Ironton Park as shown in figure 2. The beds are tilted westward at about ten degrees and the upturned edges are truncated by Telluride conglomerate and San Juan tuff. Burbank[10] has suggested that the late Tertiary ore-forming solutions in part rose along the more permeable beds of this wedge and into steep fissures in the base of the Tertiary beds. Fissures similar to those in the San Juan tuff occur in the sedimentary rocks of the wedge although they are not as numerous. The coincidence in direction of the Mineral Farm ore channel in the top of the Leadville limestone with the strike of underlying slate and quartzite bands of the Uncompahgre formation has been pointed out by Burbank[11], who has also suggested other possibilities of finding ore south of the Mineral Farm mine under Hayden Mountain. Prospecting and development have as yet produced no ore from bedded deposits in this area, but possibilities of finding ore are explained on page 383.

TERTIARY FISSURES, FAULTS, AND TILTED BEDS

Upper Uncompahgre-Canyon Creek Area

A marked contrast exists between the number of fissure veins in the Tertiary rocks and the number in the pre-Cambrian rocks. In Uncompahgre Canyon most of the numerous fissure veins in the San Juan tuff bottom abruptly at the pre-Cambrian contact; furthermore, many of the fissures and veins terminate upward within the tuff, and fissure veins are therefore not so numerous in the upper part of the tuff or in the overlying andesites and latites. The major fissures are upward extensions of fractures and faults that existed in the pre-Cambrian rocks prior to the accumulation of Tertiary rocks. The most conspicuous of these are the divergent tension fractures in the Uncompahgre anticline; they include the Dunmore, Columbus, Thistledown, Chapman, and Ores & Metals fissure veins, and a few fissures that are practically barren or simply occupied by

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[10] Burbank, W. S., Structural control of ore deposition in the Uncompahgre district, Ouray County, Colo.; U. S. Geol. Surv. Bull. 906-E, p. 256, 1940.

[11] Idem, p. 241.

dikes. In addition, a few less extensive fissures are nearly parallel to the local strike of the quartzites and slates of the Uncompahgre formation; these were caused by renewed bedding-plane adjustments after the accumulation of the Tertiary volcanic rocks.

The Dunmore fissure, on which there was from 2,800 to 4,500 feet of displacement in pre-Tertiary time, was extended into the San Juan tuff by a nearly vertical displacement of 80 feet. The numerous N.10°-15°W. minor fissures that branch from the Dunmore, Columbus, and other major fissures were probably formed by secondary stresses generated by the displacements along the major faults. In this sector no fractures that are radial with respect to the Silverton caldera (pl. 1) are indicated, and the area is too distant from the Stony Mountain or Cow Creek intrusive centers of radial thrust to have fractures related to them. All the faults are normal, that is the kind in which the hanging wall has dropped with respect to the footwall. The graben-like structure along the inclined fissure veins in the area near the Sutton mine is probably due to a combination of displacement along the pre-Cambrian bedding planes and westward slipping along bedding-planes near the base of the Paleozoic sedimentary rocks induced by the weight of the superincumbent beds of Tertiary age (see fig. 8).

The prominence of fractures and hence fissure veins in the lower part of the San Juan tuff is the result of a combination of causes, among the most important of which are (1) the compact, hard, and brittle nature of the rock, and (2) the local impact of vertical and steep stresses generated from the top of the pre-Tertiary blocks. The dying out of the fractures in the upper part of the San Juan tuff and overlying andesites and latites is caused by the upward dissipation of energy represented by the branching of fractures, and by the inability of clean-cut continuous fractures to form in the less compact shallower beds.

The bedding of the San Juan tuff is generally horizontal around Hayden Mountain, and the small components of dip that can be estimated locally are not uniform in direction. The original dips may have been affected slightly by the tilting of small blocks between fault fissures.

Mineral Point-Poughkeepsie Gulch Area

The fissures of this area form an extraordinary system of branching, intersecting, and conjugate sets. Although generally of late Tertiary age, their origin is most probably the result of many stresses which changed with igneous activity and broader crustal movements. Some of the fissures of this area are probably upward extensions of older fissures in the non-volcanic basement; some originated with the earliest volcanic activity and were extended upward with and into successive accumulations; and some fissures probably continued to form until the end of volcanism. Late mineralization and the accompanying widespread alteration probably leached and softened masses of rock to an extent that allowed gravitational adjustments or slumpage and hence fracturing to continue long after volcanism and even mineralization had ceased.

The most prominent feature of the fissure veins of this area is the northeasterly course of the principal set which forms in a general way part of the roughly radial arrangement of fissures with respect to the Silverton caldera (see pl. 1). Several of the fissure veins of this set are as much as five miles long. As seen on the index map of plate 1, these are neither as straight nor as individual as the Red Mountain-Sneffels or the Sunnyside-Eureka systems. They have principally steep to vertical dips to the southeast, and displacements on them are such that the southeast hanging walls moved down and, as indicated below, perhaps southwestward with respect to the footwalls. The northwestern fissures of this set have little or no measurable displacements in the lower Poughkeepsie and western Mineral Point areas, but displacements are larger in fissures to the southeast. Near the southeast edge of the area the Sewell and Hadley fissure veins dip to the northwest and the dropping of the northwest or hanging wall blocks is considerable. The Mountain Queen vein, which is the southeasternmost of those mapped, dips southeast, but the amount of displacement along it has not yet been determined. In general these fissures are marginal to the more highly faulted and parallel Cinnamon-Rainbow-Anaconda fracture zone to the southeast.

In addition to the northeastward-trending set of fissure veins there is an eastward-trending cross set which usually shows a broad convexity to the northeast. This set is principally in upper Poughkeepsie and California gulches and is roughly parallel to the northeast margin of the Silverton caldera. The marginal eastward-trending fissure veins form a conjugate set; some of them dip southward, but northerly and vertical dips predominate. In general it appears that these fissures may be secondary to parallel but larger faults farther south, such as the Ross Basin fault.

The fissures are generally more numerous and intricate in their branchings in the Burns latite than in the Eureka rhyolite. In the pyroxene andesite unit fissure veins are less numerous and many lose their individual sharpness or identity in wide zones of altered rock. The remarkable exposures of braided, split, and curved "horsetail" veins in the Lake Como area and on the glacial moors south of Mineral Point are almost without parallel. One of the most important and significant features of the northeast-trending fissure veins, especially near Lake Como, is a widening near or along sharp east turns. The widened turns appear to be a tendency of the northeast-trending fissures to "step over" on certain east-trending fractures, and the widening probably indicates a southwestward shift of the southeast walls.

In the Mineral Point, Poughkeepsie, and Engineer Mountain areas the Silverton volcanic series dips from 10° to 20°N. to NW. This may have been partly caused by a doming uplift in the early stages of deformation, but with the formation of the northeastward-striking fissures the tilting to the northwest was accomplished by dropping of the northwest edges of elongate blocks with reference to their southeast edges.

ORE DEPOSITS

GENERAL CHARACTER OF MINERAL DEPOSITS

The ores of this general area of the San Juan Mountains have been described variously and in some detail by Ransome, Irving, Bastin, Burbank, Moehlman, and others. In general they are dominantly siliceous and the gangue materials may consist of quartz, rhodonite, rhodochrosite, ankerite, pyrite, marcasite, barite, kaolin, sericite, and altered wall rock, which was impregnated and partly replaced by most of these minerals during several stages of vein formation. In addition, fluorite and hematite may be locally abundant. In the early history of local mining, sphalerite, chalcopyrite, and even galena were treated like ordinary gangue. The ore minerals may be auriferous and argentiferous sulfides and sulfosalts, such as galena, sphalerite, chalcopyrite, bornite, tetrahedrite, and chalcocite. Argentite, ruby silver, brittle silver, and gold are sparingly present. Argentite, native silver, and gold may have enriched some deposits near the surface, and cerargyrite, or horn silver, is said to have enriched a few outcrops. Locally, oxidized ore minerals of lead, zinc, and copper are present, as is native sulfur, termed sulfurettes by the miners. These minerals, however, are unimportant, and generally do not extend more than a few tens of feet below the surface. A few lodes have contained ore shoots of tungsten, usually huebnerite, the manganese tungstate, and a few others have contained sulfbismuthites of lead and silver, such as alaskaite ($(\mathrm{(Pb,Ag_2)S.Bi_2S_3})$). Very locally enargite and several rarer minerals have formed.

The usual vein of the region, however, consists dominantly of quartz with more or less pyrite, sphalerite, galena, chalcopyrite, rhodochrosite, or barite; however, concentrations of base-metal minerals (galena, sphalerite, or chalcopyrite) probably can not be depended upon to yield much silver or gold unless they include tetrahedrite or other sulfosalts. Gold and silver are commonly separated from the base-metal shoots in a vein or lode, and siliceous vein matter, particularly the gray quartz, may contain more gold and silver than high-sulfide vein matter. Recorded output from the mines shows no relationship between the tenors of any of the base metals and the silver or gold tenors. Highly argentiferous or auriferous sulfides, silver minerals, and gold usually form only local ore shoots.

The veins are typically vuggy and open. Banded and crusted structures are exceedingly common and well exemplified (see fig. 19). Inclusions of shattered wall rock "frozen" in quartz are very abundant and the veins typically show many stages of mineral deposition in which quartz and pyrite are often repeated. One of the most common features of the lodes is the presence of late white coxcomb quartz cutting earlier gray to white quartz and sulfides. Deposition and leaching appear to have alternated in many veins. Although many walls are thoroughly impregnated with quartz, pyrite, kaolin, sericite, and ankerite, the dominant process of vein formation seems to have been the filling of open fissures. Nearly all the larger or prominent veins have bands of gouge usually at one or both walls as the result of displacements after vein formation.

More than 23,000 tons of ore were mined from 1901 through 1941 from about 30 mines in the region, widely distributed with regard to district and altitude. This includes many shipments of sorted high-grade ore and a few from large-scale operations such as the Frisco tunnel, Frank Hough, and Vermillion mines. The average content of gold per ton is 0.06 ounces, and of silver content 12.8 ounces; the average content of copper is about 4.0 percent, that of lead 3.7 percent, and that of zinc 1.3 percent. The high ratio of copper to lead indicated by these figures results from the relatively large output of copper ores from the Frank Hough mine. During 1909-1910 shipments from the Frank Hough mine amounted to 2,420 tons, averaging nearly 0.2 ounce in gold, 37 ounces in silver, and about 26 percent in copper; on the other hand, the Mountain Queen mine has long supplied ores dominant in lead, 67 tons of ore shipped in 1926 averaging 35 percent lead, 0.6 percent zinc, and no copper. In the usual deposit lead is most abundant, zinc ranking second, and copper generally third. Something of the base-metal ratios in the ores may be seen in the accompanying comparison of average tenor of mill ore from the Frisco and Vermillion mines. The tenor of the Frisco tunnel ore is especially noteworthy since they represent low-grade ores of several veins.[12]

	Frisco (1913-1914) (7,140 tons)	Vermillion (1910) (2,673 tons)
Gold	0.015 ounces per ton	0.01 ounces per ton
Silver	1.8 ounces per ton	1.8 ounces per ton
Copper	0.08 percent	0.04 percent
Lead	2.3 percent	3.9 percent
Zinc	1.1 percent	3.6 percent

In the absence of lead, zinc with copper is very uncommon, and shipments of ores in which zinc is dominant are unknown. In several shipments of ore from the Mountain Monarch mine the zinc content has equaled or slightly exceeded that of lead. Mines in whose ores copper has been dominant are the Frank Hough, Silver Link, Guadaloupe, and Poughkeepsie; those whose ores have predominated in lead are the Mountain Queen, Tempest, Pactoles, Wewissa, and Thistledown.

Silver and gold shoots are commonly separated from the base-metal bearing parts of veins, and it is possible to mine selectively for these in many deposits. Many of the very rich small shipments of the early days were made from deposits in which this separation was pronounced. Small shipments from the Wyoming mine from time to time

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[12] No figures were available for the tenor of the mill heads, and the mill recoveries are unknown. The figures, which are low, were obtained by dividing the gross metal in the concentrates by the tonnages.

have contained from one to five ounces of gold and 100 to 300 ounces of silver per ton. Similarly, streaks in the Early Bird vein have yielded small-lot shipments containing 0.6 to 10. ounces of gold and up to nearly 1,400 ounces of silver per ton. In the seventies ore from a 22-inch gray copper ore shoot at the Saxon mine contained nearly 1,400 ounces of silver; in the Alaska mine a 3- to 7-inch gray copper shoot contained 612 ounces of silver per ton.

TYPES AND ORIGIN OF DEPOSITS

Three structural and genetic classes of deposits can be recognized. Although these may be mixed in a single deposit, they are largely distinct. The classes described are (1) fissure and cavity fillings, (2) breccia-chimney and breccia-dike deposits, and (3) replacement deposits.

Fissure and Cavity Fillings

In the 25 square miles covered by the district, more than 125 miles of veins ranging from ½ to 150 feet in width have been mapped. Probably the most common width is about three feet. Because of the great width of some vein zones the average width may be between 5 and 10 feet. There is about one billion tons of vein matter in the three districts represented in plate 1. Most of the deposits were formed by the filling of open channelways along fault fissures; only a few were formed in solution cavities in quartzite. The fissure openings were nearly all the result of displacements along curved or undulating fault surfaces. On some fissures the openings were more or less clogged by angular material broken from the walls during faulting. In other deposits the openings were thin and closely spaced, forming sheeted zones. Most of the openings were along transverse fissures, but a few, especially in strong and prominently bedded rocks such as the pre-Cambrian quartzites, were along bedding planes.

The mineral-forming solutions entered and travelled through many differently shaped and sized channels, as can be seen from the multiplicity of structures in the deposits. Some of the smaller fissures were filled by a single deposition of coxcomb quartz, with a few sulfides interlocking in the middle of the vein. The large fissure veins generally had a longer history, involving repeated opening and filling. Fissures were reopened by expansion of veins barely filled to the middle, by fracturing along and in the walls, or by fracturing irregularly across the vein. Fissures along which movement occurred only once or twice had considerable areas in which the walls remained in tight contact. These areas were only slightly or not at all mineralized. Many of the smaller veins, as well as veins of average length and width, have barren areas or areas in which the vein matter nearly pinches out. The "swelled" or wide parts of the veins represent areas of the fissure that were opened wider or opened repeatedly.

Mineralization followed a sequence controlled by deep magmatic actions, and any metal introduced at only one particular stage of deposition is obviously confined to channels through which the solutions passed at that time. Only the persistent metals and minerals, or those supplied more or less continuously or over several periods of a sequence, occur continuously along a vein. Pyrite and quartz are of this class.

Some of the early mineral fluids were especially corrosive to quartz in the wall rocks. In the pre-Cambrian quartzites open pockets, caverns, and channels are common. These openings are for the most part very irregular, small, and unrelated to bedding or fractures. They were later more or less filled by quartz and sulfides. At the Mother Cline mine a steep irregular solution chimney was formed by a fluid that was a ready solvent of the quartzite. Later this cavity was filled by vuggy quartz, pyrite, sphalerite, chalcopyrite, galena, and barite. The breccia chimney along the highway 1,000 feet south of the Dunmore tram terminal may have been opened by mineralizing solutions first and later perhaps enlarged and filled with breccia by violently and rapidly escaping solutions and gases. In many places the quartzites of the core of the pre-Cambrian anticline are locally rather porous or cavernous as a result of this early solvent action.

Breccia-Chimney and Breccia-Dike Deposits

In some places fragments ground from the walls of a fissure during faulting were carried through open fissures by rapidly moving solutions which may have expanded to gases during their ascent and escape to regions of lesser pressure. Fissures or channels filled with such transported material are known variously as breccia, clastic, or pebble dikes, chimneys, and pipes. Some fragments appear to have moved great distances as shown by their rounding to cobble- or pebble-like forms and their foreign nature with reference to the inclosing walls. Probably in some places because of constrictions in the channels, little transportation was involved, and rounding was produced by a combination of gas or solution corrosion and bumping of the fragments during boiling.

Both the chimney and dike forms of breccia deposits are present in the area, but the filling or cementation with ore minerals does not reach the proportions that it does in the adjoining Red Mountain district.

Several small dikes and one chimney are remarkably exposed along the Silverton-Ouray highway (see plate 1). The Dunmore lode contains several pebble and breccia dikes besides irregular breccia chimneys, but these are described under the mines. A few dikes are found in the fissure deposits of Poughkeepsie Gulch, and the Grand View deposit contains pebbles and cobbles cemented locally with enargite.

Replacement Deposits

Although fissure and general cavity filling has been the most abundant process of deposition, much "replacement" has also occurred. Replacement effects are common in the ores, as has been illustrated by Moehlman[13] and others in the adjoining districts. The principal replacements, however, have been of gangue by ore minerals or earlier minerals by later ones in a manner that enables the sequence of minerals of veins to be determined. Nevertheless, this replacement is largely confined to the veins and accompanies cavity filling; it is therefore not possible to demonstrate conclusively that a vein three or four feet wide has grown by replacement of the fissure walls.

Alteration of wall rocks adjacent to the fissure is common along long stretches of one or both walls of many of the fissure veins. It is more common in the hanging walls of inclined veins. The most common alteration products are finely disseminated pyrite, kaolin, sericite, quartz, epidote, and chlorite. For the most part these alteration products are the result of decomposition of the original minerals of the rock under the action of the corrosive solutions and gases that passed along the channels of the fissures. These solutions and gases were usually the same ones that deposited minerals in the fissures. The altered aggregate of the wall-rock minerals, however, generally contrasts strongly in composition and texture with that of the fissure filling. Reaction of the mineralizing solutions with the walls is considered to be one reason for mineral deposition in the vein. Wall-rock reactions, however, may result from changes in the solution that are caused by mineral deposition in the vein. In an alteration product of the type described here, quartz, although abundant in the veins, is commonly absent or so fine-grained and so mixed with sericite as to be quite inconspicuous in the walls.

In many deposits small veinlets of quartz, sulfides, or other minerals penetrate the wall rocks in intricate and irregular fashion and appear to have no relationship to joints or fractures. These features are undoubtedly the products of replacement.

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[13] Moehlman, R. S., Ore deposition south of Ouray, Colo.; Econ. Geol., vol. 31, pp. 488-504, 1936.

Dissemination and "replacement" in the wall rocks adjacent to fissure-filled veins have in a few places formed ore shoots even where the fissure vein is barren or relatively unproductive. The sampling of deposits should not always be limited to the filled part because in some places the adjoining zones of altered rock and the inclusions or "horses" of altered rock within the filled fissures constitute ore.

Formation of Primary Ore Shoots

It is sometimes stated that the geologist usually comes along after an ore body is mined and explains why it formed where it did. Quite naturally it is more difficult to explain the localization of an ore body before its shape is known than after. The fact of the matter is that neither before nor after is as good a time to determine the reason for the localization of ore as during mining. Not only may the control be more surely determined then, but also the ore may be better followed and the way pointed sooner for discovery of other ore bodies.

The material in the following paragraphs is a review of ore-shoot control in general. This review should be helpful, and even necessary, inasmuch as the districts are still in the prospecting stage and much of mining and development is still to come. Furthermore, because of the inactivity in the district at the time of the survey, it was possible to obtain the information necessary to determine the detailed controls for ore in only a few mines. More specific controls and suggestions for prospecting, however, are given under the descriptions of the mines. The primary localization and formation of ore in the fissure veins or in the deposits in general is the result of many factors; however, in the fissure veins of this area the formation of ore shoots appears to have been caused principally by structural features.

As the deposits and ore shoots are mostly the result of filling of channelways, knowledge of the attitude of a fissure, its local warps, and the direction of displacement on them will enable the forecasting of the best possibilities for finding ore. The simple cases wherein the warps of fault fissures are along straight axes and displacement is in any direction not parallel to these axes have been known and simply illustrated for a long time. They may be stated in the form of rules as follows:

- (1) When a vertical warp axis—that is, a change in the bearing of the vein—is encountered during drifting,
    - (a) If the left-hand wall has moved in the direction of drifting, turns to the right will be richer or will lead to an ore shoot and turns to the left will be leaner or barren (see fig. 3a).
    - (b) If the right-hand wall has moved in the direction of the drifting the opposite conditions can be expected.
- (2) When a horizontal warp axis—that is, a change in the dip of the vein—is encountered during sinking or raising,
    - (a) If the hanging wall has moved down (normal fault) the steeper parts will be richer and the gentler dipping parts will be leaner (see fig. 3b). This is commonly the case in the San Juan region.
    - (b) If the hanging wall has moved up (reverse fault), then the opposite conditions may be expected.

Most fissures are not warped along straight axes, except for relatively short distances, and this fact coupled with both horizontal and vertical components of displacement may make channelways very irregular or at least very difficult of analysis where changes in attitude of both fissure walls can not be known in advance of mining. In some deposits, for complicated reasons, ore shoots may coincide with the warp axes of a fissure vein. Channelways and hence ore shoots are made even more complex by warping of the fissure during displacement and by branching and

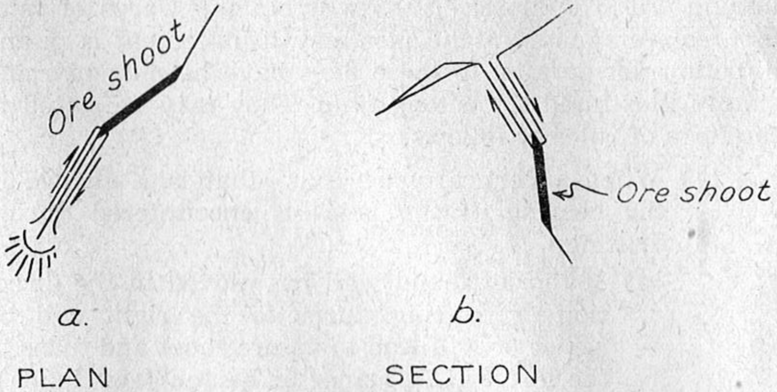

Figure 3. Simple controls for ore shoots caused by displacement along irregular (or curved) fissures.

acutely intersecting fractures within a fissure zone. Furthermore, breccia-clogged channelways are produced on the gliding or bearing faces of a fault in areas other than those dilated by reason of change in attitude.

Although intersections of veins are well known as favorable positions for ore shoots, it has been pointed out[14] that they have commonly not proved to be ore shoots in most places in the San Juan region; however, the acute and intricate interlacing of fissure veins in the Poughkeepsie and Mineral Point systems seem likely to result in ore shoots of this type. Furthermore, the widened turns of some of the veins are the consequence of intersections of fissures. Intersections may also control ore shoots by terminating them in one direction or another; thus, cross fractures or "crossings" as they are termed in some districts, may be barren fissures, sheeted zones, or unproductive veins, and they may terminate an ore shoot simply because the displacement on the main fissure vein was limited in its extent by the crossing. The formation of ore shoots at such intersections has been illustrated for an ore shoot in the Sunnyside mine by Hulin.[15]

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[14] Moehlman, R. S., op. cit., p. 397.

[15] Hulin, C. D., Structural control of ore deposition: Econ. Geol., vol. 24, p. 42, 1929.

The effect of the kind of rock adjoining the fissure has been emphasized by Moehlman.[16] The influence of the wall rock in the localizing of ore shoots along a fissure may be expressed in three ways: (1) the pattern of its fracturing, (2) its permeability, and (3) its chemical reactivity to ore-forming solutions.

(1) Some rocks such as massive flows may yield a single clean-cut fracture which will maintain a channelway for ore-forming solutions. Other rocks develop sheeting or multiple fractures with much breccia or heavy, impervious gouge. Still other rocks such as breccias or tuffs yield more by flowage and fail to maintain channelways for ore-forming solutions. Burbank[17] has illustrated the general effect of the physical influence of rock types upon the character of fissuring. The physical properties of a rock and hence the character of the fracturing are also related to depth. Rocks of identical character are relatively less brittle at depth than near the surface.

(2) Some wall rocks, because of their permeability, may exert a sponge-like action and absorb mineralizing solutions rapidly. This action in turn may precipitate metallic minerals from the solution and thus cause a localization of ore; on the other hand, ore minerals may be so thinly disseminated in the adjoining rocks that no ore shoot results. On the whole, differences in permeability are more likely to affect the extent and character of wall-rock alteration than the position and extent of ore shoots within the fissure vein.

(3) Moehlman[18] has pointed out that andesite is the most reactive and rhyolite the least reactive to the ore-forming solutions. The contrasts in chemical susceptibility between the volcanic rocks of the San Juan region, however, are not nearly as great as the contrast between limestone and shale, sandstone, or igneous rock. The degree to

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[16] Op. cit., pp. 391-392.

[17] Burbank, W. S., Vein systems of the Arrastre Basin and regional geologic structure in the Silverton and Telluride quadrangles, Colo.: Colorado Sci. Soc. Proc., vol. 13, no. 5, p. 204, fig. 4, 1933.

[18] Op. cit., p. 392.

which differences in chemical or mineralogical composition of these volcanic rocks are influential in localizing ore shoots is doubtful; for example, such differences as those described by Bastin[19], in which the silver content of a vein in andesite is as much as 150 times that in rhyolite, may be attributable to physical as well as chemical conditions.

The most important influence of the wall rock upon the localization of ore shoots is in determining the manner of fissuring. The manner of fissuring, however, may be more closely controlled by the depth below the surface than by differences in the kind of wall rock. The great majority of rocks in the districts are capable of maintaining open fissures, and the problem of deciphering any specific ore-shoot control is therefore more likely to be structural than lithologic. The important fact to bear in mind is that there is a control in each place and that ore shoots do not occur by chance or at random. The determination of control very early in the mining of an ore body is highly important. This determination, however, commonly requires experienced and continuous examination of the ore body and frequently precise and detailed mapping of the vein, including its structural and compositional variations. Occasionally very detailed and intricate methods[20], such as contouring the vein and even its parts, may be necessary and warranted in order to yield results that will enable extrapolation and successful exploration.

In these and adjoining districts some ore shoots appear to be localized beneath certain volcanic contacts, and this is commonly ascribed to a damming effect on the rising ore solutions by the overlying rock unit. It has been noted in the Sneffels region, for example, that productive shoots tend to terminate upward below the base of the Potosi rocks. At the Camp Bird mine, although there is a fairly regular termination of the ore shoots at the base of the

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[19] Bastin, E. S., Silver enrichment in the San Juan Mountains, Colo.: U. S. Geol. Survey Bull. 735, p. 79, 1923.

[20] Conolly, H. J., A contour method of revealing some ore structures: Econ. Geol., vol. 31, pp. 259-271, 1936.

Picayune volcanic group, some shoots are mined above this contact.[21] The upward termination at a change in rock may be due to a difference in manner of fissuring and maintaining of fissure openings. It may be due also to difference in permeability, but the termination or localization is not necessarily beneath a less permeable rock, for, as pointed out by Burbank[22], in the Sneffels-Telluride districts the Potosi rocks are more permeable than the underlying ones in which the ore shoots terminate. The alteration of the "so-called" capping rocks indicates considerable penetration of permeable rocks by the mineralizing solutions, and as Burbank points out probably release of pressure in the porous rocks near the surface caused boiling and hence precipitation of ores immediately below.

In the Poughkeepsie Gulch district there is much evidence that ore shoots are localized in an irregular vertical range near the top of the banded Burns latite and that ore shoots do not continue into the flows, tuffs, and breccias of the overlying pyroxene andesite. As pointed out elsewhere, the veins are less prominent and alteration more widespread in the upper rocks. The situation is similar along the Tuttle Mountain ridge. The Frank Hough ore shoot may have "mushroomed" in the permeable Henson tuff beneath the overlying rhyolite which again is extensively altered but poorly veined. The Polar Star ore shoot, however, was formed beneath the Henson tuff in the pyroxene andesite even though its altitude is higher than that of the Frank Hough ore body. The Wyoming ore shoot was still lower stratigraphically than the Polar Star ore shoot, and it has been suggested by those operating the mines that better ore made along the flow breccias adjoining the Polar Star and Wyoming veins than in the andesites. On the other hand, it is a noteworthy fact that in many places the rocks are more extensively altered above ore shoots than adjoining them.

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[21] Bell, C. N., Oral communication.

[22] Burbank, W. S., Structural control of ore deposition in the Red Mountain, Sneffels, and Telluride districts of the San Juan Mountains, Colo.; Colorado Sci. Soc. Proc., vol. 14, pp. 250-251, 1941.

The depth beneath the surface or level of rapid release of pressure and boiling for the ore solution column may be of greater significance to the localization of ore shoots than the physical or chemical character of the rocks immediately adjoining the ore shoot.

ORE IN DEPTH

Introduction

One of the most important geologic problems to be solved in this and adjoining regions is that of the vertical range of ore shoots. Prediction of ore in depth is as difficult as it is practical because of the variable and even conflicting factors of control. At the outset the origin of the ores is a matter of prime importance. Mineral deposits formed by solutions derived from the same deep source as the volcanic rocks may extend downward beyond the limits of practical mining, but the different ore minerals and the structural conditions that permitted their concentration in mineable quantity may be not only irregularly distributed but also restricted in depth. Ore that was originally lean may be enriched at or near the surface through the action of descending water. In some mining districts the only ores worth mining are the result of such enrichment, and the suggestion has been made that the shallow, rich ores of the San Juan region belong to this class of supergene deposits. I believe, however, that the ore shoots of the Mineral Point and adjoining districts were mainly deposited without appreciable subsequent modification by solutions ascending from a deep source and are therefore to be classed as hypogene.

Hypogene Deposition

Early workers in this region, and Ransome[23] in particular, suggested that the rich ore shoots were supergene and hence were formed by the leaching of primary (hypogene) metals from the deposits during prolonged erosion, and by

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[23] Ransome, F. L., A report on the economic geology of the Silverton quadrangle, Colo.: U. S. Geol. Survey Bull. 182, pp. 132-141, 1901.

the continued redeposition and concentration of these metals just below the progressively lowering surface. Ransome considered that such minerals ar argentite, polybasite, stephanite, pyargyrite, proustite, and possibly even the tetrahedrite and such sulfbismuthites as alaskaite were supergene. Later microscopic studies of the San Juan ores by Bastin[24] demonstrated that many of the minerals responsible for the high silver content of the ores are hypogene; that is, they were original constituents of the veins formed during or shortly after igneous activity. He found that the minerals tetrahedrite, tennantite, enargite, and the sulfbismuthites were invariably hypogene. Native silver was interpreted to be invariably supergene, and argentite although supergene for the most part was believed to be hypogene in several occurrences.[25] Similarly the brittle silver minerals, polybasite and stephanite were believed to be both hypogene and supergene. Although pyargyrite and proustite were believed by Bastin to be mostly hypogene in the Ouray-Telluride area, in the Red Mountain district[26] he considered them to be mostly supergene. Burbank[27], however, considered the ruby silver of the Red Mountain chimney deposits to be hypogene.

The recent tendency among those who have investigated silver minerals is to regard practically all the sulfides and sulfosalts as hypogene with the exception of argentite which may be supergene. The fact that such minerals as the brittle silvers are among the last minerals to be deposited in the hypogene sequence makes it difficult to disprove that they might be supergene. The silver-bearing minerals, however, are not always late to form. At the Dunmore mine the ore shoot containing chalcopyrite and silver-bearing aikinite ($Cu_2S.PbS.Bi_2S_3$) is cut by veins containing sphalerite and galena. Native silver is commonly supergene especially if

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[24] Op. cit.

[25] Idem., pp. 77, 82, 91.

[26] Idem., p. 103.

[27] Burbank, W. S., Structural control of ore deposition in the Red Mountain, Sneffels, and Telluride districts of the San Juan Mountains, Colo.: Colorado Sci. Proc., vol. 14, pp. 181-182, 1941.

found close to the bottom of the oxidized zone. Chalcocite, which in the "sooty" variety is commonly assumed to be supergene, is uncommon in this area. Marcasite may be supergene in origin and its presence might be evidence of some secondary sulfide deposition, but the marcasite found at such mines as the San Juan Chief, Old Lout, and Emperor Wilhelm is intergrown with quartz and sulfides in a manner that makes its hypogene origin certain.

The silver content and perhaps the gold content have decreased to some extent with depth in certain ore shoots and this is one reason for suspecting supergene concentration of these metals near the surface. In figure 4 the average precious-metal content of ores shipped from a large number of mines is plotted against the altitudes of the different mines. The distribution of plotted points fails to show any definite relation between rich ore and high altitude; of the two richest silver ores one was mined at an altitude of 12,150 feet and the other at an altitude of 9,750 feet. Similar graphic analyses of ores shipped support the following conclusions:

(1) No relation exists between the copper, lead, or zinc content of the ore shoots and altitude.

(2) No relation exists between the silver or gold content and any of the base metals in the ore shoots.

(3) No relation exists between the silver content and gold content in the ores.

Ores containing the gray coppers, tetrahedrite and tennantite, are found throughout almost the entire vertical range of exposures. Aikinite is found in the Dunmore ore shoot at an altitude of 9,250 feet, and alaskaite in the Alaska mine is at an altitude of 12,400 feet. Tungsten in the form of huebnerite occurs mostly at low altitudes in the areas under consideration, and its identification at the Mountain Monarch mine (9,993 feet) is the highest definitely recorded. Its greater vertical range is indicated, however, in the Cement Creek area north of Silverton where in the