and they are believed to be late primary (hypogene). Proustite intercrystallized with base-metal sulphides is continuous with relatively large proustite crystals in vugs.

In conclusion, the ores of the Yankee Boy mine that were studied, including specimens very rich in ruby silver, carried their silver entirely in primary minerals—proustite, pearceite, and probably argentiferous tennantite. Although none of the specimens came from depths of more than a few hundred feet, the mine workings being shallow, no evidences of enrichment were observed. A more exhaustive study of the vein, had it been possible, would probably have revealed some enrichment, but it seems clear that the process was of minor importance, and that the rich bodies of ruby silver ore formerly mined were in the main primary. Further development, if ever attempted, should not be hampered by any popular prejudice against the idea that rich ruby silver ores may persist in depth. If new

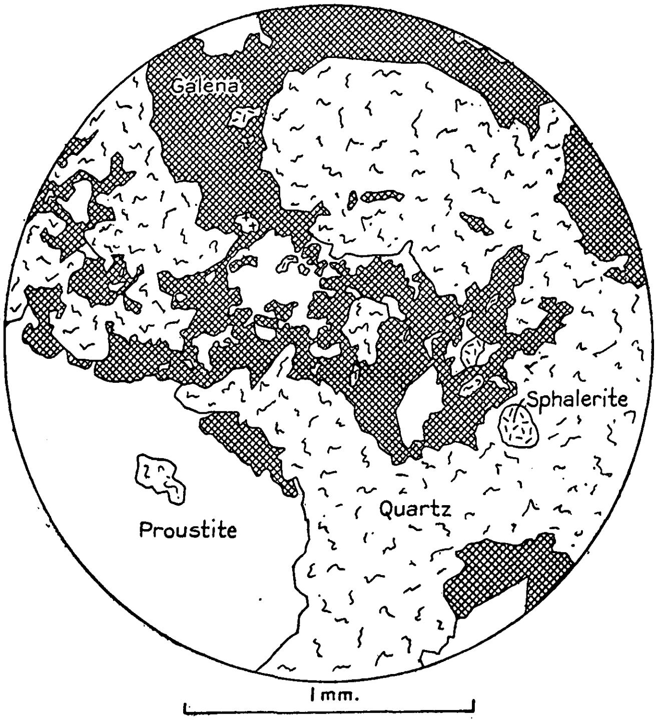

FIGURE 16.—Primary intergrowth of proustite, galena, quartz, and sphalerite in ore from Yankee Boy mine, between Ouray and Telluride, Colo. Camera lucida drawing from polished specimen.

bodies of rich silver ore are discovered, representative samples should be studied microscopically by a competent geologist to determine the primary or secondary character of the silver minerals.

RUBY TRUST TUNNEL.

The Ruby Trust tunnel, long ago abandoned and caved, lies about three-quarters of a mile southeast of the Yankee Boy. The portal is only about 20 feet above the level of Canyon Creek. No rich silver minerals were noted on the dump, but according to Mr. Fred Carroll ruby silver occurred in the shallower portions of the vein nearest to the portal but became much less abundant at greater depths farther in the tunnel. In view of the primary character of rich ruby silver ore in the Yankee Boy mine, this reported decrease in abundance of the rich ruby silver ore with increasing depth is probably to be attributed to irregular and spotty primary mineralization and not to enrichment near the surface that died out in depth.

It is probable that the mine is worthy of geologic study to determine definitely whether the rich ore is primary or secondary and, if primary, whether the vein is sufficiently well mineralized to justify further development.

MOUNTAIN TOP TUNNEL.

The Mountain Top tunnel, whose portal is in the Marshall Basin north of and below the Humboldt mine, is a crosscut tunnel trending about N. 83° E. The Terrible No. 3 vein, cut by this tunnel about 1,230 feet from the portal, strikes about N. 66° W. and dips 75° SW. No ore had been shipped from this vein at the time of visit, but as exposed in the tunnel it has a width of about 3½ feet, of which 5 inches is quartz with abundant sulphides and the remainder is fractured and decomposed wall rock cut by several seams of gouge.

The richer ore consists of finely crystalline white quartz carrying scattered irregular bunches of galena, sphalerite, pyrite, and tennantite. The tennantite is slightly argentiferous. In narrow fractures cutting through this ore occur very thin interrupted patches of proustite (light ruby silver). The proustite is unmixed with other minerals and can be cleanly stripped from the walls of the fracture. It was probably deposited by descending solutions. There is no oxidation along the fractures that carry proustite, but other adjacent fractures are iron stained.

The intersection of the vein by the tunnel is about 400 feet below the surface, and there are no higher workings. Water dripping through the vein gave a slightly acid reaction with methyl orange. Sampling of 1 foot in width of the richest portion of this vein is said to have shown 0.2 ounce of gold and 64 ounces of silver to the ton.

From the meager exposures available it appears that some of the silver content of the ore is in primary argentiferous tennantite, but also that some of the silver is in the mineral proustite occurring along small cracks and probably the result of supergene enrichment. The solutions that accomplished this enrichment were probably slightly acid or neutral. What proportion of the silver content is in primary or in secondary minerals can be determined only by detailed studies of a considerable number of specimens. It should be noted, however, that the silver in the neighboring Smuggler-Union vein is mainly primary.

HUMBOLDT MINE.

The Humboldt mine is on the northeast slope of St. Sophia Ridge, at an altitude of about 12,700 feet.[14] The mine develops the northwestward extension of the Smuggler-Union vein, and the workings of the two mines are connected. The general trend of the vein is about N. 20°–30° W. The width of the vein in the Humboldt mine, according to the sampling map, ranges from 1 to 5 feet and averages between 2½ and 3 feet.

Access to the vein is had through an adit or crosscut tunnel leading to a hoist at the collar of a vertical winze through which the second, third, fourth, and fifth levels are reached. The workings are mainly in the andesites of the San Juan "series," as the rocks are designated in the Telluride folio, but also extend upward into the overlying Potosi rhyolite that caps St. Sophia Ridge. The ores, which are worked for both gold and silver, are pronouncedly richer in the andesite than in the overlying rhyolite, as exemplified by the following assays of samples obtained on the third level:

Assays of samples from Humboldt mine.

Wall rock.	Distance from shaft (feet).	Width of vein sampled (feet).	Gold (ounces to the ton).	Silver (ounces to the ton).
Andesite	689	2.0	0.06	45.90
Do	693	1.1	.90	96.70
Do	696.5	1.1	.12	90.90
Do	700	2.4	.12	157.00
Do	704	2.0	.12	64.60
Do	706	1.5	1.40	58.20
Rhyolite	709.7	2.2	Trace.	90
Do	713	1.0	.02	1.60
Do	716	1.7	.02	1.30
Do	719.3	1.3	.04	5.60

Such relations are not exceptional but are characteristic throughout the workings. The assay maps show gold contents on the fifth level as high as 3 to 4½ ounces. The decrease in richness of many of

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[14] Cross, Whitman, and Purington, C. W., U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), economic-geology map, 1899.

the veins of this region in passing from the andesite to the rhyolitic series was long ago noted by Purington, to whose paper[15] the reader is referred for further discussion.

An excellent exposure of the vein in rhyolite was found on the third level 1,000 feet north of the shaft. Here it formed a fractured zone 3 feet wide showing oxidation along the fractures. A little pyrite occurred along narrow fractures, and there was a single band 1 to 2 inches wide of quartz carrying a sparse scattering of sulphides.

With this may be contrasted the appearance of the vein in andesite about 520 feet north of the shaft on the same level, where the vein is 5 feet wide. For 3 feet next to the footwall occurs altered andesite traversed by numerous stringers of quartz and sulphides as much as 2 inches wide, all nearly parallel to the trend of the vein. The remaining 2 feet of the vein is dark-colored andesite carrying abundant grains of disseminated pyrite. A few feet away along the vein the sulphide-bearing quartz veinlets are less regular and form essentially a filling between fragments of pyritized andesite. Stains of iron oxide in places discolor the quartz. The sulphides in the quartz

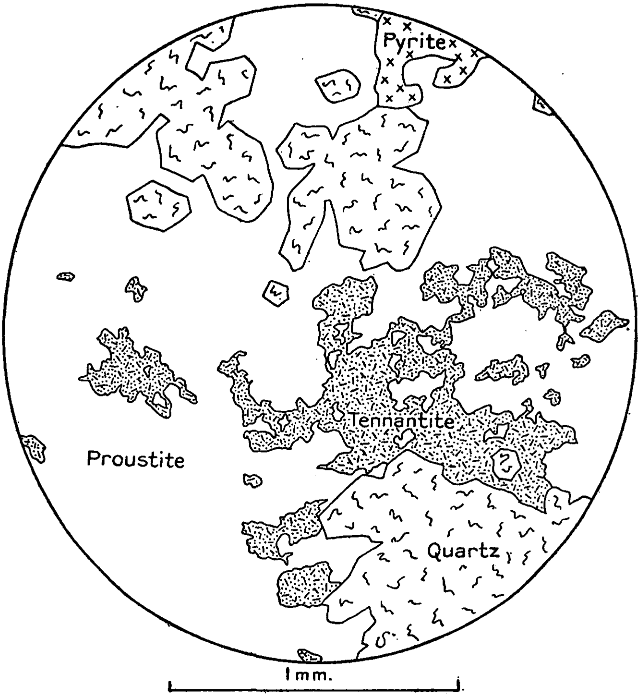

FIGURE 17.—Irregular intergrowth, apparently primary, of tennantite and proustite, Humboldt mine, between Ouray and Telluride, Colo. Camera lucida drawing from polished specimen.

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[15] Purington, C. W., Ore horizons in the veins of the San Juan Mountains, Colo.: Econ. Geology, vol. 1, pp. 129–133, 1905.

veinlets are in small grains and include pyrite, sphalerite, galena, tennantite, and a little chalcopyrite. The tennantite was shown by wet tests to be notably argentiferous; it is intergrown irregularly with the other ore minerals and is unquestionably primary. In spite of the stains of iron oxide in this ore the microscope shows no replacement phenomena or other features suggestive of enrichment.

Ore carrying the same minerals in essentially the same relations was obtained near the shaft on the fifth level at a vertical depth of about 730 feet. Arsenopyrite is also present in this ore; the tennantite is highly argentiferous and is clearly primary, containing numerous inclusions of sphalerite, galena, and quartz. Tarnishing of the galena with hydrogen peroxide shows that it has not been replaced by any secondary minerals. The quartz is in places stained brown by iron oxide.

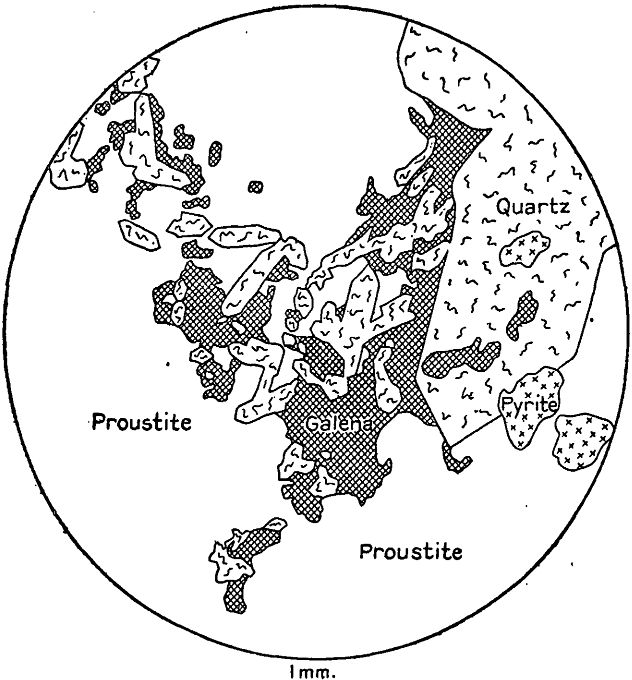

FIGURE 18.—Irregular intergrowth, apparently primary, of galena, quartz, and proustite, Humboldt mine, between Ouray and Telluride, Colo. Camera lucida drawing from polished specimen.

Light ruby silver (proustite) is abundant in many parts of the mine. A specimen from old stopes between the adit level and the second level, from a vertical depth below the surface probably not exceeding 300 feet, was polished and studied under the microscope. It carried the following minerals, named in approximate order of abundance: Quartz, proustite, sphalerite, galena, pyrite, and tennantite.

The proustite forms in places pure masses 1 centimeter across. There were no evidences that the proustite had replaced older minerals; on the contrary, it is in places intergrown with galena and tennantite so intimately and irregularly as to indicate contemporaneity, as is shown in figures 17 and 18. In a few places sphalerite is traversed by minute veinlets made up of quartz, tennantite, proustite, and rarely galena in irregular intergrowth. One of these veinlets carrying only quartz and proustite is shown in figure 19. The quartz, tennantite, and galena of such veinlets are certainly primary, though deposited after some sphalerite had formed and had been fractured; there is every indication that the associated proustite is also primary.

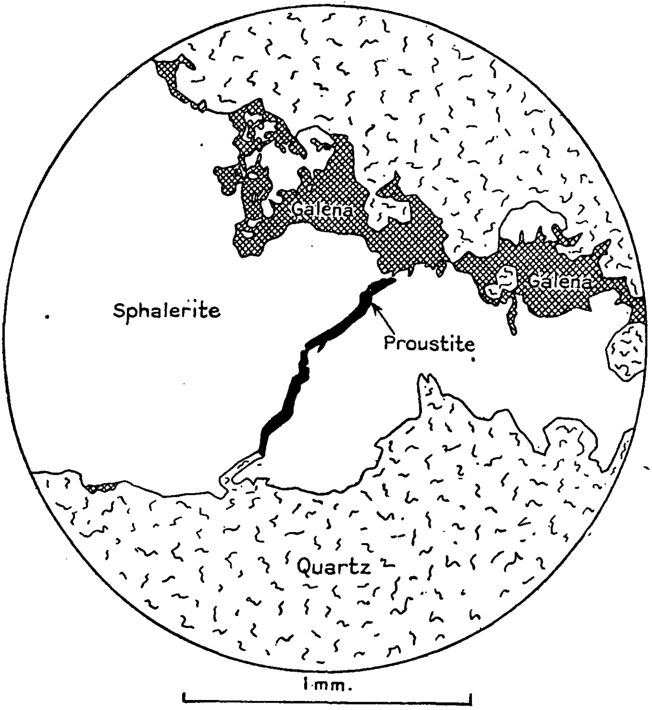

FIGURE 19.—Primary veinlet of quartz and proustite traversing sphalerite, Humboldt mine, between Ouray and Telluride, Colo. Camera lucida drawing from polished specimen.

Another specimen rich in ruby silver was collected about 700 feet north of the shaft on the third level. To the unaided eye it appears to be a fine-grained aggregate of quartz, sphalerite, and proustite. The microscope reveals the presence also of arsenopyrite and tennantite and shows that all these ore minerals are intergrown very intimately and irregularly and are certainly primary.

The quality of the waters descending through the vein was tested with indicators at several places in the workings. Water distinctly acid toward litmus paper was encountered on the upper or adit level and on the second level, but all waters from deeper levels were neutral toward litmus. Details of the tests are given below.

Tests of mine waters in Humboldt mine.

Level.	Distance north of shaft (feet).	Reaction toward litmus paper.	Remarks.
Adit	200	Acid	Drip from rhyolite roof, 180 feet vertically below surface.
Second	350-400	do	Drip from roof. From seam stained with iron oxide but showing no sulphides.
Third	910	Neutral	Drip from rhyolite roof. No stopes above.
Do	1,000	do	Oxidation along fractures.
Fifth	(a)	do	Drip from roof.
Do	370	do	Do.

[a] Opposite shaft.

To summarize, the Humboldt mine workings develop portions of the northward extension of the Smuggler-Union vein lying within 800 feet or so of the surface. Oxidation to the greatest depths that had been reached in 1913 was shown by stains of iron oxide on the vein quartz, but throughout most of the workings such oxidation has been slight and spotty. Waters dripping through the vein were acid on the two upper levels but neutral on the three lower levels. In the presence of acid waters and of some oxidation we should naturally expect to find some evidences of downward sulphide enrichment. The vein crops out, however, at elevations close to 13,000 feet, on the barren slopes of one of the steepest of the mountain ridges, where erosion is very rapid. In such a situation oxidation of vein material is not likely to be thorough, though it may extend to considerable depths along the vein, and it may encroach directly on primary ore. Microscopic study of the ores confirms these probabilities by showing that the silver occurs in argentiferous tennantite and in ruby silver (proustite) that are clearly primary. Microscopic evidences of replacement or other phenomena suggestive of downward enrichment are wholly lacking. An added factor tending to prevent downward enrichment is the passage of the vein near the surface into the Potosi rhyolite, in which primary mineralization was notoriously poorer than in the underlying andesitic series. The primary nature of the ores, even those which are rich in ruby silver, obviously offers encouragement for deeper development.

SMUGGLER-UNION MINE.

The Smuggler-Union mine has for many years been one of the large producers of gold and silver in the Telluride district. Ore is said to have been shipped from the Smuggler claim as early as 1875. The main workings of the mine develop the Smuggler-Union vein, which strikes about N. 25° W. and dips about 73° W.; there are some workings in subsidiary veins. Within the limits of this mine stoping on the Smuggler-Union vein has been continuous for about 6,700 feet. The Humboldt workings, already described, carry development about 1,000 feet farther north on the same vein. As shown on the economic-geology map of the Telluride folio[16] the vein is traceable on the surface for more than 2 miles. In 1913 stoping had extended to vertical depths of about 2,400 feet in the northern part of the Smuggler-Union mine.

At the time of the writer's brief visit in 1913 very little high-grade ore was being mined and the older upper workings of the mine were in the main inaccessible. Systematic studies of the extensive workings were not possible in the time available, and the writer's efforts were confined mainly to collecting representative samples of the richer ores from as great a vertical range as possible and to determining by later microscopic studies whether the silver content of these ores was in primary or secondary minerals.

The minerals reported from this mine by Purington[17] and earlier observers are quartz, calcite, siderite, rhodochrosite, barite, pyrite, chalcopyrite, sphalerite, galena, tetrahedrite, gold, proustite, pyrargyrite, polybasite, stephanite(?), and native silver.

The Smuggler-Union vein lies mainly between walls of andesite tuff and breccia of the San Juan "series," but passes above into the Potosi rhyolitic series. It declines notably in width and in richness in the rhyolite, as pointed out by Purington.[18]

Samples of rich ores from the older shallow workings could not be collected because all workings above the Mendota crosscut level were inaccessible, but Mr. L. S. F. Holland, the superintendent of the mine, furnished specimens from a sack of rich ore that had been inadvertently left in the old stopes and later recovered. This ore came from stopes between the second and third levels above the adit level, at a depth probably not far in excess of 500 feet. Narrow fractures in this ore are stained with limonite, but between these fractures there is no oxidation. The dominant minerals are white quartz and dark resin-colored sphalerite, with which are minor amounts of galena, pyrite, chalcopyrite, and light ruby silver (proustite). Even to the unaided eye there are indications that the proustite may be primary. Some proustite forms crystalline masses as much as 1 centimeter across, filling partly or completely the spaces between quartz crystals in vugs in the more quartzose parts of the ore. Such proustite might be either the last of the primary ore min-

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[16] Cross, Whitman, and Purington, C. W., U. S. Geol. Survey Geol. Atlas, folio (No. 57), 1899.

[17] Purington, C. W., Preliminary report on the mining industries of the Telluride quadrangle, Colo.: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 834, 1898.

[18] Purington, C. W., Ore horizons in the veins of the San Juan Mountains, Colo.: Econ. Geology, vol. 1, pp. 129–133, 1905.

erals or a secondary mineral. Near such crystals, however, proustite, quartz, chalcopyrite, and pyrite may be found very intimately intergrown, all apparently formed by late primary crystallization. Microscopic examination of polished surfaces confirms the primary character of the proustite and shows it to be intimately intergrown with quartz, pyrite, sphalerite, and tennantite in a fashion entirely similar to that noted in proustite ore near the adit level and illustrated in figure 20. There is no indication that the proustite replaces earlier minerals. Thus in spite of the comparatively shallow depths from which these specimens came and the presence of oxidation products along seams the silver content of the ore is wholly in primary minerals, mainly in proustite but probably also in tennantite.

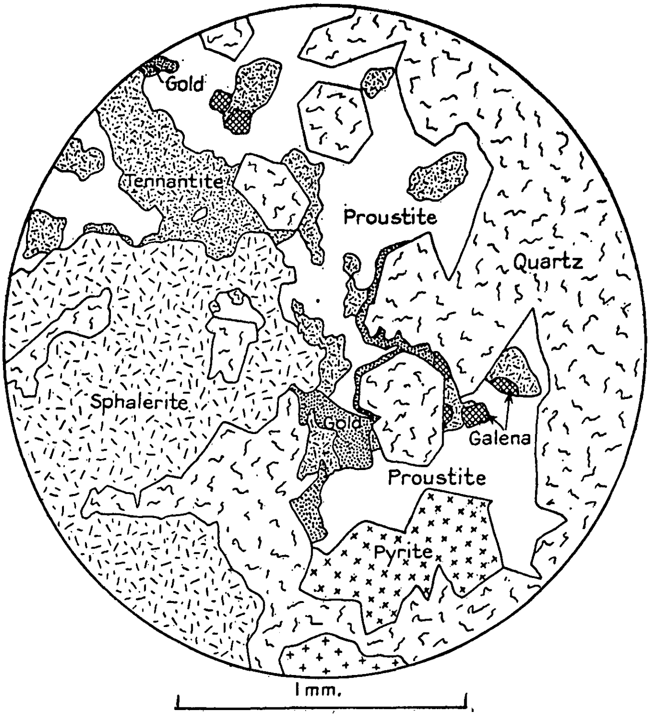

FIGURE 20.—Primary intergrowth of quartz, sphalerite, galena, tennantite, proustite, pyrite, and gold, Smuggler-Union mine, Telluride, Colo. Vertical depth about 1,200 feet. Camera lucida drawing from polished specimen.

Another specimen showing primary proustite in even greater abundance came from a vertical depth of about 1,200 feet, from a stope above the adit level, near the north boundary of the Mendota claim. To the unaided eye this ore is a granular aggregate of white quartz, proustite, sphalerite, pyrite, and rare galena, all apparently contemporaneous.

The microscopic examination of polished specimens confirms the conclusion that all these minerals are primary and reveals in addition the presence of tennantite and gold. The characteristic textural relation between these minerals is shown in figure 20. There is no indication that the proustite replaces any of the other minerals. Although all these minerals are primary and belong to the same period of mineralization, there are evidences that sphalerite began to be deposited first and that the deposition of proustite continued longest. This led to relations like that shown in figure 21, sphalerite having been fractured and the fracture healed by a late primary veinlet of quartz and proustite. Some such veinlets carry tennantite and a little galena in addition to quartz and proustite. Similar relations in the Humboldt mine are shown in figure 19 (p. 82). That proustite continued to be deposited to the very end of the primary period of deposition, even after quartz had ceased to form, is shown by its occurrence in vugs as a filling between well-formed quartz crystals. If additional evidence of the primary nature of the proustite were needed, it would be furnished by the occurrence here and there of bright-red proustite wholly inclosed within the tips of the clear hexagonal crystals of quartz that line some of the vugs. The quartz crystals interlock at their bases with the base-metal sulphides, and it is not considered possible that they are secondary.

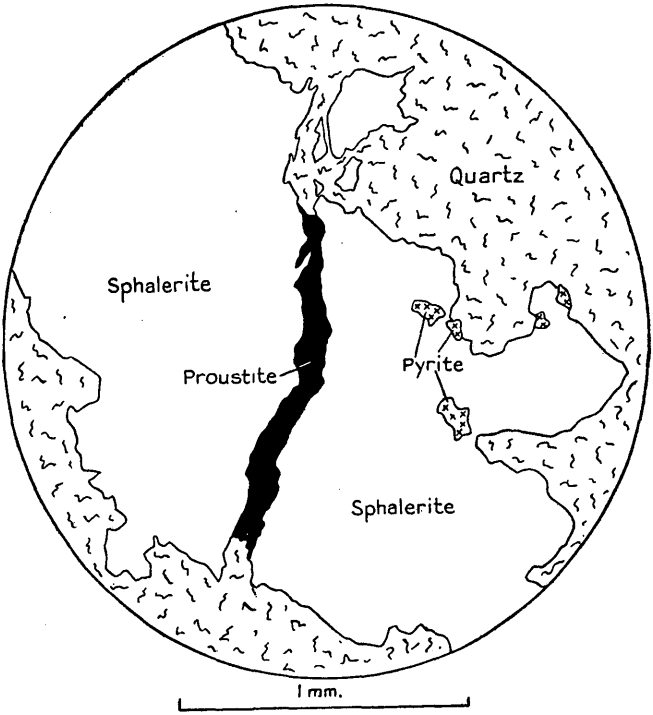

FIGURE 21.—Late primary veinlet of quartz and proustite traversing sphalerite, Smuggler-Union mine, Telluride, Colo. Same locality as figure 20. Camera lucida drawing from polished specimen.

The hand specimens of this rich ore show that proustite is particularly abundant in certain veinlets traversing the more massive ore. These veinlets, commonly one-sixth to one-eighth inch in width, carry pyrite and quartz intimately intercrystallized with the proustite. As a rule the quartz and sulphides of the veinlets show continuity with the same minerals in the massive ore that borders the veinlets. It is not possible to strip the proustite cleanly from the walls of these veinlets, as can usually be done with secondary proustite deposited in sharp-walled fractures in primary ore. These are therefore interpreted as late primary veinlets. Along them there has been some staining with iron oxide, and a peacock tarnish has developed on some of the proustite. The ore tends to break easily along the veinlets.

In contrast to the ores just described, ores from several other places in the mine showed secondary silver minerals in small amounts. A specimen obtained a short distance above the tenth level, near chute 83, about 1,700 feet vertically below the surface, when studied under the binocular microscope was found to carry as primary minerals quartz, galena, sphalerite, chalcopyrite, and the black brittle silver mineral pearceite. The pearceite occurs alone or irregularly intergrown with chalcopyrite between quartz crystals in the coarser and more quartzose parts of the ore. Although in the main the pearceite is later than the quartz, some of it is wholly inclosed within the tips of transparent quartz crystals. This relation and its intergrowth with coarse chalcopyrite indicates that the pearceite is a late primary mineral. Along narrow, clean-cut fractures traversing this ore occur thin fungus-like patches of argentite, native silver, or an association of these two. Argentite associated with wire silver occurs also in a few vugs. The silver wires are tapering and are attached to a base of argentite, from which they have probably formed. Both argentite and native silver are clearly later than the bulk of the ore, for they occupy sharp fractures in it; they are probably products of downward enrichment.

Ore from the Pennsylvania tunnel, about on the line between the Smuggler and Sheridan claims and about 1,750 feet vertically below the surface, carries as primary minerals quartz, pinkish calcite, pyrite, galena, and sphalerite. In vugs in the more quartzose parts of the ore occurs argentite deposited on and between the well-formed quartz crystals that line the vugs. It is uncertain whether this argentite is primary or secondary, but out of the argentite, clearly as an alteration product, have sprung tapering curling " teeth " of native silver.

Very fresh appearing ore from the eleventh level, about 1,300 feet vertically below the surface, carries bright wires of native silver. believed to be secondary, on quartz crystals in a vug.

The occurrence of primary gold in association with proustite has been described on page 85 and is shown in figure 20. Ore very rich in gold was collected from the eleventh level near the line between the Union and Smuggler claims, at a vertical depth of about 1,200 feet. Pale-yellow gold forms irregularly branching, mosslike masses and occurs also as "wires," some of which are an inch in length. Here and there small crystal faces are developed in both wire and mosslike forms. Some of the gold is irregularly intercrystallized with pure-white quartz, which also carries pyrite but no other sulphides. The intimate intercrystallization with quartz shows that the gold is primary.

The mine waters were tested with indicators at several places in the mine, but no samples were collected for analysis. Water dripping from the roof of the Mendota crosscut level at a point about 600 feet vertically below the surface was acid toward litmus paper. This water had passed through old stopes, and its quality may not be representative of descending waters there prior to mining operations. The lowest working on the vein is the Pennsylvania tunnel, which throughout most of its length develops the vein at vertical depths of 1,500 to 1,700 feet. Waters dripping from the roof at five points, 220 to 1,250 feet from the portal, were neutral, yielding no acid reaction with litmus or alkaline reaction with phenolphthalein. These neutral waters had not traversed any mine stopes.

The salient results of the study of the Smuggler-Union mine may be epitomized as follows: In samples of very rich ores from depths of 500 to 1,200 feet all the precious-metal content was in primary minerals, the gold native and the silver in primary proustite and pearceite and probably also in argentiferous tennantite. Secondary silver minerals are probably present here and there in this part of the vein, though absent from the particular samples studied, for secondary argentite and native silver were noted in ores from the deepest workings, those of the Pennsylvania tunnel, at vertical depths of 1,750 feet. Oxidation extends to the deepest workings, but is commonly limited to slight staining with limonite along fractures. The mine waters could not be tested in the exact situations at which secondary argentite and native silver were noted, but in analogous situations with respect to the surface the waters dripping from the roof in drifts following the vein were neutral.

Without studying a large number of samples from all parts of the workings it is impossible to state what proportion of the silver which the mine has produced has come from primary minerals and what from secondary minerals. The secondary minerals, argentite and native silver, though richer in silver than the primary minerals, proustite, pearceite, and argentiferous tennantite, appear to be present only sporadically and in relatively meager amounts. It is safe to say, however, that a very large part and possibly the major part of the silver content of the vein, even close to the surface was primary.

Oxidation of the vein material, though extending to the maximum depths attained in mining, has not been thorough even close to the surface and is characteristically restricted to mere staining along fractures. As pointed out in the description of the Humboldt mine, this is a consequence of the topographic position of the vein in a region of high altitude combined with high relief, which favored rapid mechanical erosion of the vein at its outcrop with a minimum of chemical disintegration.

LIBERTY BELL MINE.

The Liberty Bell mine, near Telluride, has been a large producer of gold and silver, the total yield of these metals from 1899 to 1918 inclusive being, according to a report of the operating company, nearly 4,000,000 ounces of silver and more than 500,000 ounces of gold. Most of this output came from the Liberty Bell vein. According to Mr. W. H. Staver, superintendent in 1913, all the ore then being mined was of concentrating grade, and the average metal content of the concentrates was about as follows: Gold, 0.25 ounce to the ton; silver, 2.5–3 ounces to the ton; copper, 0.1–0.2 per cent; lead, 0.1–0.2 per cent; zinc, 2.5 per cent. Some selenium and tellurium are present in the matte obtained from smelting the concentrates, but no selenium or tellurium minerals have been recognized in the ores.

The silver content of the ores very rarely exceeds 10 ounces, and assays of 300 ounces are among the highest on record. As no high-grade silver ores were accessible in the workings at the time the writer was in Telluride, the mine was not visited. In September, 1920, however, Mr. Charles A. Chase, the present superintendent, sent to the writer several samples of rich silver ores from new workings on a branch vein known as the Waters vein. The results of the study of these specimens are reported below.

Along the main or Liberty Bell vein oxidation, according to Mr. Staver, extends to depths of 2,500 feet measured along the vein, whose average dip is 60°. The mine waters are apparently all of surface origin, their flow fluctuating with the seasons.

The Waters vein, from which the specimens studied were taken, rises vertically into the hanging wall from the Liberty Bell vein. Rich silver ore was found in the Waters vein above its junction with the Liberty Bell and in the Liberty Bell vein below the junction. In the Liberty Bell vein above the junction only medium or low-grade ore was found.

The eight samples studied were all from the Waters vein at distances of 20 to 200 feet above its junction with the Liberty Bell vein. The writer is much indebted to Mr. C. H. Behre, jr., for assistance in the study of these specimens. According to Mr. Chase the Waters vein was in places a foot or more in width, but much narrower single fissures or groups of fissures were more characteristic. Some of the ore has carried several hundred ounces of silver to the ton, with gold to an almost equal value. The junction of the two veins lies 1,000 to 1,400 feet below the surface. There is little oxidation near the junction, but considerable immediately above the junction, and very much 100 to 200 feet above.

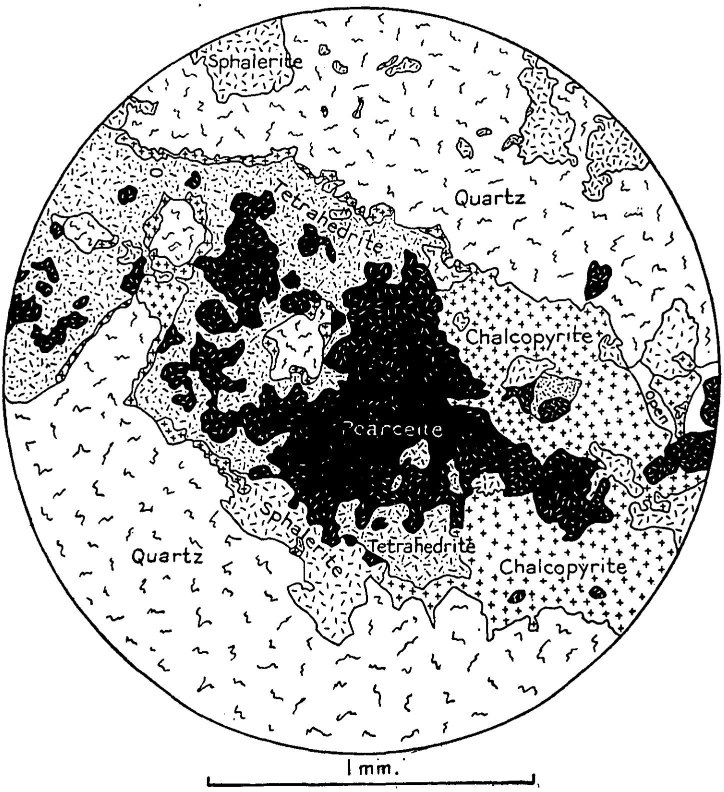

FIGURE 22.—Ore showing primary pearceite intergrown with tetrahedrite, chalcopyrite, and sphalerite, Waters vein, Liberty Bell mine, Telluride, Colo., at a depth of about 1,400 feet.

The several specimens show no consistent differences and will therefore be described together. The ore lies in sharp-walled veins rich in white quartz, traversing wall rock that is silicified and profusely speckled with minute grains of pyrite. Veins as much as 2 inches in width commonly show crustification, a band next to each wall being mainly quartz, and the median portion of the vein being a mixture of quartz and metallic minerals and also showing numerous small vugs lined with crystals of quartz and in places metallic minerals.

The ore minerals that are undoubtedly primary are the common base-metal sulphides sphalerite, galena, pyrite, and chalcopyrite, in a gangue of quartz and sparse calcite. Two other minerals, tetrahedrite and pearceite, are believed to be primary. Tetrahedrite, which is recognizable in the hand specimen by its characteristic brown streak, is shown by the microscope to be intergrown in very irregular fashion with quartz, sphalerite, chalcopyrite, and pearceite, as is clearly shown in figure 22. There is no evidence that any one of these minerals replace any of the others; all are believed to be contemporaneous and primary. In a number of specimens argentite occurs side by side with galena and shows the same textural relations to other minerals; it also forms numerous irregular inclusions in sphalerite. In both these modes of occurrence there is nothing to suggest that the argentite has replaced any other mineral, and it is interpreted as primary.

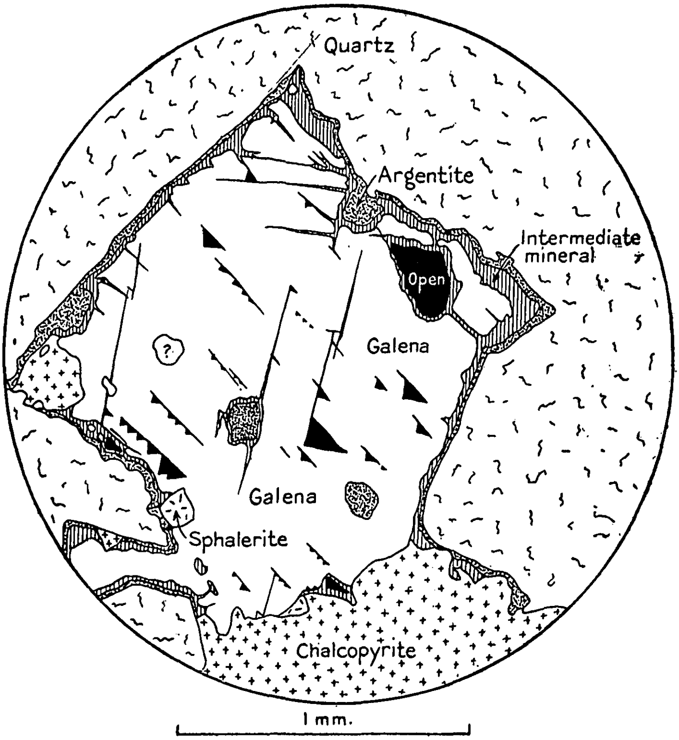

FIGURE 23.—Replacement of galena by argentite, showing an apparently intermediate mineral, Waters vein, Liberty Bell mine, Telluride, Colo. Vertical depth about 1,400 feet. Primary minerals in addition to galena are sphalerite and chalcopyrite. Black triangular areas are pits produced in galena in grinding the specimen; the sides of these pits correspond to galena cleavages. The intermediate mineral forms long, narrow replacement bands parallel to some of the galena cleavages. Camera lucida drawing from polished surface of ore.

Undoubtedly secondary argentite is also abundant in several specimens. Tarnishing with hydrogen peroxide shows that some of the galena has been replaced peripherally and along cleavage planes in the fashion shown in figure 23. The final product of such replacement is argentite, but a galena-white mineral, probably a sulphide of lead and silver (see p. 95), is invariably present between the argentite and the galena. In many places the alteration has not progressed to the argentite stage, only the intermediate product being developed. Such argentite is believed to be a product of downward enrichment. Argentite also occurs in vugs in several of the ores and here also is probably though not certainly secondary. Another important secondary silver mineral is native silver. This is common in vugs as minute tapering wires or "teeth," generally attached to a base of argentite, from the reduction of which they have evidently been formed. Polished specimens also show silver irregularly replacing small areas of pearceite surrounded by quartz. Usually argentite is an intermediate alteration product between the pearceite and the native silver. No gold minerals were seen in the polished specimens examined, but assays show that gold is present.

To summarize, the detailed study of the ores shows that silver is present in the primary minerals pearceite and argentite and in the secondary minerals argentite and native silver. It is probable that all the gold is primary. Of minor interest is the occurrence in several of these ores of a mineral which is undoubtedly rare and possibly new. This mineral occurs characteristically in quartz-lined vugs near the median portions of ore veinlets in ore that is not oxidized. It forms thin black plates lying on or between the quartz crystals and is clearly younger than the quartz, but because of its highly refractory nature it seems probable that it is late primary rather than secondary. The properties of this mineral so far as determined are as follows:

> Color black, streak black, luster submetallic to vitreous, opaque, brittle, without well-defined cleavage. Forms thin plates without well-defined crystal outlines. Before the blowpipe infusible alone and in borax, sodium carbonate, or sodium meta-phosphate beads. Unaffected by electromagnet. Insoluble in nitric acid and aqua regia.

It is hoped that additional material can be obtained and this mineral definitely identified.

SUMMARY AND CONCLUSIONS.

One of the most fundamentally important questions in any silver-mining district is, Are the primary ores sufficiently rich in silver to be mined at a profit? Upon the answer to this question depends the success of deep-mining operations. It has happened that in many mining districts—for example, at Butte, Mont., and in Clear Creek County, Colo.—ores rich in silver near the surface have passed at moderate depths into ores poor in silver, which if mined at all were valuable mainly for the base metals that they carried. It is now clearly understood that the shallow ores in such deposits owed their richness in silver to the action of surface waters that descended through the ore bodies; that is, to the process known as downward enrichment. The knowledge of such relations has unquestionably operated to discourage deep development of silver deposits in other districts where the tenor of the primary ores and the quantitative importance of downward enrichment were more problematic. Thus in the Ouray region the belief has been current among some mining men that rich ruby silver ores were due mainly to downward enrichment and therefore would play out at very moderate depths.

Evidence has been accumulating, however, that in many districts primary silver ores are sufficiently rich to be profitably mined. This seems to be true, for example, at Tonopah[19] and on the Comstock lode.[20] The most fundamental fact brought out by the writer's studies near Ouray and Telluride is that many ores of bonanza richness carry their silver wholly or mainly in primary minerals.

The judgment as to the probable success of deep mining in veins rich in silver near the surface should not be prejudiced by preconceived ideas of the importance of enrichment. Each district and in some districts each mine presents a special problem. The methods of microscopic study of ores worked out in recent years offer a method of determining, roughly at least, the relative importance of primary and secondary processes in the deposition of silver ores far in advance of the ultimate test by actual development. The practical value of information of this sort is out of all proportion to the moderate cost at which it may be procured through comparatively brief studies by a competent geologist.

It must be remembered, however, that even ores that are wholly primary show variations in mineral composition and tenor in depth. Such variations as a rule are less abrupt than those due to downward enrichment but may be of practical importance in regions like the San Juan Mountains, where, because of the high relief, single veins may be followed in mining through vertical distances of many thousands of feet. The detailed studies of the Ouray-Telluride ores show that in that region, as in the Tonopah district of Nevada, the primary silver minerals were formed more abundantly in the later

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[19] Bastin, E. S., and Laney, F. B., The genesis of the ores at Tonopah, Nev.: U. S. Geol. Survey Prof. Paper 104, 1918.

[20] Bastin, E. S., Bonanza ores of the Comstock lode, Virginia City, Nev.: U. S. Geol. Survey Bull. 735, pp. 41–63, 1922 (Bull. 735–C).

stages of the mineralization and the base-metal sulphides were formed more abundantly in the earlier stages. This fact is to be correlated with the fact that rich primary silver ores like those of Tonopah and the Comstock lode, and probably many of the Mexican deposits, were deposited relatively near the surface, for they lie between walls of relatively young rocks. Both these facts point to a probable decline in the primary-silver content of the ores in depth, but such changes, unlike those due to decreasing enrichment, are recognizable only through vertical intervals measured in thousands rather than hundreds of feet.

The primary silver-bearing minerals recognized in the ores of this region include argentiferous tetrahedrite, argentiferous tennantite, proustite, pearceite, and probably argentite. In general the argentiferous minerals are dominantly arsenical rather than antimonial. A specimen from the Bachelor mine carrying primary argentiferous tetrahedrite and pearceite (see fig. 15, p. 71), but apparently free from secondary silver minerals assayed 2,190 ounces of silver to the ton. The possibility of some enrichment can not be ruled out, but it is clear that considerable silver is contained in primary minerals. Bonanza ore mined in the early days from slight depths in the Yankee Boy mine carried primary proustite in great abundance and also primary tennantite. (See fig. 16, p. 77.) In some specimens from this mine the proustite is a component (with quartz, calcite, and minor amounts of base-metal sulphides) of late primary veinlets that cut across earlier ore which appears to be free from silver minerals. Ore from a vertical depth of not more than 300 feet in the Humboldt mine carried primary ruby silver (proustite) in great abundance and also carried primary argentiferous tennantite. (See figs. 17 to 19, pp. 80–82.) Ore from old bonanza stopes in the Smuggler-Union mine from depths probably not exceeding 500 feet was very rich in primary proustite, some pure masses of this mineral being 1 centimeter across. Some of the proustite was intergrown with gold. Primary tennantite intergrown with the proustite but probably argentiferous was also abundant. (See figs. 20 and 21, pp. 85, 86.) Ore from the Waters vein in the Liberty Bell mine carried abundant primary pearceite intergrown with tetrahedrite and also carried argentite that appeared to be primary. (See fig. 22, p. 90.) The vertical interval between the observed occurrences of primary ruby silver in the Yankee Boy mine and the highest occurrences in the Smuggler-Union Humboldt vein is about 1,000 feet.

Although it has been shown that many rich silver ores in the region are wholly or in the main primary, nevertheless other ores afford clear evidences of notable enrichment. The conditions existing in the veins of the Ouray-Telluride region are not those most favorable for the deposition of secondary (supergene) silver minerals in large amounts. For the formation of ores rich in secondary silver minerals thorough oxidation within a surface zone of considerable thickness is requisite. In this region of high altitude and great relief mechanical disintegration has been so active that the chemical processes of the oxidation and solution of rock and ore minerals have not had full play. Unoxidized primary sulphides are frequently found within a few feet of the surface, and complete oxidation is generally very superficial. In consequence secondary silver minerals, though fairly common, are in general very minor components of the ores. The great relief, in consequence of which the outcrops of many veins extend far above the main stream channels, has, however, led to deep partial oxidation. In the Smuggler-Union mine spotty oxidation is noted to the greatest depths attained, about 2,400 feet vertically below the surface. In the Liberty Bell mine, according to Mr. W. H. Staver, superintendent in 1913, oxidation extended to depths of 2,500 feet. In the Klondike vein of the Atlas mine oxidation was noted at the deepest point visited, about 1,500 feet below the surface. In the Virginius vein oxidation was noted at vertical depths of about 2,100 feet, although possibly the oxidation to this depth has occurred subsequent to mining. High relief combined with the uniformity and persistence of many of the veins has favored the ready descent of surface waters along them to depths even greater than those attained by oxidation.

The secondary silver minerals noted in the Ouray-Telluride region include proustite, argentite, an intermediate replacement product between galena and argentite (probably a lead-silver sulphide), and native silver. In the Virginius vein at a depth of about 2,100 feet thin films of proustite occurred along sharp fractures in primary ore, and from these fractures the proustite could be cleanly stripped. Similar occurrences of proustite were noted in the Terrible No. 3 vein in the Mountain Top tunnel at a depth of about 400 feet. In both localities the proustite was present in very meager amounts. In primary ore from depths of about 1,700 feet in the Smuggler-Union mine argentite and native silver were noted on the quartz of vugs and in clean-cut fractures. Both of these minerals are secondary, and the silver is the younger, being clearly an alteration product of the argentite. In the Waters vein of the Liberty Bell mine at depths of 1,000 to 1,400 feet secondary argentite has replaced galena, and between the two occurs an intermediate replacement product, probably a sulphide of lead and silver. (See fig. 23, p. 91.) In vugs secondary argentite and native silver were noted. Here and there the native silver replaces argentite; elsewhere it forms tapering, striated, and curved "teeth" implanted on a pedestal of argentite, out of which they have obviously grown as an alteration product.

In an earlier paper Chase Palmer and the writer[21] pointed out that chalcocite precipitates metallic silver very promptly from dilute neutral solutions of silver sulphate. An interesting example of the natural operation of this process is afforded by ore from a depth of about 650 feet in the Wedge mine. Here narrow veinlets 1 to 2 millimeters wide in sandstone originally consisted mainly of chalcopyrite, but in places they have been altered next to their walls to chalcocite. On the chalcocite here and there native silver has been deposited. In some places the alteration has progressed so far that no chalcopyrite remains, and the veinlet consists of a center of chalcocite bordered next to the walls by thin deposits of native silver. A little argentite is associated with the native silver. The presence with the chalcocite and silver of unattacked remnants of primary calcite shows that the solutions concerned in the deposition of chalcocite and of argentite and silver were not strongly if at all acid. All features of the natural occurrence appear therefore to harmonize with the reaction worked out by Palmer in the laboratory and expressed as follows:

$$\underset{\text{Chalcocite}}{Cu_2S}+2Ag_2SO_4\rightarrow 2CuSO_4+\underset{\text{Argentite}}{Ag_2S}+2Ag$$

The quality of the waters that deposited the secondary silver minerals is a matter of some scientific import. A caution first to be noted in studying this subject is that waters now descending through old stopes may differ in quality from the waters that passed through that part of the vein before mining began. Thus waters dripping from the roof of a drift at depths of about 600 feet on the Smuggler-Union vein were acid toward litmus but had passed through old stopes. A second caution to be noted is that the present association of secondary silver minerals with acid mine waters does not prove that such minerals were originally deposited by acid waters. The near-surface zone characterized by acid waters is constantly descending as erosion progresses and may overtake minerals deposited earlier from neutral solutions. In the Terrible No. 3 vein in the Mountain Top tunnel at a depth of about 400 feet waters dripping from the roof were slightly acid toward methyl orange and had not passed through old stopes. Secondary proustite occurs in the ore at that locality. Waters in the upper levels of the Humboldt mine at depths ranging from 180 to 300 feet were acid toward litmus paper and had not passed through old stopes. The vein there showed slight spotty oxidation, but no secondary silver minerals were noted.

Below a very superficial zone the waters descending through the veins are neutral or at most not strongly acid. Thus in the Smuggler-Union vein as exposed in the Humboldt mine waters descending

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[21] Palmer, Chase, and Bastin, E. S., Metallic minerals as precipitants of silver and gold: Econ. Geology, vol. 8, pp. 154–155, 1913.

through the vein on the third and fifth levels were neutral toward litmus. Waters dripping from the roof of the Pennsylvania tunnel of the Smuggler-Union mine at vertical depths of 1,500 to 1,700 feet were also neutral. At one point in this tunnel secondary argentite and native silver were noted in vugs. The presence of fresh-appearing carbonates in close association with secondary silver minerals may justly be interpreted as an indication that the waters that deposited the silver minerals were at most not strongly acid. In the Bachelor mine at Ouray secondary pearceite is intergrown with calcite in clean-cut fractures cutting primary ore. The occurrence of remnants of primary calcite in association with secondary chalcocite and native silver in the Wedge mine has already been mentioned. At a depth of 2,100 feet in the Virginius vein small amounts of secondary chalcocite, covellite, and proustite occur in the ore that carries fresh-appearing crystals of primary siderite in vugs.

From these observations it would appear that acid waters are characteristic of the upper portions of certain veins within a few hundred feet of the surface, but that at greater depths the waters cease to be notably acid. Apparently secondary argentite, native silver, and proustite have been deposited in some of the veins of this region from neutral or only faintly acid solutions.

No horn silver (AgCl) or other halogen salts of silver were noted by the writer in any of the silver ores of this region, and so far as he is aware such salts have not been described by earlier observers. Though possibly present close to the surface, they are certainly not abundant. Their rarity may be attributed to the low chlorine content of most of the surface waters.

Field tests[22] on water from a very considerable flow coming down from the surface along the Ainsworth vein in the Smuggler-Union mine showed less than 10 parts per million of chlorine. This water was tested at a point about 100 feet below the surface. Waters of a small creek between the Smuggler-Union mill and Bear Creek carried between 5 and 10 parts per million of chlorine. This creek flows over andesitic rocks of the San Juan tuff and sandy sediments of the Dolores formation (Upper Triassic). Analysis of descending waters in the No. 3 ore body of the Genesee mine at Red Mountain showed only a trace of chlorine. (See table on p. 108.)

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[22] In the field estimation of chlorine tablets containing uniform amounts of silver nitrate are used. A measured amount of water, to which a few drops of a 5 per cent solution of potassium chromate have been added, is titrated in a glazed porcelain mortar with the silver nitrate tablets. The appearance of a permanent red coloration marks complete titration. The chlorine content in parts per million is calculated from the number and standard of the tablets and the quantity of water used.

RED MOUNTAIN REGION.

GENERAL GEOLOGIC FEATURES.

The Red Mountain mining district lies about midway between Ouray and Telluride, near the subdued divide that separates the headwaters of the northward-flowing Red Mountain Creek from the southward-flowing Mineral Creek. The valley occupied by these two creeks has not been developed wholly by erosion, as faulting has contributed in some measure to its formation. What has been said in regard to the bedrock formations of the Ouray-Telluride region applies equally to the Red Mountain region, but certain conditions peculiar to the Red Mountain region have produced there primary mineralization and downward enrichment of a type not characterstic of the Ouray-Telluride region. The relief near Red Mountain is moderate as compared with that near Ouray and Telluride, the mines studied lying at altitudes of 10,500 to 11,000 feet and the highest neighboring summits reaching nearly 12,900 feet.

The characteristic ore bodies are not veins but stockworks or "chimneys," most of which are distributed along a belt less than 1 mile wide and about 4 miles long that trends slightly east of north and extends from Ironton to a point about a mile south of Red Mountain village. The stockworks have been developed by the Yankee Girl, Guston, Silver Bell, and other mines. They appear to be brecciated portions of the andesitic country rock of the Silverton volcanic series which have become the loci of mineralization by replacement of the andesite and by the filling of spaces between andesite fragments. The stockworks appear to occur within two adjacent and nearly parallel zones of complex intersecting fractures that trend roughly between N. 20° and 30° E. and stand nearly vertical.[23]

The wall-rock alteration adjacent to the stocks has been very intense and widepread, as contrasted with that characteristic of the veins. For long distances from the ore bodies the rocks were silicified and impregnated with pyrite, and by oxidation the pyrite has produced the red coloration to which the district owes its name.

The widespread alteration of the rocks, conjoined with other causes, has resulted in a great development of landslides, which in turn have tended to block the natural drainage, rendering the streams more sluggish and even developing small ponds within the landslide areas. The alluvial plain known as Ironton Park is one expression of the obstruction of the normal drainage by landslides and the further transportation of landslide material by occasional torrential rains. The principal shafts of the region occupy small knolls of altered

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[23] Ransome, F. L., Economic geology of the Silverton quadrangle, Colo.: U. S. Geol. Survey Bull. 182, pp. 214–220, 1901; U. S. Geol. Survey Geol. Atlas, Silverton folio (No. 120), pp. 32–33, 1905.

bedrock in the midst of landslide débris not far above the valley bottom. It is not surprising that in this situation the mines should characteristically be wet and that the abundance of pyrite in the ores and altered wall rocks should render many of the mine waters acid. The copious flows of corrosive waters have in fact been one of the principal obstacles to mining at Red Mountain; to their action, moreover, is to be attributed downward enrichment in silver and in copper on a scale not found in the veins near Ouray and Telluride. In the mines of the Red Mountain district the permanent ground-water level is reported to have stood 50 to 200 feet below the surface, fluctuating somewhat seasonally.

YANKEE GIRL AND ROBINSON MINES.

The ore deposits of the Yankee Girl mine are typical of the series of ore "chimneys" or stockworks characteristic of the Red Mountain region. The mine has been idle and inaccessible for many years, but three specimens taken from the mine in its period of active development were obtained through the courtesy of Mr. William Rathmell, of Ouray, and a number of specimens of the deep ores were picked by the writer from the dumps. The minerals that have been noted in previous descriptions of this mine are pyrite, chalcopyrite, galena, sphalerite, enargite, gray copper, cosalite, chalcocite, stromeyerite, bornite, bournonite, proustite, polybasite, galena, pyrite, argentite, kaolin, barite, and calcite.

The testimonies of previous observers unite in indicating that not only in the Yankee Girl but in the Guston, Silver Bell, and other mines of this vicinity there were notable variations in the mineral character of the ores with depth. To quote Ransome:[24]

> The ore first struck, in some cases actually at the surface, consisted chiefly of argentiferous galena. At a depth which varied somewhat in different mines but which appears usually to have been less than 200 feet this galena changed to an ore consisting chiefly of highly argentiferous stromeyerite. At a still greater depth—usually about 500 feet—the stromeyerite changed to argentiferous bornite. Still deeper to chalcopyrite and pyrite and finally to low grade auriferous and argentiferous pyrite. These changes were more or less irregular and overlapping.

S. F. Emmons and F. L. Ransome[25] have both attributed the formation of the rich silver ores of the Yankee Girl and neighboring mines to downward enrichment, citing in support of this view not only the mineral variations in depth above described but also the abundance of highly cupriferous and corrosive mine waters and the termination of the very rich stromeyerite ores at a highly talcose flat-lying fault encountered at a depth of about 500 feet.

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[24] Ransome, F. L., Economic geology of the Silverton quadrangle, Colo.; U. S. Geol. Survey Bull. 182, p. 137, 1901.

[25] Idem, p. 136.

The writer collected a number of specimens of the leaner ores, presumably from the deeper workings, from the old dump at the Yankee Girl shaft. None of these reacted appreciably for silver when dissolved in HNO_3 and treated with HCl. All were medium to fine-grained fresh aggregates of pyrite, enargite, tennantite, quartz, chalcopyrite, and a little galena. All these minerals are intimately intergrown and are closely contemporaneous and primary. No specimens carrying bornite were obtained by the writer.

Specimens of the rich ores carrying stromeyerite were obtained from the collections of John McLeod and William Rathmell at Ouray. In one specimen, said to have come from a depth of about 600 feet, the microscope shows remnants of sphalerite which exhibit borders of the utmost irregularity next to stromeyerite and which are traversed by typical replacement veinlets of stromeyerite as shown in figure 24. It is perfectly clear, therefore, that stromeyerite has replaced sphalerite. There are present also in the stromeyerite patches of galena and of tennantite (?), whose relations to the stromeyerite are shown in figure 25. The presence of small outliers of galena with the same crystal orientation as the neighboring larger masses (see fig. 25) suggests that they have been isolated by replacement of the intervening parts. The outlines of the tenantite (?) areas, irregular but free from angularities, suggest that they also are probably replacement remnants. Although absolute proof is lacking, there are suggestions, therefore, that stromeyerite has also replaced galena and tennanite (?). Small areas of covellite in turn have distinctly replaced the stromeyerite.

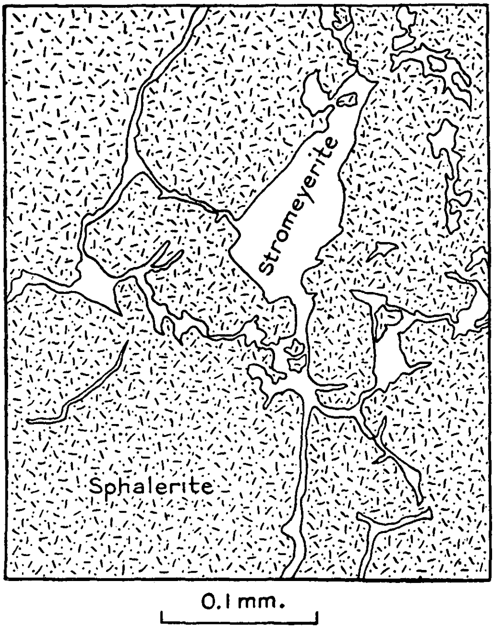

FIGURE 24.—Replacement veinlets of stromeyerite in sphalerite, Yankee Girl mine, Red Mountain, Colo. Depth about 600 feet. Camera lucida drawing.

The second specimen shows under the microscope numerous areas of chalcopyrite, pyrite, barite, quartz, and some galena inclosed in a matrix consisting of an intimate mixture of chalcocite and stromeyerite. The chalcocite and stromeyerite appear to have been deposited simultaneously; it is clear that they have not replaced pyrite or chalcopyrite, for these minerals commonly show straight crystal faces next to chalcocite and stromeyerite rather than the irregular contacts characteristic of replacement. Careful inspection shows the presence within the stromeyerite areas (and nowhere else) of many areas of probable bournonite ($3[Cu_2Pb]S.Sb_2S_3$).[26] The nuclear position of these areas and their irregular but not angular outlines clearly indicate that they are replacement remnants. The stromeyerite is therefore a replacement pseudomorph after probable bournonite. The characteristic relations are shown in figure 26. Bournonite (?) remnants are never found within the chalcocite, but in a few places the chalcocite contains groups of irregular inclusions of enargite. Viewed under the high power of the microscope, these inclusions show outlines that are smoothly rounded and not suggestive of crystal faces. These inclusions are interpreted as replacement remnants analogous to the bournonite (?) remnants in stromeyerite but less numerous.

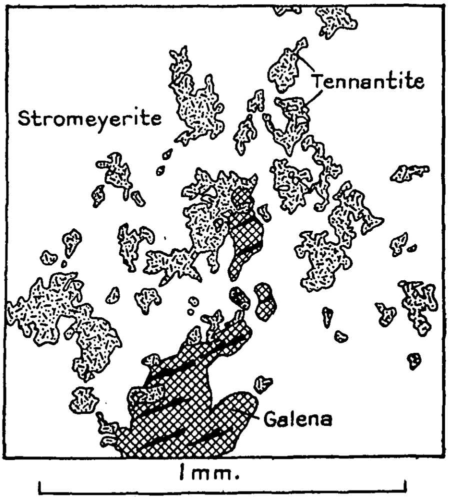

FIGURE 25.—Probable replacement remnants of galena and tennantite (?) in secondary stromeyerite, Yankee Girl mine, Red Mountain, Colo. Depth about 600 feet. Camera lucida sketch from polished specimen. Note the parallel orientation of adjacent galena areas, which suggests that they were originally connected.

The Robinson mine was essentially a part of the Yankee Girl, both being worked together. A small specimen from an uncertain but slight depth in this mine consists largely of argentite through which many isolated grains of chalcopyrite, some as much as 1.5 millimeters in diameter, are scattered and in which there are also a few small rounded grains of galena. There are no certain microscopic evidences of replacement, but the texture is very unusual and may be interpreted as the result of nearly complete replacement of primary ore by argentite. Complete replacement of stromeyerite, chalcocite, or both by argentite in specimens like those found in the Yankee Girl mine might produce such a texture. It is noteworthy that the chalcopyrite areas, in contrast to those in the specimen illustrated in figure 26, are rounded, suggesting their

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[26] Grayish white; hardness about equal to stromeyerite; with concentrated HNO_3 fumes tarnishes slowly brown. Unaffected by HCl, KCN, $FeCl_3$, $HgCl_2$, and KOH applied in accordance with method described by Davy and Farnham (op. cit., pp. 20–29). Original crystal forms prismatic. Unattacked by $FeCl_3$ in presence of electric current. (For differentiation from enargite or famatinite, see Davy and Farnham, op. cit., p. 9.)

final yielding to replacement in the late stages of downward enrichment. In porous parts of this specimen the argentite has been replaced by native silver in the form of networks of minute veinlets.

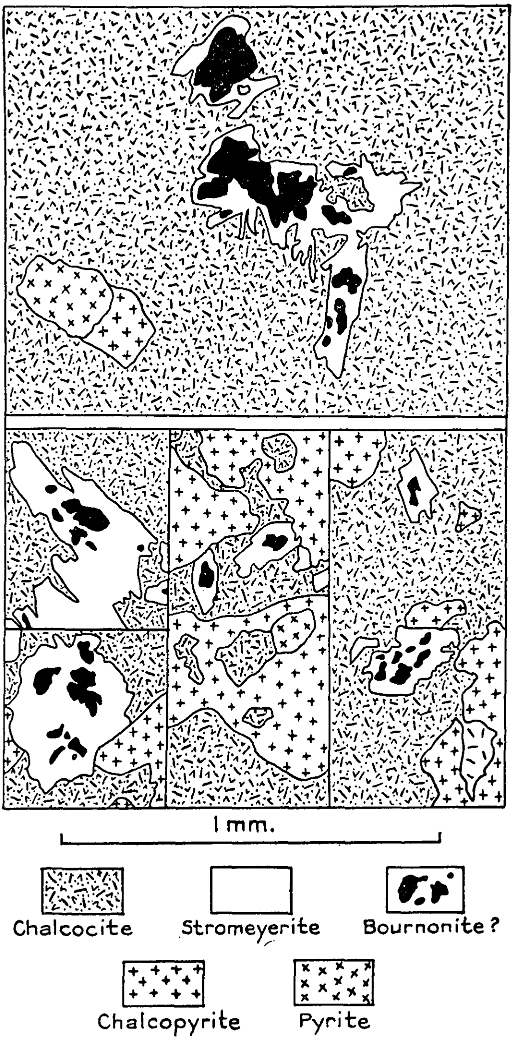

FIGURE 26.—Stromeyerite as a pseudomorphic replacement of bournonite (?), Yankee Girl mine, Red Mountain, Colo. Replacement remnants of bournonite (?), irregular but free from angularity, occur within the stromeyerite. Camera lucida sketches from polished specimens.

From shallow workings in the Robinson mine rich ruby silver ore was formerly obtained. A specimen of such ore, donated by Mr. John McLeod, of Ouray, was polished and studied under the microscope. The principal ore mineral is pyrite; with it are associated galena, proustite (light ruby silver), and pyrargyrite (dark ruby silver). The pyrite and galena are irregularly intercrystallized and are regarded as primary. The proustite and pyrargyrite are irregularly intergrown with each other and therefore appear to be of the same age. They are younger, however, than the galena, which they replace. The replacement relations are clear and typical. Contacts between the ruby silver minerals and galena are prevailingly very irregular. Complete transitions exist from areas which consist wholly of proustite and pyrargyrite to areas in which these minerals inclose a multitude of ragged remnants of galena and finally to areas which are made up largely of galena. In the galena areas a few minute replacement veinlets of proustite or pyrargyrite are found along cleavage planes or irregular fractures. Some of these veinlets start from the larger ruby-silver areas and project into the galena with decreasing width. Most of the ruby-silver areas lie between galena and pyrite or between separate crystals of galena. Such replacement deposits may have been formed late in the period of primary mineralization, but if so they are unique for the district. Primary ruby silver where found in the veins of the Telluride-Ouray region is contemporaneous with other primary minerals and does not replace them. The rich ruby-silver ores of the Robinson mine appear to have been confined to deposits close to the surface, and it seems probable that the proustite and pyrargyrite are products of enrichment by descending solutions.

In conclusion, the microscopic studies show that in the Yankee Girl and Robinson mines chalcocite, covellite, stromeyerite, native silver, proustite, pyrargyrite, and probably argentite have replaced earlier minerals. The playing out in depth of the ores rich in these minerals indicates that the replacement was probably accomplished by descending solutions. In figure 27 most of the metallic minerals noted in the ores are grouped as primary or secondary and arrows are used to indicate what minerals have been replaced by others; thus native silver has replaced argentite, and argentite in turn may have replaced stromeyerite, galena, chalcocite, and chalcopyrite, uncertainty being indicated by the question mark. The approximate percentage composition of each mineral is indicated, and from these figures it is obvious that the replacement processes involved in the downward enrichment of the ores—changes that proceeded without change in volume—have involved a loss of lead, zinc, arsenic, antimony, and iron and a corresponding gain of copper and silver. The consider-

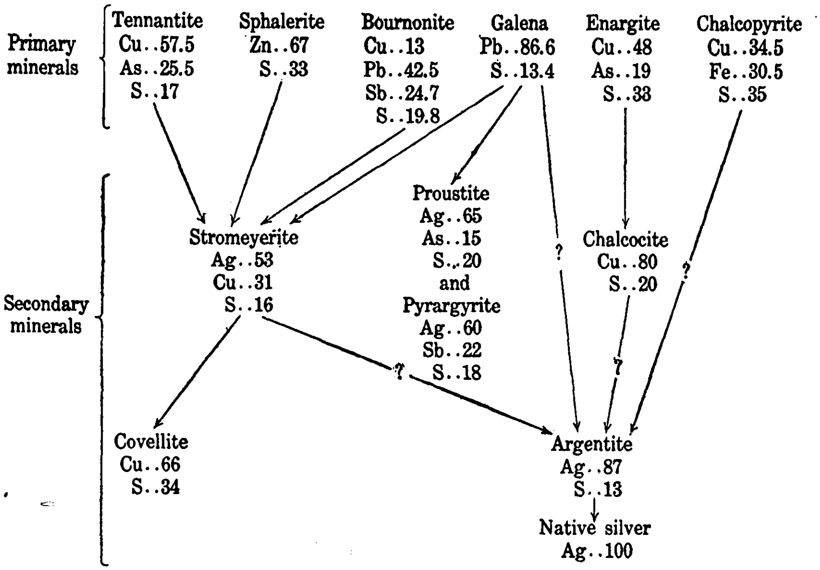

FIGURE 27.—Diagram showing what minerals have replaced others in the ores of the Yankee Girl mine, Red Mountain, Colo. Figures indicate percentage composition of the minerals.

able number of minerals widely different chemically and physically that have been replaced by stromeyerite is noteworthy. In the early stages of such processes the replacement is likely to be selective only, one or perhaps two primary minerals being replaced, as illustrated by the pseudomorphic replacement of bournonite by stromeyerite shown in figure 26. As the process proceeds other primary minerals begin to be attacked, and eventually earlier secondary minerals are replaced by later secondary minerals. An example of such extreme alteration is probably furnished by the specimen from the Robinson mine that shows rounded remnants of chalcopyrite in a matrix of argentite, all other ore minerals, whether primary or secondary, having been completely replaced.

GENESEE MINE.

The only mine in the Red Mountain district that could be entered at the time of the writer's visit in 1913 was the Genesee, accessible through a tunnel which exposed several small ore bodies. This mine is close to the Yankee Girl described above. The older workings described in Ransome's report[27] were inaccessible in 1913. With respect to the older workings Ransome says:

> According to Mr. Otto J. Schulz, of St. Louis, at present trustee of the Genesee-Vanderbilt mine, there were four separate pay shoots on the surface, only one of which was explored to the 700 level. The best ore occurred at a depth of about 250 feet below the collar of the main shaft and extended down to within about 20 feet of the 300 level. * * * The value of the ore, never high grade as a whole, fell off with increase of depth below the 300 level, depreciating rapidly below the 500 level and changing near the 700 level to large bodies of low-grade pyrite.

Ransome states that particulars regarding the mineralogy of the ore were difficult to obtain, but he reports the occurrence of cosalite (a sulphide of lead and bismuth, $2PbS.Bi_2S_3$), of "very argentiferous bornite," and of proustite. Stalactites of pyrite were observed in small cavities in certain of the ore bodies. "The water encountered in the Genesee-Vanderbilt was of the same corrosive character as that met with in the Yankee Girl and Guston."

The Genesee tunnel develops territory much below the old shaft workings. The principal ore body exposed in 1913 was the so-called 7½ ore body, which was discovered by diamond-drill prospecting from the tunnel and is therefore off the course of the tunnel, about 4,400 feet from the portal. It is of particular interest because it is the only ore body in the district that shows large amounts of covellite. As exposed in a winze that extended about 100 feet below the tunnel level this ore body appeared to form a nearly vertical "chimney" 10 to 20 feet in width. Much of the ore is coarse. Vugs are numerous

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[27] U. S. Geol. Survey Bull. 182, pp. 227–230, 1901.

and are reported to be filled with water when struck. The principal ore mineral is covellite associated with abundant pyrite and enargite ($3Cu_2S.As_2S_5$) and with minor amounts of other minerals. The primary ore minerals are pyrite, enargite, tennantite or tetrahedrite, sphalerite, galena, cosalite, quartz, and barite; the secondary ore minerals are covellite, an unidentified galena-white mineral, and kaolin. The wall rock adjacent to this ore body is highly silicified and impregnated with pyrite in minute crystals.

Microscopic study of polished specimens shows that all the minerals listed above as primary are intimately and irregularly intergrown in a fashion that shows that they crystallized simultaneously. Pyrite and enargite are the most abundant minerals of this group. A grayish-white mineral intergrown with the enargite fulfills the microchemical tests given for tetrahedrite and tennantite by Davy and Farnham, but was found in too small amounts to be isolated for more certain chemical tests and will be referred to below as gray copper.

From the hand specimens there is no indication that the dominant ore mineral, covellite, is secondary; it is not pseudomorphous after other minerals, but, on the contrary, in places assumes its own characteristic form of hexagonal plates. Examination of polished specimens under the microscope, however, shows conclusively that the covellite has replaced enargite, sphalerite, cosalite, gray copper, and possibly also galena. The entire absence of chalcopyrite may indicate complete replacement of that mineral by covellite. Typical very irregular replacement borders are common between covellite and enargite and between sphalerite and gray copper, and these minerals are traversed by characteristically irregular replacement veinlets of covellite. Such veinlets of covellite in enargite are shown in figure 28. Entirely similar textural relations exist between covellite and sphalerite or gray copper.

Subsequent to the deposition of covellite thin coatings of finely crystalline pyrite and of a gray undetermined mineral were deposited on covellite and on enargite. The gray mineral closely resembles enargite in color, hardness, and tarnishing by chemical reagents but occurred in too thin coatings to be isolated for definite determination.

A representative shipment of ore from this body assayed gold, 0.03 ounce to the ton; silver, 2.87 ounces to the ton; copper, 20.34 per cent; iron, 15.30 per cent. No silver minerals were recognized in the ore. The ore body above described lies about 900 feet vertically below the surface.

Water was seeping into the winze developing the No. 7½ ore body from its walls near the bottom. The pump being temporarily out of commission, the water level in the winze was rising rapidly. It was thought that information concerning the quality of this water might have a bearing on the genesis of the ore. A field test showed that some ferrous iron was present; with methyl orange the water gave a faint acid reaction. A sample for analysis had to be dipped from the bottom of the winze and so was somewhat contaminated with rock dust, etc. After settling and filtering, the sample was analyzed by Dr. Chase Palmer, with the results shown in the table on page 108 and figure 29. The water is essentially a solution of sulphates of aluminum and copper, the former the more abundant. It carried 7,280 parts per million of dissolved matter. Close analogies among mine waters elsewhere are to be found in the descending copper-bearing mine waters in the mines of the Tennessee Copper Co. at Ducktown, Tenn., and the Mountain View mine at Butte, Mont., as shown in figure 29. The Genesee water differs from these, however, in that it carries no free acid.

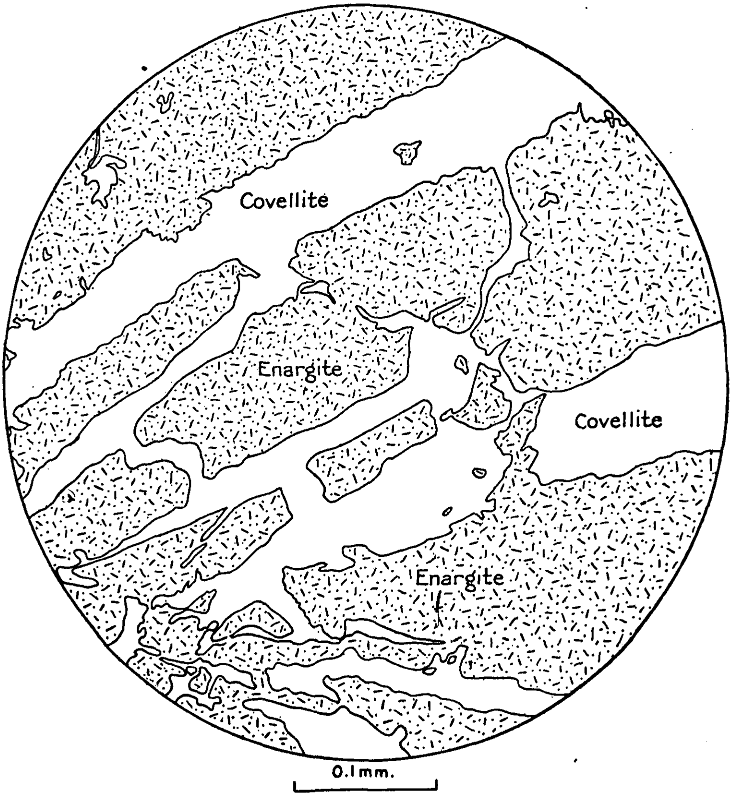

FIGURE 28.—Replacement veins of covellite in enargite, Genesee mine, Red Mountain, Colo. Depth about 900 feet. Camera lucida drawing.

A second sample of mine water was taken from a small ore body (No. 3) cut in the Genesee tunnel about 1,400 feet from the portal. Here the ore is a breccia of angular rock fragments in a matrix that is mainly sphalerite. Water dripping through this ore and depositing limonite stalactites in the roof of the tunnel did not give an appreciably acid reaction with methyl orange, but the wet limonite stalactites were slightly acid. A gallon bottle was allowed to fill overnight under one of the drips from the roof, and the analysis of the water thus collected is given in the table on page 108. As there are no higher workings on this ore body, the water was presumably uncontaminated. As shown in figure 29 (No. 2) it is similar in general qualities to the water from the No. 7½ ore body, but it carries no appreciable amounts of copper and is more dilute, the dissolved matter amounting to only 508 parts per million as against 7,280 parts in the water from No. 7½ ore body. The copper-bearing water from the No. 7½ ore body is very similar to that from the Burra Burra mine at Ducktown, Tenn.,[28] shown as No. 3

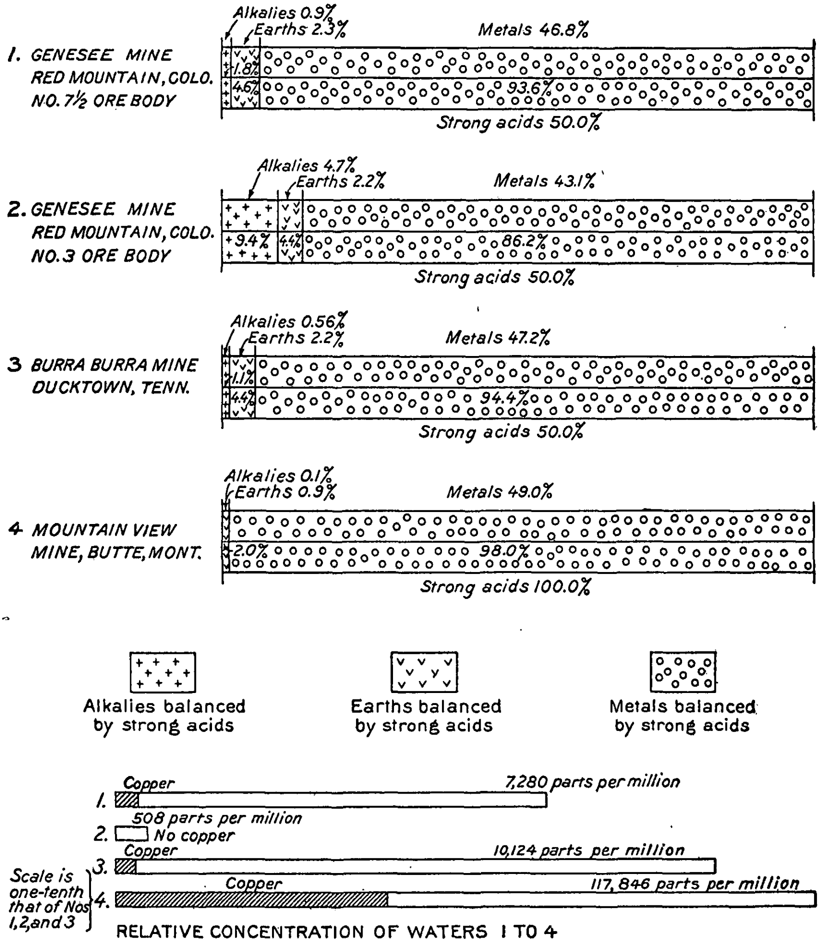

FIGURE 29.—Composition diagrams of mine waters from Genesee mine, Red Mountain, Colo., and of waters of similar quality from Ducktown, Tenn., and Butte, Mont.

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[28] Emmons, W. H., and Laney, F. B., Preliminary report on the mineral deposits of Ducktown, Tenn.: U. S. Geol. Survey Bull. 470, pp. 171, 172, 1910.

in figure 29, although the latter carries proportionately more iron and less aluminum and also carries zinc. This was a descending water collected just below the zone of chalcocite enrichment. The Genesee copper-bearing water also bears some resemblance to water from the Mountain View mine at Butte, Mont., shown as No. 4 in figure 29, although the Butte water is very much more concentrated and carries a much larger proportion of copper. This water seeped down through old stopes and was depositing chalcanthite on the second level of the mine.

Analyses of mine waters from Genesee mine, Red Mountain, Colo.

[Chase Palmer, analyst.]

No. 7½ ore body.

Radicle.	Parts per million.	Reacting value.			
		By weight.	Per cent.		Adjusted (per cent).
Na	35.0	1.5225	0.7	0.9	0.9
K	23.0	.5888	.2		
Ca	70.0	3.4930	1.5	2.3	2.3
Mg	22.0	1.8084	.8		
Fe''	840.0	45.1080	19.6	47.6	46.8
Al	485.0	53.6895	23.2		
Mn	Trace.	....	.....		
Cu	350.0	11.0250	4.8		
SO_4	5,436.0	113.0688	49.0	49.2	50.0
Cl	19.0	.5358	.2		
	7,280.0	230.8398		100.0	100.0

	Per cent.
Alkalies balanced by strong acids	1.8
Earths balanced by strong acids	4.6
Metals balanced by strong acids	93.6
	100.0

No. 3 ore body.

Na	11.3	0.4915	3.3	4.9	4.7
K	9.5	.2432	1.6		
Ca	1.1	.0549	.4	2.3	2.2
Mg	3.4	.2795	1.9		
Fe''	31.0	1.1098	7.5	44.7	43.1
Al	50.0	5.5350	37.2		
Mn	Trace.	....	....		....
SO_4	345.0	7.1760		48.1	50.0
Cl	Trace.	....	....		....
SiO_2	57.0	....	....		....
	508.3	14.8899		100.0	100.0

	Per cent.
Alkalies balanced by strong acids	9.4
Earths balanced by strong acids	4.4
Metals balanced by strong acids	86.2
	100.0

SUMMARY AND CONCLUSIONS.

The ore bodies most characteristic of the Red Mountain region, including all those considered in this report, are stockworks or chimneys and thus are markedly different in form from the fissure veins that constitute the dominant type in the Ouray-Telluride region. The principal ore bodies crop out in the lower portions of an elevated mountain valley which receives the drainage from a considerable territory. The stockworks are permeable by surface waters and are bordered by large bodies of altered wall rock that are also permeable. Masses of broken and altered rock carried in by landslides occupy most of the surface near the mines; this material likewise is readily permeable by surface waters. Several conditions combine, therefore, to favor a copious and ready circulation of surface waters through the ore bodies, and this circulation has produced enrichment of the ores on a large scale.

The primary ore minerals noted by the writer in the ores of the Yankee Girl, Robinson, and Genesee mines are quartz, barite, pyrite, chalcopyrite, sphalerite, galena, enargite, cosalite, argentiferous tennantite or tetrahedrite, and bournonite (?). Additional minerals that are probably primary reported by previous observers are bornite and calcite. Among all these minerals quartz, pyrite, and enargite are commonly dominant.

The secondary minerals noted by the writer in the ores of these mines are stromeyerite, chalcocite, covellite, pyrite, proustite, pyrargyrite, argentite, and native silver. It is believed that these minerals are products of downward enrichment. Stromeyerite was noted as having replaced sphalerite, as shown in figure 24. As suggested by figure 25, it may also have replaced galena and tennantite (?). Chalcocite is not abundant; it was noted in intergrowth with stromeyerite, the stromeyerite having replaced probable bournonite (see fig. 26) and the chalcocite having replaced enargite and possibly other minerals. Covellite has replaced enargite (see fig. 28), famatinite, sphalerite, tennantite or tetrahedrite, stromeyerite, cosalite, and possibly galena. Proustite and pyrargyrite in a single specimen from the Robinson mine replace galena.

Water collected from an ore body rich in covellite in the Genesee mine, at a depth stated to be about 900 feet, upon analysis proved to be essentially a concentrated solution of sulphates of aluminum, iron, and copper, named in the order of abundance (see table, p. 108); it is probably fairly representative of the waters that have been instrumental in copper and silver enrichment in the mines of the Red Mountain region. This water is similar in general quality to descending mine waters in the Burra Burra mine at Ducktown, Tenn., and the Mountain View mine at Butte, Mont.

RICO-DUNTON REGION.

GENERAL GEOLOGIC FEATURES.

The mining camp of Rico, in Dolores County, is on the Rio Grande Southern Railroad between Durango and Telluride. It lies about 8 to 10 miles beyond the southwest front of the great San Juan Mountain region, which is characterized by Tertiary volcanic flows, tuffs, and breccias in great abundance and variety. In the vicinity of Rico Tertiary intrusive rocks are abundant as sills, stocks, and dikes, and although Tertiary volcanic rocks are now absent it is probable that they once extended over the site of Rico and have since been eroded. Within less than 5 miles northwest, west, and south of Rico the intrusive igneous rocks disappear, except for an occasional small dike or sill, and sedimentary rocks occupy the surface. Dunton, on West Dolores River about 8 miles northwest of Rico, lies within this sedimentary tract and is just beyond the border of the area described in the Rico geologic folio.[29] The sedimentary rocks of the Rico region include small areas of schist, possibly of Algonkian age, Algonkian quartzites and conglomerate, Cambrian quartzite, and rocks of Devonian, Carboniferous, Triassic, Jurassic, and Cretaceous ages. In the vicinity of Rico these sediments have been gently folded, partly as a result of the intrusion of igneous rocks, but mainly by later arching movements that were apparently not connected with igneous activity. During the period of these later movements faulting took place and then mineralization. Some of the ore deposits follow fault planes and constitute veins; others are comparatively flat-lying blanket or "contact" deposits; still others, which will not be touched upon in this report, are irregular replacement bodies in limestone and stockworks or " chimneys." The source of the solutions that deposited the primary ores is problematic; they presumably came from a deep-lying igneous source in late Tertiary time.

The Rico district was formerly a large producer of high-grade silver ores, but when visited by the writer in 1913 most of the famous silver-producing mines had long been idle, and as most of the workings were inaccessible, ore specimens had to be gleaned from the dumps and from old collections. Of recent years mining has been confined mainly to lead, lead-zinc, and copper concentrating ores carrying relatively small amounts of silver. Dunton is a comparatively new camp that has produced small amounts of gold and silver ores.

In the Rico district the principal bodies of rich silver ore, and the only ones considered in this report, occurred in Newman Hill. The

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[29] Cross, Whitman, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Rico folio (No. 130), 1905.

structural relations of these ore bodies have an important bearing on the problem of silver enrichment and will be briefly described.[30] The rather flat-lying Carboniferous formations of Newman Hill are traversed by two sets of steeply inclined mineral veins, of which one set (with northeast trend) is productive and the other (with north to northwest trends) is unproductive. These veins are typically exposed in the Group (Enterprise), Lexington, and Syndicate tunnels and the drifts connected with them. Large amounts of rich silver ore have been taken from the northeast veins.

The veins do not reach the surface but die out at what is known as the "contact." This is essentially a zone of faulting, solution, and mineralization parallel to the bedding of the gently dipping Carboniferous sediments and thus lying nearly at right angles to the veins already referred to. Along it the lower part of a bed of black shale has been shattered to form a breccia, but the upper part remains intact, to form a relatively impervious roof, which is useful in keeping the copious surface waters out of the workings. Along the "contact" also a bed of gypsum has been dissolved, leaving a silty residue of dolomite and celestite that originally formed impurities in the gypsum. Subsequent mineralization has replaced part of this silty residue by ore and locally mineralized also the shale breccia to form blanket ore bodies.

The minerals of the blanket ore bodies are similar to those of the productive veins, and these veins pass into the blanket, though usually breaking up into small stringers in joining it. The productive ore bodies are not continuous along the blanket but are confined to the vicinity of the veins. The ores of the blanket deposits and of the veins below showed little oxidation.

The veins proved to be workable for 100 to 200 feet below the blanket ore bodies. Below that depth they continue with little change in size, but the character of their mineralization gradually alters, the rich silver minerals disappearing. That this change is primary is indicated by the fact that the undoubtedly primary minerals—galena, sphalerite, and rhodochrosite—also play out.

There were thus in Newman Hill a series of ore bodies evidently deposited in the first instance by ascending solutions that rose along the veins and spread laterally along the "contact." These ores apparently did not reach the surface and were protected from extensive oxidation and the action of surface waters by the impervious black shale and higher beds. The conditions were therefore not especially favorable for the oxidation of silver minerals and the transfer of silver in descending meteoric waters to enrich ores farther down.

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[30] See Ransome, F. L., The ore deposits of the Rico Mountains, Colo.: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 2, pp. 237–397, 1901; Rickard, T. A., The Enterprise mine, Rico, Colo.: Am. Inst. Min. Eng. Trans., vol. 26, pp. 906, 980, 1897.

JUMBO NO. 3 VEIN.

The Enterprise tunnel was entered to the Jumbo No. 3 vein, which belongs to the northeasterly group of veins of Newman Hill, the group that comprises most of the productive veins. The vein is nearly vertical. Ransome[31] described the general character of this vein as follows:

> Northeast of the Group tunnel the vein is usually a solid tabular mass or plate of quartz, rhodochrosite, and ore. It is generally less than 14 inches in width and is, as a rule, adherent or frozen to the walls of the fissure. Such ore is always banded, and the colors of the component minerals render this structure unusually striking. * * * Individual bands can rarely be followed far before they die out or coalesce with others. Nor does the succession of minerals from the walls in toward the medial plane of the vein follow any observable regular sequence. Usually quartz was first deposited on the fissure walls, but often rhodochrosite is the earliest mineral to form. The ore minerals, galena, pyrite, chalcopyrite, and sphalerite, occur in all proportions in the vein, but tend to be more abundant in the middle. There are usually numerous small vugs along the medial plane of the vein, and in these occur the rich silver minerals, proustite, argentite, stephanite (?), and polybasite, and occasionally free gold and silver, which form the richest ore. * * * There is unmistakable evidence, not only along the Jumbo No. 3 vein but also in others of its class, that the fissure after having been wholly or partly filled with ore was reopened, usually next to one wall, and the opening again filled by fresh deposition. As far as could be determined, this latter filling always consisted of nearly barren white quartz carrying a little pyrite.
>
> The characteristics of the vein so far described are those which obtain above the [Group] tunnel level and below the Enterprise limestone. In all the northeasterly veins the ore at a certain fairly constant distance below the Enterprise limestone becomes too low grade to pay for working. The veins continue downward and carry pyrite, chalcopyrite, sphalerite, and galena, but the rich ores of silver which made the upper portions profitable are no longer found. The depth at which this change takes place is apparently not dependent upon the topographic surface but is related to the so-called "contact" resting on the blanket limestone and with reference to the latter is remarkably small.

This depth is placed by various observers at 100 to 200 feet.

The Jumbo No. 3 vein was accessible to the present writer only on the Group tunnel level and at or near this tunnel. Here it is about 600 feet below the surface and 125 feet below the so-called "contact" or blanket deposits of ore. Water dripping from the roof of the Jumbo No. 3 drift about 100 feet northeast of the Group tunnel was depositing minute crystals of gypsum and produced no change in color in methyl orange solution, thus showing that it was neutral in quality.

A pile of ore at the mouth of the Group tunnel, stated by the manager of the tunnel, Mr. Alden C. Massey, to have come from the Jumbo No. 3 vein near the level of the tunnel, showed a number of interesting features. Wall rock, apparently a coarse sandstone carry-

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[31] Ransome, F. L., op. cit., pp. 315–318.

ing scattered minute grains of pyrite, is traversed by veins carrying primary (hypogene) white quartz, rhodochrosite, manganiferous siderite, chalcopyrite, pyrite, galena, sphalerite, argentiferous tennantite, and pearceite, and probably secondary (supergene) chalcopyrite, pearceite, and argentite. Concerning the primary character of the argentiferous tennantite there can be no question. Its grains interlock intimately with rhodochrosite, siderite, quartz, and the base-metal sulphides, indicating complete contemporaneity. It is very abundant in some specimens and reacts strongly for silver.

In certain specimens pearceite is abundant in and near small vugs. It is not a superficial deposit on the undoubtedly primary minerals of the vugs but is in intimate and interlocking intergrowth with quartz, manganiferous siderite, and chalcopyrite. Such intergrowths are confined mainly to the vicinity of vugs, but many of them extend nearly 1 centimeter back from the actual open space of the vugs. This pearceite is interpreted as belonging to the same general period of mineralization as the common base-metal sulphides and gangue minerals of the ores, though its particular abundance in or near the vugs of the central parts of the veins shows that it was deposited more abundantly in the later part of this mineralization than in the earlier part.

In view of the recognition of primary pearceite the next point to be considered is whether any of the silver minerals of the ores are of secondary origin. From general knowledge of the process some downward enrichment in silver would seem inevitable in ores of the composition and situation of these. Study of the ores from the Group tunnel level of the Jumbo No. 3 vein appears to verify this assumption. These ores are traversed by numerous small fractures, some parallel to the course of the vein and others cutting both vein and wall rock at considerable angles. Along such fractures pearceite, argentite, and chalcopyrite have been deposited indiscriminately on vein minerals and on barren wall rock, in discontinuous patches as much as 8 millimeters across looking like patches of lichens on a tree trunk. No gangue minerals accompany these sulphides.

The origin of these sulphides through downward enrichment can not be demonstrated but is most probable. They lie on and do not interlock with the primary ore minerals; they were deposited after the primary ore and wall rocks had been fractured, and they are unaccompanied by any gangue minerals. If they are deposits from descending solutions, such solutions were probably not strongly acid, because these sulphides in places rest on primary siderite and rhodochrosite that show no signs of etching. Furthermore, waters now descending through the Jumbo No. 3 vein are neutral in the Group tunnel level as has already been noted.

RICO-ASPEN MINE.

Two specimens of rich ore from the Rico-Aspen mine, collected by George W. Tower in 1898, were available for study. A piece of vuggy ore obtained near the Silver Glance shaft was found to be composed mainly of white quartz, chalcopyrite, and resin sphalerite. In or near the vugs but intimately intergrown with chalcopyrite and calcite occur crystals of the silver sulpharsenide pearceite. In the vugs these crystals lie side by side with crystals of chalcopyrite and sphalerite, neither coating the other. This pearceite is interpreted as primary, and its intergrowth with calcite shows that the waters which deposited it were not acid.

A specimen, presumably from the "contact" or blanket ore body, as it is marked "gypsum level," carries white quartz, pyrite, chalcopyrite, highly argentiferous tennantite, pearceite, and argentite. Small vugs are numerous. The tennantite is unquestionably primary. Crystal faces of tennantite and chalcopyrite show no superficial tarnish or replacement by secondary minerals, but a little malachite is deposited on them locally. The pearceite lies mainly in and near vugs, but is intercrystallized with chalcopyrite and other commoner ore minerals and is interpreted as belonging to the same epoch of primary mineralization. Argentite also occurs in the vugs, usually in more or less rounded crystals. It lies beside crystals of dolomite in the vugs, neither appearing to coat or replace the other. Small crystals that consisted mainly of argentite were detached, embedded in sealing wax, polished, and studied microscopically to determine more certainly the relations between argentite and other minerals. The contacts between argentite and galena were curved but smooth and regular and showed no embayments or lenses of argentite penetrating the galena along cleavage planes, such as are common where galena is replaced by argentite. Neither were there any outliers of galena in the argentite that might be interpreted as remnants left by incomplete replacement. On the contrary, there were a few inclusions of argentite, nearly rounded in outline, in the galena. The argentite is therefore interpreted as primary and contemporaneous with the galena. That the argentite is not a secondary mineral formed by replacement of the galena is rendered even more probable by the presence of minute irregular replacement veinlets of chalcopyrite, and chalcopyrite. The ore is vuggy, and the vugs contain bly products of downward enrichment, and a number of the veinlets have followed the contact between argentite and galena, though they replace only the argentite.

The same polished specimens show argentite in contact with tennantite. The contacts are more irregular than those with galena but in many places are straight, evidently following crystallographic directions of the tennantite. The argentite apparently has not replaced the tennantite.

ENTERPRISE VEIN.

The Enterprise vein was accessible in 1913 only in the Group tunnel. Specimens collected near the line of this tunnel show abundant coarse white quartz with which are intergrown small amounts of manganiferous siderite and the base-metal sulphides galena, sphalerite, and chalcopyrite. The ore is vuggy, and the vugs contain calcite and argentite in addition to the minerals already mentioned. The crystals of the argentite are usually rounded. The galena and chalcopyrite associated with argentite in the vugs are fresh in appearance, and the hand lens discloses no indications that the argentite is of a different age from the base-metal sulphides with which it is associated. To make sure of these relations, pieces of argentite and associated sulphides from vugs were embedded in sealing wax, polished, and examined microscopically. The relations thus shown were similar to those already noted for argentite from the Rico-Aspen mine. Sharp and regular boundaries exist between the argentite and unquestionably primary chalcopyrite and galena, and there is an entire absence of evidence of replacement of these minerals by the argentite. Furthermore, the argentite has itself been replaced to a minor degree by covellite and chalcopyrite. These minerals replace the argentite peripherally or form irregular replacement veinlets in the argentite or between argentite and chalcopyrite. These specimens occurred about 200 feet below the so-called "contact" or blanket ore body and about 500 feet below the surface. Waters descending through the Enterprise vein near this locality were neutral toward methyl orange and were depositing stalactites of calcite. The persistence of primary calcite in the vugs with the argentite and the presence of malachite coatings on the argentite render it probable that the covellite and chalcopyrite that replaced argentite were not deposited by strongly acid waters.

"CONTACT" ABOVE THE UTE VEIN.

A specimen said to have come from the blanket ore body above the Ute vein was obtained from Mr. Alden C. Massey. This specimen is a coarse aggregate of quartz, manganiferous siderite, sphalerite, galena, and chalcopyrite. In some of the vugs are crystals of chalcopyrite and pearceite, both fresh and lustrous and apparently contemporaneous and primary. This assemblage of ore minerals is traversed by small fractures lined with white quartz and dotted with small crystals of pearceite, many of which are rather intimately intergrown with the quartz. If this pearceite is a deposit from descending solutions the associated quartz was also so deposited. A primary origin can not be demonstrated but seems probable.

EMMA MINE.

Dunton is reached by a poor wagon road from Rico. It lies in a region occupied almost exclusively by sedimentary rocks, which appear to include the Cutler formation (Permian?), the Dolores formation (Upper Triassic), and the La Plata sandstone (Jurassic) as recognized in the adjacent Rico area.

The Emma mine, at Dunton, was visited in September, 1913, when very little mining was in progress. The mine develops the Emma vein, which strikes nearly due north. The workings consisted of five tunnels on this vein on the southwest side of West Dolores River; their relations were as follows:

Tunnels of Emma mine, 1913.

No.	Length (feet).	Vertical distance above next tunnel (feet).
1	120	100
2	2,150	60
3	250	100
4	1,800	80
5	3,100	....

The portal of tunnel No. 5 is near the level of West Dolores River.

Most of the vein between tunnels Nos. 4 and 5 has been stoped out. A large block between No. 4 and No. 2 has also been stoped. In places a little stoping has been done above No. 2. A shaft descends for 187 feet below tunnel No. 5 near its portal, and from the bottom of this shaft level No. 6, 20 feet long, had been started in 1913.

The rocks exposed in the mine are mainly shales of terra-cotta color, in part thin bedded and fissile and in part thicker bedded and somewhat sandy. No fossils were found in these rocks, but from the descriptions given in the Rico folio it is evident that they belong either to the Cutler formation (Permian?) or to the Dolores formation (Upper Triassic).

Near the veins the rocks have been bleached from red to gray by the action of the mineralizing solutions; thus in tunnel No. 1 the red shales are bleached gray for 4 feet on one side and 8 to 10 feet on the other side of the vein. This bleaching has evidently involved a reduction of ferric iron to the ferrous state, for disseminated pyrite is usually scattered in minute grains through the bleached rocks.

Nature of primary ores.—Exposures of undoubted primary ores were not very numerous or satisfactory. In the small stope between tunnels Nos. 2 and 3 the vein is 1 to 2 feet (in a few places 4 feet) wide and consists commonly of irregular veinlets of quartz and chalcopyrite. Quartz-lined vugs are common. In places the fracturing that preceded mineralization was so irregular that the ore minerals became essentially a filling between fragments of a breccia. Here and there galena, sphalerite, and pyrite are present in addition to quartz and chalcopyrite. All these minerals are contemporaneous. Ore obtained near chute No. 19 in tunnel No. 5 carries barite in addition to the minerals already mentioned.

Near chute No. 37 in tunnel No. 5 pyrite in botryoidal crusts one-eighth to one-fourth inch thick, with radiating structure as seen in cross section, coats ore composed of galena, sphalerite, chalcopyrite, and quartz and appears clearly to be a later deposit, probably from ascending solutions.

Hot mine waters.—At several points on the lower level (tunnel No. 5) thermal waters accompanied by gaseous emanations and in places depositing mineral matter were observed. Thus at nearly 3,000 feet from the portal warm waters were rising along the vein and evolving carbon dioxide gas. Here also epsomite ($MgSO_4.7H_2O$) in delicate crystals was noted on the walls of the drift, along with stalactitic masses of calcite, both apparently deposited by the thermal waters. Near chute No. 42 on the same level calcite occurred as a scum on the surface of pools of the hot water. This calcite was finely crystalline, and some of it assumed the form of minute hollow spheres, having crystallized apparently around bubbles of carbon dioxide. The calcite carried a little iron but no magnesium.

At a point in tunnel No. 5 about 25 feet beyond chute No. 25 a sample of water was collected from a clear, rapidly flowing stream issuing from the floor of the tunnel. This water had a temperature of 82° F. and was evolving carbon dioxide in abundance, together with small amounts of hydrogen sulphide. It had a chalybeate taste, and a scum of ferruginous calcite partly oxidized to ferric hydroxide had formed on its surface where it was ponded. The analysis of this water is given in the accompanying table. It is a bicarbonate and sulphate water in which the dominant positive radicles, named in the order of abundance, are calcium, sodium, potassium, and magnesium. The heat of the waters in the Emma mine affected the air temperature to such an extent that workmen perspired profusely and worked stripped to the waist. Hydrogen sulphide is evolved much less abundantly in the Emma mine than in the Rosebud mine, described on pages 124–127.

The thermal waters of the Emma mine are undoubtedly ascending. They are possibly to be regarded as the somewhat impotent successors of the solutions that deposited the primary ores, but whether they have this origin or are surface waters that have descended, become heated, and ascended is still in doubt. The water of the Emma mine is similar in general to that of the "Soda Spring" at Dunton, though richer in alkalies and strong acids and warmer by about 30° F. Both waters resemble in a general way Emmons and Harrington's average of 17 analyses of hot-spring waters from regions of remote volcanic activity,[32] as shown in figure 30.

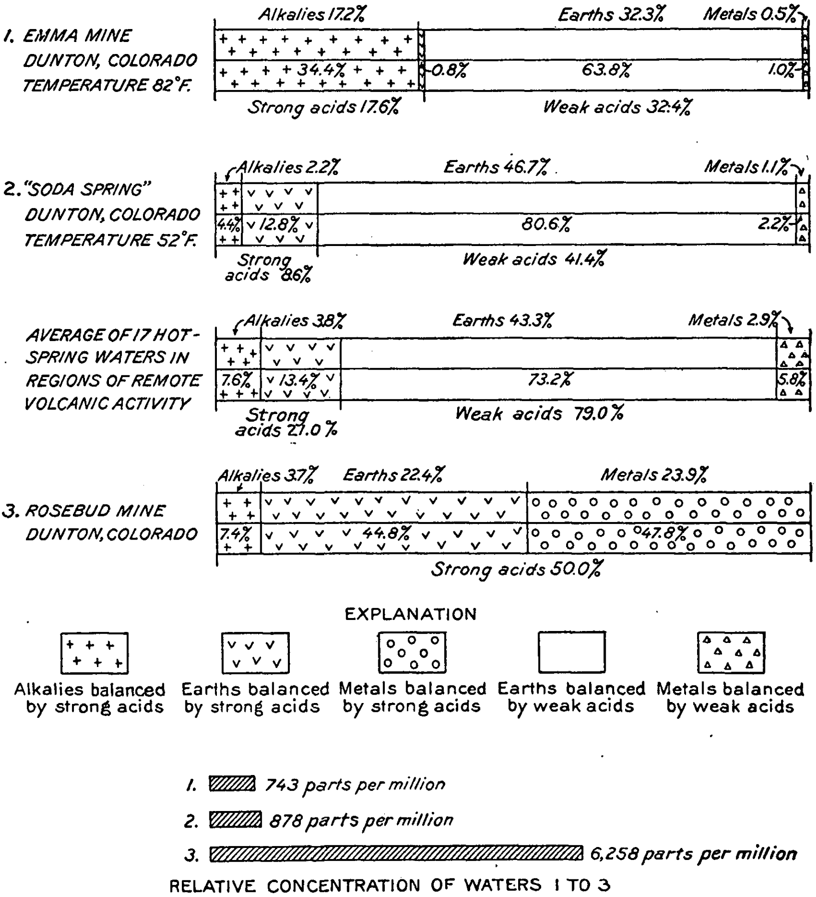

FIGURE 30.—Composition diagrams of waters from Emma mine, "Soda Spring," and Rosebud mine, Dunton, Colo.

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[32] Emmons, W. H., and Harrington, G. L., A comparison of waters of mines and of hot springs: Econ. Geology, vol. 8, p. 661, 1913.

Analyses of mine waters at Dunton, Colo.

[Chase Palmer, analyst.]

Ascending thermal water, Emma mine.

Radicle.	Parts per million.	Reacting value.				
		By weight.	Per cent.		Adjusted (per cent).	
Na	55	2.3925	13.1	17.2	17.2	50.0
K	29	.7424	4.1			
Ca	74	3.6926	20.2	32.3	32.3	
Mg	27	2.2194	12.1			
Mn	None.					
Fe''	2.7	.0967	.5		.5	
SO_4	155	3.2240	17.6		17.6	50.0
Cl	Trace.					
HCO_3	358	5.8612	32.2		32.4	
SiO_2	42					
	742.7	18.2288	99.8		100.0	

	Per cent.
Alkalies balanced by strong acids	34.4
Earths balanced by strong acids	.8
Earths balanced by weak acids	63.8
Metals balanced by weak acids	1.0
	100.0

" Soda Spring " between Smuggler-Almont and Free Coinage mines.

[Temperature, 52° F. Evolving some CO_2 and H_2S.]

Na	8.9	0.3871	1.8	2.1	2.2	50.0
K	2.8	.0717	.3			
Ca	150.6	7.5149	35.3	43.7	46.7	
Mg	22.0	1.8084	8.4			
Mn	None.					
Fe''	6.2	.2220	1.0		1.1	
SO_4	88.6	1.8429	8.6		8.6	50.0
Cl	Trace.					
HCO_3	584.0	9.5776	44.6		41.4	
SiO_2	15.0					
	878.1	21.4246	100.0		100.0	

	Per cent.
Alkalies balanced by strong acids	4.4
Earths balanced by strong acids	12.8
Earths balanced by weak acids	80.6
Metals balanced by weak acids	2.2
	100.0

Cool water from Rosebud mine.

[Evolving CO_2 and H_2S.]

Na	116.0	5.0460	2.7	3.7	3.7	50.0
K	75.0	1.9200	1.0			
Ca	480.0	23.9520	12.8	22.4	22.4	
Mg	219.0	18.0018	9.6			
Mn	3.3	.1201	.7	23.8	23.9	
Fe''	563.0	20.1554	10.7			
Al	211.0	23.3577	12.4			
SO_4	4,591.0	95.4928	50.1			50.0
Cl	Trace.					
	6,258.3	188.0458	100.0			100.0

	Per cent.
Alkalies balanced by strong acids	7.4
Earths balanced by strong acids	44.8
Metals balanced by strong acids	47.8
	100.0

Deposits from descending waters.—On the walls in the older parts of tunnel No. 5 there are incrustations of ferrous sulphate, melanterite, associated in several places with the aluminous iron sulphate holotrichite, which forms a very waxy white deposit of silky or fibrous structure. In one place near chute No. 28 white crystalline alungen, pure aluminum sulphate, incrusts the walls, and elsewhere crusts of gypsum coat walls and mine timbers. It is probable that all these incrustations are deposits from solutions that have descended through the vein from the oxidized zone.

Primary or secondary silver minerals.—In small quartz-lined vugs in ore from stopes between tunnels Nos. 2 and 3 polybasite was noted in characteristic short six-sided tabular prisms. The polybasite is coated in places with very finely crystalline chalcopyrite. Polished specimens of this ore when tarnished with hydrogen peroxide showed no replacement of galena or other minerals by silver minerals. Argentite was fairly abundant as small irregular (usually angular) areas within sphalerite, and several small areas of polybasite were entirely surrounded by quartz that showed crystal faces. In view of the complete absence of evidences of replacement it appears probable that both the argentite and polybasite are primary. Whether the crystals of polybasite, pyrargyrite, and chalcopyrite developed with free faces in vugs are primary or secondary can not be definitely stated.

Ore tenor.—Sampling-works assays of two lots of smelting ore from stopes between tunnels Nos. 2 and 3 and one lot of concentrates shipped from the Emma mine in 1913 gave the following results:

Assays of concentrates and ore from Emma mine.

	Net weight (pounds)	Gold (ounces to the ton).	Silver (ounces to the ton).
Concentrates	38,312	3.47	259.83
Ore	32,314	2.72	253.70
Ore	35,168	3.17	202.20

Sampling of the ore from the lowest tunnel (No. 5) shows great variation in tenor. According to Mr. Colin Timmons, who did the sampling, the average value of the ore was $15.15 a ton, about 45 per cent in gold and 55 per cent in silver. At the average price for silver in 1913 of 60 cents an ounce, this would be equivalent to about 0.3 ounce of gold, and 14 ounces of silver to the ton.

SMUGGLER-ALMONT MINE.

Location and development.—The Smuggler-Almont mine, operated by the Milwaukee Gold Mining Co., of Racine, Wis., is near

Dunton and develops two adjacent and nearly parallel veins, the Smuggler and the Almont. The workings on the Almont vein consisted in 1913 of four tunnels. The portal of the lowest or No. 4 is at an altitude of about 9,100 feet, 450 feet or so above the level of West Dolores River. This tunnel was slightly more than 1,200 feet in length. Tunnel No. 3, 205 feet vertically above No. 4, was also more than 1,200 feet long; tunnel No. 2, about 110 feet above No. 3, was about 650 feet long; tunnel No. 1, about 95 feet above No. 2, was a little more than 150 feet long. Some overhead stoping had been done from all these levels for most of their length, but in 1913 it had not extended more than 50 feet above any of them.

The Smuggler tunnel, 75 feet lower than the lowest tunnel on the Almont vein, is between 500 and 600 feet long and develops the Smuggler vein, which is nearly parallel to the Almont and may join it farther in the hill. Some stoping has been done from this tunnel, but the Smuggler vein has not proved as profitable as the Almont and the workings were blocked at the time of visit in 1913. The observations that follow therefore apply only to the Almont vein. On the property was a 20-stamp concentrating mill (800 to 850 pounds, 95 drops a minute), equipped with 10 Wilfley tables.

Primary mineralization.—The width of the Almont vein is commonly between 1 and 3 feet. As observed at several points in tunnels Nos. 3 and 4 the ore is an irregular aggregate of primary quartz, chalcedony (rare), barite, galena, sphalerite, chalcopyrite, argentite, and polybasite or pearceite. No banding occurs; small vugs are common and are usually lined with quartz crystals. Maximum diameters of about 1 centimeter were noted in quartz and pyrite crystals, but most of the sulphide grains are 1 to 2 millimeters or less across. In a single specimen from tunnel No. 3 milky chalcedonic silica of botryoidal outlines was noted in small amounts associated with finely crystalline quartz.

The primary silver minerals occurred in grains so minute that they were observable only under the microscope. In polished specimens sphalerite was observed to carry numerous small masses of argentite in the manner shown in figure 31. The mineral had the characteristic rough appearance of argentite, was highly sectile, and gave all the reactions for argentite listed by Davy and Farnham.[83]

Another part of the same specimen showed polybasite or pearceite locally in isolated areas in quartz but elsewhere so intergrown with the common base-metal sulphides of the ore as to leave no doubt of its primary (hypogene) origin. These relations are shown in figure 32. Tests with reagents on the polished specimen identify the mineral as

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[83] Davy, W. M., and Farnham, C. M., Microscopic examination of the ore minerals, p. 67, New York, 1920.

either pearceite or its antimonial equivalent, polybasite. The grains were too minute to be isolated for blowpipe tests.

Stibnite was noted at several places on the No. 3 level. It occurs in clusters of small radiating crystals on well-formed crystals of quartz in vugs and is also found along fractures that cut ore carrying the usual base-metal sulphides. The stibnite was obviously deposited after the main primary mineralization. Whether it was deposited by ascending or by descending waters is uncertain, but the usual absence of stibnite in association with the proustite and pyrargyrite of these ores favors the conclusion that it was deposited by ascending solutions. (See p. 123.)

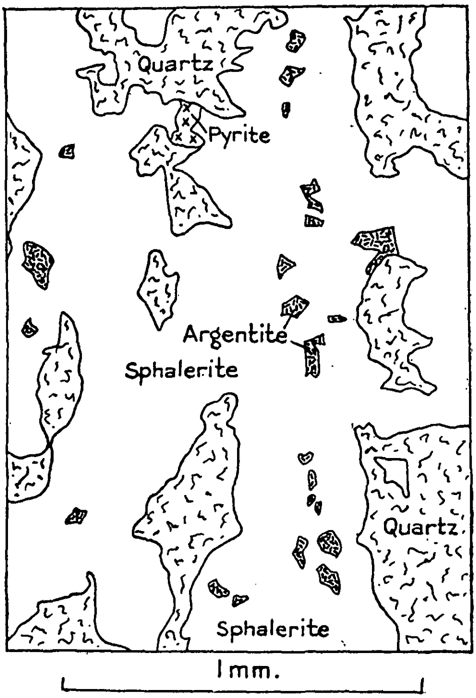

FIGURE 31.—Primary argentite in sphalerite, Smuggler-Almont mine, Dunton, Colo. Camera lucida drawing from polished surface of ore obtained 25 feet above tunnel No. 4.

The terra-cotta colored, somewhat calcareous shales that form the wall rock wherever observed have been bleached buff, probably by the solutions that deposited the primary ores. In places the bleaching exhibited in crosscuts extends 10 to 20 feet from the vein. The bleached rocks near the vein carry minute disseminated pyrite grains, are noncalcareous, and have been silicified. Near the outer limits of the bleached zone the bleached rocks remain calcareous.

Gases.—On levels Nos. 3 and 4 the odor of hydrogen sulphide was fairly strong, and on the third level carbon dioxide had locally accumulated along the floor. Both these gases are rising along the vein fissure, though not accompanied by springs of warm water, as in the Emma mine.

Downward enrichment in silver.—Throughout level No. 3 and the stopes above it the silver mineral pyrargyrite with some proustite and chalcopyrite was noted. In the vugs the silver minerals lie on or between well-formed quartz crystals; on irregular fractures traversing the pyrite-galena-sphalerite ore they occur as isolated crystals, clusters of crystals, or thin coatings. Proustite and chalcopyrite are everywhere very subordinate to pyrargyrite, with which they are unquestionably contemporaneous. Only in one specimen were the silver minerals noted in association with stibnite on a fracture in certainly primary ore. In this specimen pyrargyrite appeared to be deposited on the stibnite and was therefore later.

On level No. 4 pyrargyrite and proustite were noted occurring in similar relations to a point about 900 feet in from the portal but were not observed beyond this point. These observations accord with the assays, for samples taken at 15-foot intervals between points about 125 and 750 feet from the portal are reported to have carried usually over 20 ounces of silver to the ton, and one sample showed 109 ounces. From the point at 750 feet to the face the silver content ranged from 1.2 to 16 ounces. The decline in silver content is due in part to differences in the character of the primary mineralization, for near the face of this tunnel the vein is richer in pyrite and poorer in galena and sphalerite, but it is probably due also to a playing out of downward enrichment in silver with depth.

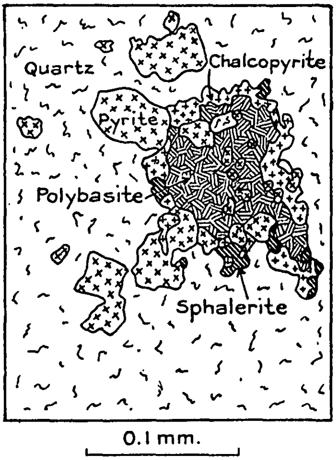

FIGURE 32.—Primary polybasite or pearceite irregularly intergrown with pyrite, sphalerite, and chalcopyrite, Smuggler-Almont mine, Dunton, Colo. Camera lucida drawing from polished surface of ore from stope 25 feet above tunnel No. 4.

Mine waters dripping from the roofs of stopes and obviously representing surface waters that had worked downward along the vein were tested at two places for acidity. In a stope 40 feet above level No. 4, about 600 feet from the portal, the waters were in some places neutral and in others faintly acid. Pyrargyrite and proustite were abundant in the ore of this stope. In a stope 20 feet above level No. 4 and 1,050 feet from the portal water dripping from the roof was neutral with methyl orange. In this stope, it is reported, very little pyrargyrite or proustite occurred.

Slight oxidation, probably antedating the opening of the mine, was noted in ore from the face of level No. 3 at depths of about 500 feet. Local oxidation was reported in stopes above level No. 4 at 600 feet from the portal at the time these were first opened. This locality is about 300 feet below the surface and near the inner limit of rich ore in this level.

Summary and conclusions.—The evidence presented in detail above shows that the silver content of the ore of the Almont vein is partly in primary minerals deposited by ascending solutions (hypogene) and partly in secondary minerals deposited by descending waters (supergene). As the ores available for study carried both primary and secondary silver minerals it is impossible to say what proportion of the silver content is primary and what is secondary. Primary silver minerals appear sufficiently abundant to warrant exploration of the vein at depths below the surface greater than those to which the ruby-silver minerals extend, in order to determine whether the primary ore is of workable grade.

The primary silver minerals of the Almont vein are argentite and either polybasite or pearceite. Both of these are fairly abundant in certain of the ores. The argentite is commonly inclosed by sphalerite. Pyrarygrite and proustite, believed to be secondary in origin, are abundant in vugs and fractures of the primary ores but were not noted contemporaneously intergrown with any of the primary sulphides or replacing them. Replacement of galena by supergene silver minerals, so common in some silver ores, was not noted even close to fractures that carried the supergene ruby-silver minerals.

Hydrogen sulphide and carbon dioxide gases, possibly coming from the same deep sources as the solutions that deposited the primary ores, are now rising along the Almont vein. In the presence of hydrogen sulphide silver salts carried downward by descending solutions could presumably not descend far below the ground-water level before being precipitated.

The pyrargyrite and proustite of the ores were apparently deposited after the primary ore had been somewhat fractured. They were not observed intergrown contemporaneously with any of the undoubtedly primary ore minerals. In view of this fact and their apparent playing out with depth they are regarded as products of downward enrichment—that is, as deposited by descending waters of meteoric origin. Tests in stopes where these ruby-silver minerals are present indicate that the waters depositing them were probably neutral or only weakly acid.

ROSEBUD MINE.

Location and development.—The Rosebud mine, operated by the Rosebud Gold & Silver Mines Co., of Denver, is on Gas Creek about 3 miles east of its confluence with West Dolores River. This confluence is 3 to 4 miles below the town of Dunton.

The main lower working of this mine consisted in 1913 of a crosscut running nearly east and intersecting the Rosebud vein 540 feet from the portal. The Rosebud vein is nearly vertical and ranges in strike from due north to N. 15° W. From the crosscut tunnel a drift had been carried north along the vein for 225 feet.

A higher tunnel about 75 feet above the lower one follows the Rosebud vein for about 500 feet but could be entered only through a raise from the lower tunnel and was all timbered, so that nothing could be seen of the vein there. The ore on the dump at its portal, however, was very similar to that in the lower tunnel.

To the south, across Gas Creek, a drift tunnel 75 feet long had been run on the Rosebud vein. Its portal is about 10 feet above the creek level. It could not be entered, but waters issuing copiously from its portal were collected for analysis. (See p. 119.)

Nature of primary mineralization.—The only exposures of the Rosebud vein available for study were in the lower tunnel on the north side of the creek. In general the width of the vein ranges from 1 to 4 feet. In places it is a breccia of fragments of black shale and pinkish shale with minute crystals of pyrite abundantly disseminated in the matrix and sparsely scattered through the fragments. Such portions are lean. At other places the vein consists of rhodochrosite associated with lesser amounts of calcite and both inclosing small irregular bunches of tennantite and chalcopyrite. The calcite traverses the rhodochrosite in ill-defined contemporary veinlets. The tennantite and chalcopyrite are locally intergrown with minor amounts of galena and sphalerite. Wet tests of the tetrahedrite show that it is highly argentiferous and therefore belongs to the variety known as freibergite. This is the only silver mineral noted in the ores. In places this association of rhodochrosite, calcite, and sulphides forms the matrix of a breccia of angular wall-rock fragments.

Ore of the type described above carries in small vugs and irregular fractures quartz, calcite, and pyrite, either separately or together. The pyrite usually forms octahedrons under 0.5 millimeter in size. Portions of the ore particularly rich in argentiferous tetrahedrite are incrusted along fractures with finely crystalline chalcopyrite associated with a little pyrite. All these minerals are believed to be primary, deposited by ascending solutions slightly later than the rhodochrosite and its associates.

Subsequent to the primary mineraliation faulting along the vein has produced gouge-filled slip planes and locally reduced the entire vein to a mass of gray gouge through which remnants of rhodochrosite ore are scattered.

Mine waters and gases.—A strong odor of hydrogen sulphide pervades the whole vicinity of the mine. Along the Rosebud vein in the lower tunnel workings carbon dioxide bubbles up abundantly through the waters on the floor of the drift, and a silver coin placed in the water is quickly blackened from the hydrogen sulphide also present.

From the mouth of the short tunnel on the Rosebud vein just south of Gas Creek cool water is flowing copiously, and birds, rats, and other small animals coming to drink of the water are commonly asphyxiated by the carbon dioxide accompanying it. A sample of the water from this tunnel was collected, and its analysis is in the table on page 119. Its qualities as computed from the analysis are shown diagrammatically in figure 30 (p. 118). It carries principally sulphates of the earths and the metals, and its mineral content is nearly nine times that of the thermal water from the Emma mine. Carbon dioxide and hydrogen sulphide gases are bubbling through the water. These gases, as at the Emma mine, are probably ascending along the vein and of deep-seated origin. The water because of its acidity and high metal content is believed to be in the main of surface origin and to have derived its mineral load from rocks and vein material through which it descended. Slight admixture with ascending waters that accompanied the hydrogen sulphide and carbon dioxide is probable.

Waters from the Rosebud vein evolving carbon dioxide and hydrogen sulphide are in places forming a grayish deposit of sulphur where they flow over the surface in contact with the air. This sulphur is invariably associated with small amounts of carbon, suggesting that microorganisms were instrumental in its deposition. When the sulphur is volatilized in a closed tube the residue is black, but the black color quickly disappears upon heating in the air, indicating that it is carbon.

About a quarter of a mile down Gas Creek from the Rosebud mine there is on one side of the creek a spring depositing sulphur and evolving carbon dioxide and hydrogen sulphide, and on the other side of the creek another spring is depositing calcium carbonate. No samples were taken of these waters.

Downward enrichment.—None of the ores collected from the mine or dumps showed any evidences or downward enrichment in silver. Enrichment in copper was nearly negligible and confined to the local development of thin black films of chalcocite on pyrite and chalcopyrite.

The abundance of gouge, formed by movement along the vein subsequent to primary mineralization, tends to prevent the free circulation of descending waters necessary for enrichment.

Summary.—Where observed in the lower tunnel on the north side of Gas Creek and on the dumps of this and the upper tunnel the ore showed primary rhodochrosite, calcite (in part manganiferous), quartz (sparse), argentiferous tetrahedrite (freibergite), pyrite, sphalerite, galena (sparse), and chalcopyrite.

At numerous places along and near the vein hydrogen sulphide and carbon dioxide are bubbling up through the mine waters.

Waters flowing copiously from several points along the vein are cool, and one sample carried mainly sulphates of the earths and of iron and alumina. This is very probably a water of surface origin and not related to the solutions that deposited the ores.

There were no evidences of downward enrichment. Freibergite, the only silver mineral noted in the ore, is unquestionably primary.

SUMMARY AND CONCLUSIONS.

The writer's studies near Rico were confined mainly to the mines of Newman Hill, which in the past was the principal productive locality for rich silver ores. The mines of this hill had been idle for many years, and opportunities to study the ores were restricted to the old mine dumps and part of the Group tunnel workings.

The primary ore minerals noted by the writer are quartz, rhodochrosite, calcite, manganiferous siderite, pyrite, chalcopyrite, galena, sphalerite, argentiferous tennantite, argentite, pearceite, and gold. In many specimens highly argentiferous tennantite intergrown contemporaneously with the common base-metal sulphides is very abundant. Primary pearceite and argentite appear to have formed most abundantly late in the epoch of primary mineralization, for they occur principally in vugs. In many places primary silver minerals are unquestionably sufficiently abundant to produce rich silver ores.

Because the ore bodies do not crop out but terminate upward several hundred feet from the surface in a flat-lying blanket ore deposit known as the "contact," the conditions are unfavorable for downward enrichment on a large scale, yet there are evidences that some enrichment has probably taken place. In ore from the Jumbo No. 3 vein chalcopyrite, pearceite, and argentite were noted coating clean-cut fractures in primary ore. Ransome reports the occurrence of proustite, stephanite (?), polybasite, and native silver in this vein, and these also may be secondary. Secondary silver minerals were noted to depths of 600 feet below the surface and 125 feet below the "contact." In a few places primary argentite has been replaced on a minor scale by covellite and chalcopyrite. These copper minerals may replace the argentite along galena contacts or may form minute replacement veinlets in argentite. The copper enrichment is too slight to be of commercial significance.

The waters descending through the veins at depths of 500 to 600 feet were neutral toward methyl orange and were depositing calcite and gypsum. In one place where such waters were present the ore carried secondary argentite, pearceite, and chalcopyrite. Furthermore, these minerals lie in fractures sharply cutting unetched rhodochrosite. It would appear, therefore, that the pearceite, argentite, and chalcopyrite, if secondary, were deposited by waters that were not notably if at all acid.

The impression gained from the Rico specimens studied is that by far the greater part of the silver content of the rich ores is in primary rather than secondary minerals, but it would be injudicious to base too fixed a judgment upon the rather meager collections that it was practicable to obtain.

The ore deposits of Dunton are veins, all of which come to the surface. In this respect at least conditions there are more favorable for downward enrichment than at Newman Hill in Rico. On the other hand, the presence of ascending thermal waters at very moderate depths in some of them is a feature unfavorable to downward enrichment.

The primary ore minerals noted at Dunton are quartz, chalcedony (rare), rhodochrosite, calcite, barite, pyrite, chalcopyrite, galena, sphalerite, argentite, polybasite, pearcite (?), and argentiferous tennantite. Stibnite was noted in fractures cutting ore carrying the minerals above named but was usually not associated with the secondary silver minerals later to be considered. It is interpreted as a late primary mineral. Argentite and polybasite (or pearceite) are intimately intergrown with other primary minerals in a fashion shown in figures 31 and 32. Argentiferous tennantite is very abundant in the ore from the Rosebud mine and was the only silver-bearing mineral there noted.

Small amounts of apparently secondary silver and copper minerals were noted in the Smuggler-Almont mine. In that mine proustite and chalcopyrite, intimately associated, occur along clean-cut fractures in primary ore composed mainly of quartz, pyrite, galena, and sphalerite; they also occur in small vugs in such ore. There are some indications that the ruby-silver minerals play out at very moderate depths, and it appears probable that they are products of downward enrichment. In the Emma mine polybasite, pyrargyrite, and chalcopyrite were present in vugs, but there are no indications whether they are late primary or secondary.

The water dripping from the roofs of stopes in the Smuggler-Almont mine in which the secondary ruby-silver minerals occurred was tested by methyl orange and found to be neutral in places and elsewhere faintly acid. The descending waters in the Emma mine were evidently sulphate waters, as shown by deposits of calcium, iron, and aluminum sulphates on the walls of old workings and on roof and wall timbers.

Hydrogen sulphide and carbon dioxide gases were being given off from the Emma, Smuggler-Almont, and Rosebud veins.

Water rising along the Emma vein and giving off hydrogen sulphide and carbon dioxide had a temperature of 82° F. It was depositing ferruginous calcite and had a chalybeate taste. Analysis of this water (see table, p. 119) showed that it was a bicarbonate and sulphate water in which the dominant positive radicles, named in the order of abundance, were calcium, sodium, potassium, and magnesium. Water collected from the so-called "Soda Spring" at Dunton is similar to that of the Emma mine but poorer in alkalies and strong acids, richer in carbonates, and 30° cooler. These waters differ from those of the Ouray Hot Springs in the abundance of carbonates. The "Soda Spring" water corresponds very closely to Emmons's average of 17 hot-spring waters from regions of remote volcanic activity, as is shown in figure 30. These waters are unquestionably ascending, but whether they come from a deep-seated igneous source or are waters of surface origin that have descended, become heated, and ascended is still problematic.

Cool water from the Rosebud mine that was evolving carbon dioxide and hydrogen sulphide contrasts with those above described in carrying no carbonates or bicarbonates. (See fig. 30.) This is purely a sulphate water, its positive radicles, named in the order of abundance, being iron, calcium, magnesium, and aluminum. It seems probable that this water is the result of the interaction of ascending carbonate-bearing waters like those of the Emma mine with waters rich in iron and aluminum sulphates that have descended from the surface through the vein.