sures of low-angle dip. The fissures of northwest and east-northeast trends may have been developed largely by the reopening of dike-filled and other pre-Cambrian fissures and thus represent persistent directions of weakness. General vertical uplifts or other disturbances that intervened between the Laramide revolution and the eruption of the Cripple Creek volcano, in Miocene time, tended to keep many zones in all the different systems open. When volcanic activity began, gases escaping from the rising lava took advantage of these fis-

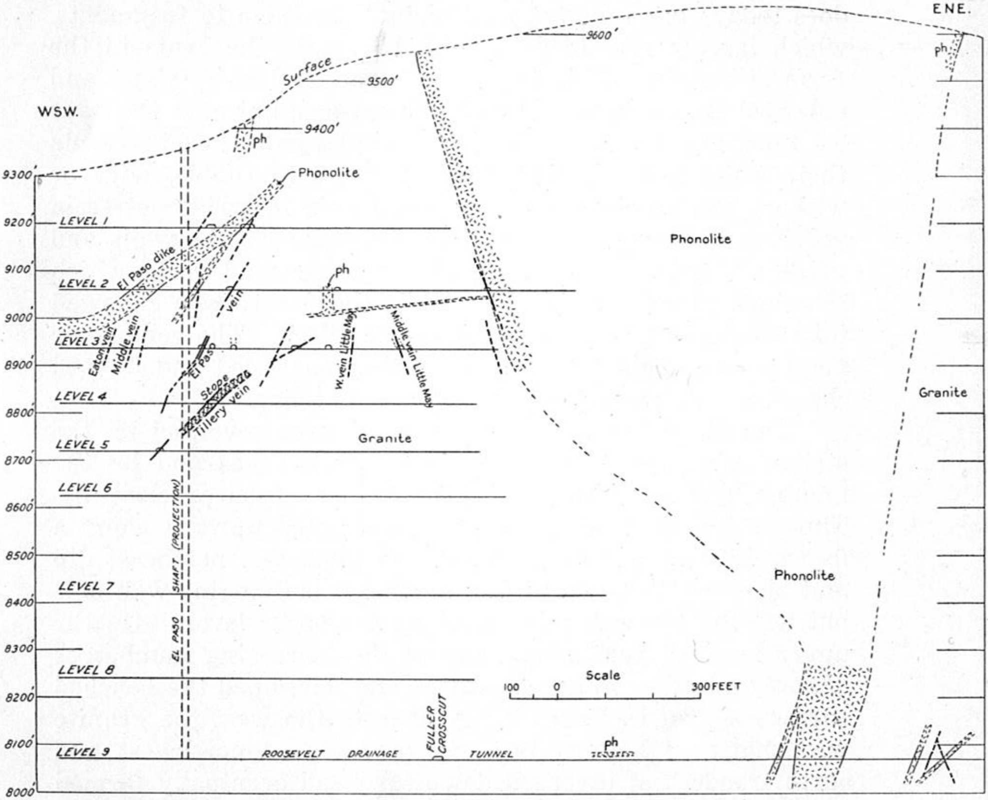

Figure 18.—Cross section along line of Roosevelt drainage tunnel showing the general form of the phonolite plug at Beacon Hill and its relations to the "flat" or sill-like dikes of phonolite and to the veins in the El Paso mine.

sure zones and especially of their intersections, and as they approached the surface they erupted with explosive force and produced vents whose upper parts flared considerably and whose lower parts were steep-walled. The debris of granite, gneiss, and schist blown from these vents was in part scattered over the surrounding surface, although no undoubted trace of it remains today, and in part settled again in the vents. Eruptions of lava (latite-phonolite) evidently followed the first explosions and doubtless formed masses that filled the fissurelike roots of the vents, much as the Beacon Hill plug does today; but renewed explosions blew them to fragments, which largely remained or settled back in the vents in the form of breccia. This process was repeated many times and enlarged the vents laterally and downward, but even the largest tapered into roots. During the enlargement of the vents their walls were shattered and reduced to rubble, with or without the admixture of much volcanic material. Breccia was locally forced upward along fissures near the walls and pried off large slabs of granite or other wall rock, which remained practically in place while the fissure was enlarged into a zone of breccia of considerable width. The vents over neighboring roots expanded until they coalesced and formed the composite crater, essentially as it is today.

The directions of explosive force were governed by the strikes and dips of the principal fissure zones and by the number and distribution of subordinate fissures close by. Thus in the Portland mine the force acted upward along a fissure zone of northwest trend and pitch and northeast dip and blew out the rock on the northeast or hanging-wall side but left the footwall side intact on the lower levels. On the upper levels it took advantage of the increasing number of "flats" and other minor fractures and developed the benched surface shown in figure 7. A little to the west the granite was shattered betwen two fissure zones of northwest and north trends that diverged downward and eventually formed the overhnging walls of an embayment. In the vicinity of the Elkton mine eruption was guided by a fissure zone of east-southeast trend and steep southerly dip, whose hanging wall was little affected, while the ground on the footwall side was completely blown away. These and similar features are illustrated in figure 9.

Settling of the fragmental material or breccia in the crater followed this dominantly explosive stage of the volcano and produced steeply dipping fissures with trends parallel and normal to the local crater walls and also "flats" whose low-angle dips were governed by movements of individual blocks of breccia. This local movement within the crater was supplemented by a tendency of the adjoining fractured pre-Cambrian rock to settle toward the crater, especially where the crater walls were overhanging. A regional north to south or north-northeast to south-southwest movement was active at the same time and tended to keep the east-west fissures and contacts of the crater tight and to keep those of more northerly trend open. It also aided in the development of local conjugate fissure systems, which are well exposed in places, and in the development of "flats." The intrusions of dikes and irregular igneous bodies followed; the earliest and latest were guided mainly by local conditions, whereas the intermediate phonolite invaded the surrounding region as well.

ORE DEPOSITS

The ore deposits, which were derived from the same general source as the dikes and, like the dikes, were formed in several stages, may be classified into three groups as regards form—veins or fissure fillings ,irregular bodies due to the permeation of shattered ground, and collapse breccias. Deposits of all three groups have the same general mineral composition and show no consistent change in composition down to the lowest levels exposed. Each stage of deposition within a single deposit, however, is characterized by one or more distinct minerals. The exact number of stages has not been determined and doubtless differs from place to place, but for practical purposes three stages, or groups of substages, have been recognized, as stated in an earlier paper.[43]

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[43] Loughlin, G. F., Ore at deep levels in the Cripple Creek district, Colorado: Am. Inst. Min. Met. Eng. Tech. Pub. 13, pp. 9-12, August 1927; Am. Inst. Min. Met. Eng. Trans., vol. 75, pp. 51-54, 1927.

Stages of deposition

The first stage was characterized mainly by local intense corrosion of the country rock and by deposition of quartz and adularia and dense aggregates of dark-purple fluorspar and quartz with comparatively coarse-grained pyrite. The quartz and adularia occur both as dense masses, locally called "jasper," and as coatings of vugs in corroded or honeycombed granite. The "jasper" may form independent veins or inconspicuous borders to veins of dense fluorspar and quartz. The honeycombed or "bug-hole" granite, so far as seen, is of the coarse-grained Pikes Peak variety, in which the large red crystals of alkalic feldspar have resisted corrosion, whereas the other minerals have been removed and their places incompletely filled by quartz and adularia. Some bodies of this honeycombed variety of granite, notably in the Portland, Ajax, and Elkton (Thompson) mines, were later permeated by telluride solutions and became rich ore, but others, both within and outside of the productive part of the district, were not reached by tellurides in appreciable quantity. Honeycombed granite associated with fissures or obscure faults was observed by Koschmann almost as far south as Marigold, notably just west of the north end of the rhyolite dike on the ridge west of Middle Creek and just below the steep bluff on the ridge between Wilson and Middle Creeks, where a little specularite was also present along cleavage cracks in the large feldspar crystals. This occurrence of specularite recalls the slight amount of leaching followed by deposition of specularite in latite-phonolite (p. 248-9).

The veins of dense fluorspar and quartz attain 2 feet in maximum thickness and are massive throughout except where fractured and veined with later minerals. In places they form a steplike succession of lenticular veins instead of single veins, and they also contain angular fragments of wall rock—in fact, except for their difference in composition, they resemble dikes. The solutions from which they were deposited evidently possessed considerable penetrative power, as some of them are very thin but persist for considerable distances. They have been rarely noted outside of the breccia area and the major shear zones in the adjacent granite, but almost no workings in granite outside of these shear zones have been accessible to us. One vein, 2 inches or less thick, was seen in the Roosevelt drainage tunnel about 2,000 feet from its portal and at least 2¾ miles from the granite-breccia contact, or 2¼ miles south-southwest of the El Paso shaft. It trends N. 44° W., at a large angle with the El Paso shear zone, and dips 80° SW. These dense fluorspar veins are of no value except where opened by fissures which follow or cross them and along which ore minerals were subsequently introduced.

Minerals of the second stage contain the same minerals as the first, except adularia, but the fluorspar is usually somewhat lighter purple, the quartz milky to somewhat smoky, and the pyrite fine-grained and inconspicuous. As these minerals occur mostly in open though narrow cracks and in vugs, their crystal outlines are distinct. Other conspicuous minerals of this stage are dolomite or ankerite in small white rhombic crystals, celestite, usually in slender prisms, and the tellurides. The green vanadium mica, roscoelite, belongs to this stage and is found here and there as small soft, drusy masses but usually as green coloring matter in rock along the edges of veins or in inclusions. A little barite has been found, in white massive aggregates. Small quantities of the base-metal sulphides, principally zinc blende, galena, and tetrahedrite ("gray copper"), are conspicuous in places. In the Cresson mine, according to Robert Gardiner, former superintendent, green roscoelite stain, delicate crystals of celestite, and conspicuous amounts of sulphides were fair indications that an ore shoot was close by; but the same minerals have been found elsewhere—for example, in the collapse breccia of the Dante mine—without leading to any ore shoots. These minerals, like other guides to ore, are helpful but not unfailing.

The most common telluride is calaverite, [$(Au, Ag) Te_2$] a silvery-white to pale-yellowish flat, striated, prismatic mineral, which contains gold with a little silver. Sylvanite and krennerite, different crystal forms of similar composition, are also present. The name "sylvanite" is frequently applied by the miners to silvery calaverite, and the name "calaverite" to the yellowish or slightly tarnished crystals, fine-grained aggregates of which may be confused with fine-grained pale yellow pyrite. Petzite [$(Au, Ag)_2Te$] has also been reported by Lindgren and Ransome,[44] and two more tellurides have recently been recognized by M. N. Short, of the United States Geological Survey, in material collected by us. These are hessite, the silver telluride, and a dense gray mineral resembling tetrahedrite that could not be separated cleanly enough for an exact analysis but is evidently a silver-copper telluride. The hessite was found as microscopic grains impregnating pyrite in the rich stope above level 29 in the Portland mine.[45] The silver-copper telluride was found in considerable quantity by the late Alex Walker and associates in the Findley vein, above level 16 of the Vindicator mine. As tetrahedrite ("gray copper") commonly contains a small amount of silver, the relatively high content of silver in ores containing it is not surprising, but it seems likely that where the silver content is as much as 2,000 or 3,000 ounces to the ton the "gray copper" consists partly or wholly of the silver-copper telluride. A grain or wire of free gold accompanies the tellurides here and there, even at depths of 2,000 feet and more.

The third stage, which includes two or more substages, is represented mainly by smoky to colorless quartz in distinct small to large drusy crystals and by yellow druses and "droplets" of chalcedony. Other minerals of this stage are fine-grained pyrite, some of it in thin radiating needles resembling marcasite and some in small drusy patches of 12-sided crystals (pyritohedrons); calcite, in small colorless to white and rarely yellow pointed crystals (scalenohedrons); and locally cinnabar, which occurs mostly as coatings on pyrite and in small, closely associated druses.[46] Minute grains of fluorspar are rarely present. The important feature of this third stage is that its minerals, particularly quartz and pyrite, may conceal tellurides of the second stage, but they are also present in barren places and cannot be regarded as so likely an indica-

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[44] Lindgren, Waldemar, and Ransome, F. L., op. cit., p. 116.

[45] Loughlin, G. F., Am. Inst. Min. Met. Eng. Tech. Paper 13, pp. 10-12, 1927.

[46] Idem, p. 16.

tion of ore as the minerals of the second stage. Quartz of the third stage has at several localities replaced celestite, dolomite, and calcite.

It is noteworthy that although quartz, fluorspar, and pyrite belong to all stages, their appearances are not the same in all stages, and they should aid rather than confuse in the search for ore. Other minerals if present in more than one stage are conspicuous only in one.

Veins and irregular bodies

The veins of the district range from simple fissure fillings less than an inch thick to sheeted zones several feet thick, and in a few places closely spaced veins or sheeted zones connected by minor cross veins have formed large, irregular ore bodies from 50 to 100 feet or more in any dimension. Where the veins coincide with dikes, the sheeted structures inherited from the dikes is likely to be conspicuous, although ore may be confined to one or a few fractures along either the sides or the middle of the dikes. Some of the more productive veins have ore shoots that are relatively persistent both horizontally and vertically, but even the shoots of the largest veins are separated by low-grade or essentially barren intervals that, so far as noted, coincide with steplike interruptions of the veins or with "flats" that separate permeable from impermeable parts of the vein.

Koschmann's study of several of the shallower to moderately deep mines in 1931 showed that the steplike or en echelon arrangement of the veins (p. 278) is more common, both horizontally and vertically, than many operators appear to have realized, and that single ore shoots are prevailingly short. Most of them are less than 500 feet long, and few of the veins have been followed any considerable distance beyond the ore shoots. Those that have been so followed have proved to be tight and of low grade or barren. In none of the veins studied by Koschmann was there a second ore shoot entirely separated from the first by a barren zone along a single fissure. Some rather closely spaced shoots, commonly regarded as parts of a single vein, proved to lie along different veins of a steplike series, as on level 10 of the Vindicator mine (fig. 19) and in the lower part of the Strong mine, especially level 13 (fig. 37).

The downward persistence of ore shoots is roughly proportional to the horizontal, as pointed out by Lindgren and Ransome.[47] Many ore bodies, including some that have been very productive, do not reach the surface—for example, the Newmarket vein in the Granite (Ajax) mine, the Captain group of veins in the Portland mine, and the south shoot in the Strong mine—but they have been found through connections with other veins or by crosscuts that explored a steplike or conjugate group of veins. The "flat" veins, though less numerous than those of steep dip, have the same general structural features. The steplike arrangement and the fact that the vein group as a whole trends at a considerable angle to the strikes of single veins (fig. 19) are things to bear in

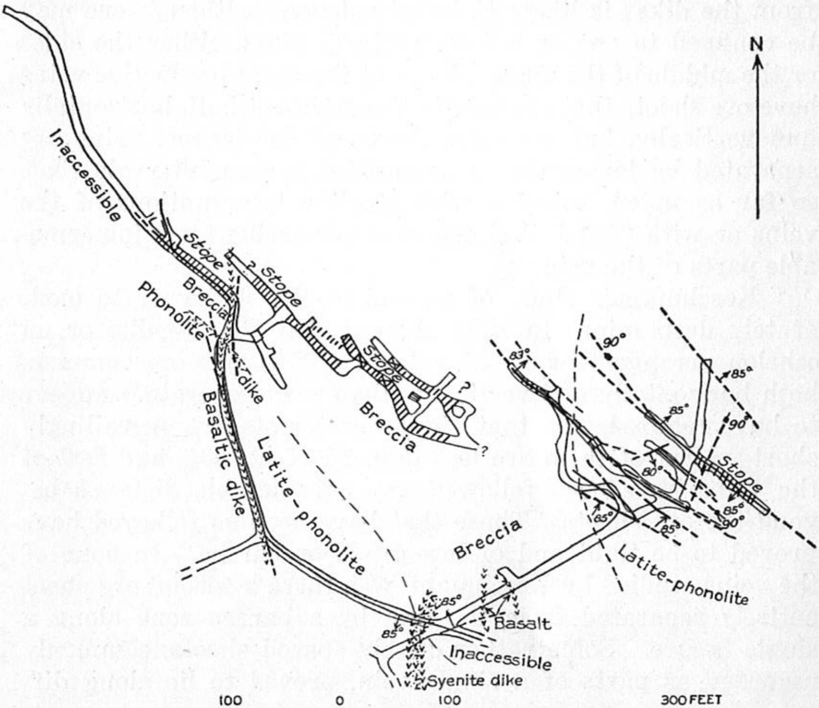

Figure 19.—Level 10 of Vindicator mine, showing steplike arrangement of veins and ore shoots in the "north" vein zone.

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[47] Lindgren, Waldemar, and Ransome, F. L., op. cit., p. 157.

mind in prospecting, especially in the shallower workings, where fissure zones are likely to be wider and more complex than in the deeper workings.

As the large irregular bodies have been formed in shattered ground where two or more fissure zones intersect, they vary greatly in their relative dimensions. Some are roughly lens-shaped, with their longest dimensions either horizontal or vertical; others are pipelike and nearly vertical, with or without short branches extending along one or more of the fissure zones. They have been found at rather great depths in breccia but are more numerous at moderate to shallow depths in both granite and breccia where fissuring has been more abundant and complex.

Collapse breccia

The term "collapse breccia" is here applied to rubblelike masses of pipelike form where shattered ground has been corroded until its originally angular fragments have become rounded and the mass as a whole has settled or collapsed to a slight or considerable degree. The well-rounded fragments grade upward and outward into shattered ground along steeply dipping fissure zones and "flats." If collapse has been sufficient to remove the support of the overlying ground, it is likely to settle and produce marginal faults, as noted by Locke,[48] but no faults of such origin have been recognized in the Cripple Creek district. The largest pipe of collapse breccia thus far found in the district is well exposed in the Dante mine and overlaps the east end of the Cresson blowout, as shown in figures 3 and 20. A basalt dike and a vein of dense first-stage fluorspar that crossed the area have been reduced to rubble, but not to so great a degree as the breccia, and their courses are maintained through the pipe. Another pipe has been opened southwest of the blowout on level 17 of the Cresson mine, according to oral information given by

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[48] Locke, Augustus, Formation of certain ore bodies by mineralization stoping: Econ. Geology, vol. 21, p. 431, 1926.

Superintendent Al Bebee in 1933, but it was inaccessible to us because of gas. A small one is exposed in Rose Nicol ground by a south crosscut from the Roosevelt drainage tunnel, and the edge of one in granite is exposed in the Coriolanus claim, at the north end of level 18 from the Ajax shaft.

The rubble fragments are partly coated and cemented with quartz, dark fluorspar, and coarsely crystallized pyrite identical with consituents of the dense fluorspar vein, and with practically all the minerals of the second stage except appreciable quantities of tellurides. Many assays of sam-

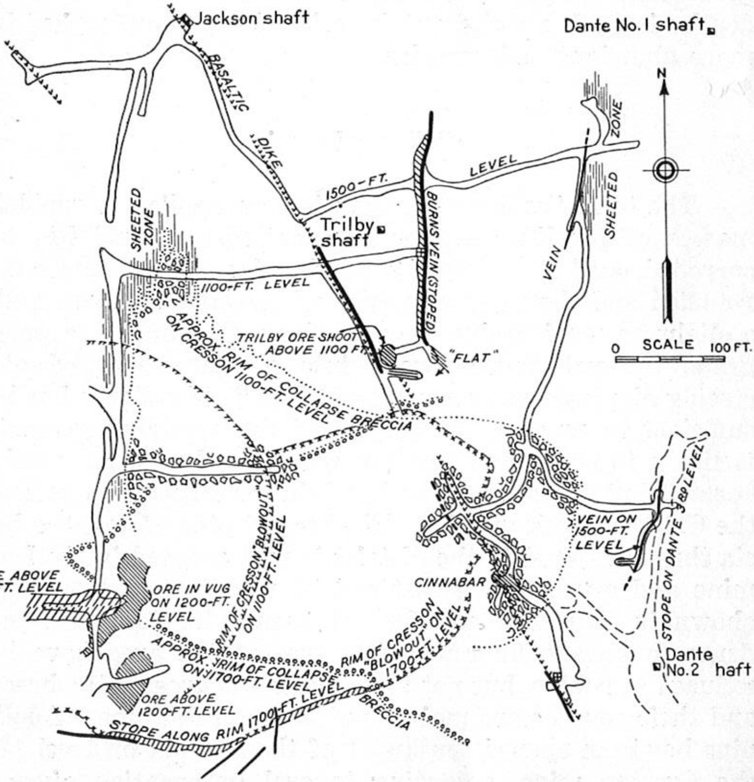

Figure 20.—Body of collapse breccia with local concentration of cinnabar, exposed on level 15 of the Dante mine and levels 11 and 17 of the Cresson mine. (After Am. Inst. Min. Met. Eng. Tech. Paper 13, fig. 7, 1927.)

ples from the Dante pipe showed only 0.15 to 0.20 ounce of gold to the ton. The mineral coating in the Coriolanus exposure contained coarse-grained pyrite and zinc blende. The third stage is represented mainly by yellow chalcedony, mostly in small round, flattened forms that resemble hardened jelly. Cinnabar is conspicuous in the central part of the Dante pipe, though not in commercial quantity, and occurs mainly as coatings on or close by pyrite crystals, suggesting that its deposition was caused by reaction between the pyrite and vapors or solutions that rose through the pipe.[49]

Renewals of collapse or mild shearing stresses have caused some brecciation of the second-stage and even the third-stage minerals.

It has also been suggested that this mass of rubble is the result of a local explosive eruption,[50] and it would be reasonable to infer that there was some recurrence of explosive activity after the completion of the Cresson blowout; but if so, the explosion was not accompanied or followed by any igneous material and was sufficiently powerful to reduce the solid breccias to rubble but too weak to open a funnel to the surface or to form a sharp, well-defined boundary like that along the Cresson blowout. Furthermore, it would be difficult to account for the large percentage of voids in the rubble without some leaching.

Processes of ore deposition and their significance

The fact that the principal mineral deposits as well as the dikes of the district are concentrated along the major fissure zones that mark the positions of subcraters and have been followed downward along them for a maximum vertical distance of 3,100 feet without change in mineral composition leaves little room for doubt that the ore-forming solutions rose from beneath the roots of the subcraters. The general distribution of the deposits and the downward terminations of those outside the principal fissure zones also indicate that

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[49] Loughlin, G. F., and Behre, C. H., Jr., The classification of ores: Am. Inst. Min. Met. Eng. Lindgren Memorial Volume, p. 34, 1934.

[50] Walker, R. T., Mineralized volcanic explosion pipes: Eng. and Min. Jour., vol. 126, p. 982, 1928.

the rising solutions spread upward and outward along the more open trunk and branch fissures, as is shown in a much generalized way in figure 8.

During the first stage of deposition the quartz-adularia aggregates may have been derived by corrosion of granite and volcanic rocks at great depth and redeposition at higher levels. The large amount of fluorine, however, represented by the dense fluorspar, and the sulphur represented by the pyrite were most probably original constituents of the rising solutions, although the calcium in the fluorspar, the iron in the pyrite, and the silica in the accompanying quartz may have been derived by deep corrosion. Whatever the exact process, the solution must have become saturated before it reached the level of the deepest mine workings and began to deposit the dense first-stage veins. The dikelike character of the veins suggests that their material was forced upward as a thick fluid that could push fissure walls apart and pry off and enclose angular inclusions of wall rock, but it may also be suggested that, inasmuch as freezing water has formed dense veins of ice with similar structural features, which are attributed to the volume pressure of growing crystals,[51] the force of crystallization and the quantity of material available may have in part produced the dikelike structure.

These veins may represent the spent force of the advance guard of mineralizing solutions. After a renewal of fissuring, unsaturated solutions of similar character rose and corroded the wall rocks. Where the ground was most open, particularly where the ends of the Cresson blowout bordered strong fissure zones, these solutions were able to rise rapidly into comparatively shallow ground before losing their corrosive power and reduced the shattered ground to rubble or collapse breccia. As their activity declined and the solutions became saturated they deposited, at lower levels, dark-purple fluorspar, coarse-grained pyrite, and quartz on the rubble fragments in the collapse breccia and at higher levels may have formed dense fluorspar veins that cannot be distin-

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[51] Wernecke, Livingston, Glaciation, depth of frost, and ice veins of Keno Hill and vicinity, Yukon Territory: Eng. and Min. Jour., vol. 133, p. 43, January 1932.

guished from those formed earlier; but, so far as the problem of ore hunting is concerned, they may all be regarded as first-stage veins.

Where unsaturated solutions rose close to the granite-breccia contact and traveled through shattered granite, they first corroded and honeycombed the granite and caused its partial recrystallization into adularia and quartz. The scarcity or absence of fluorspar in this honeycombed or "bug-hole" granite is remarkable, especially as veins of dense fluorspar may be found in the granite nearby. It would seem that the calcium in the fluorspar was derived from the deeper parts of the crater, especially where the corrosive solutions traveled for long distances in basaltic and even latitic or syenitic rocks, which have relatively high contents of calcium. Dense fluorspar veins may well represent material derived from such a source and carried outward into the granite, whereas later solutions following rapidly along newly opened fissure zones reached the granite well under their saturation point and derived the ingredients of adularia and quartz but very little calcium from it.

Another renewal of fissuring opened the way for solutions of the second stage, which were weak compared with those of the first stage. They had very little corrosive power, at least at the levels of present mine workings, and where the wall-rock or earlier vein minerals were attacked to a slight degree they were replaced by second-stage minerals. For the most part the solutions merely filled or lined cavities with minerals that may have been derived by corrosion in and below the roots of the crater. These solutions differed from those of the first stage in that they could deposit celestite, barite, and dolomite, together with zinc blende, galena, and tetrahedrite, all of which suggest a moderate to rather low temperature.

Deposition of tellurides marked the end of the second stage and may even be regarded as a distinct substage, as it took place later than that of the other second-stage minerals, although the tellurides are commonly but not everywhere closely associated with them. It appears that in some places deposition of the other earlier second-stage minerals was sufficient to seal parts of fissures, so that the later telluride solutions were diverted elsewhere. Minor fracturing may also have taken place and permitted the deposition of tellurides in otherwise unmineralized cracks, though close by those containing second-stage minerals. These details of deposition and fracturing have increased the uncertainties of prospecting and development, as deposits of second-stage minerals of generally favorable appearance may be followed for considerable distances without the discovery of ore, and workings may approach within a foot of an ore shoot without any proof of its presence.

Other factors in the localization of ore shoots were the thinly fluid if not gaseous character of the gold-tellurium solutions and the low pressure under which they were introduced. Not only were they deflected to another course if confronted by a sealed or tight fissure, but they could travel long distances through open ground without depositing any minerals until they were retarded or stagnated by some obstruction and could find no way to escape. The contrast between the Dante collapse breccia as a whole and the large vug, 40 feet high, 23 feet long, and 13½ feet wide, that borders it on level 12 of the Cresson mine[52] (fig. 20) illustrates this condition. The voids in the collapse breccia were so large and continuous that the solutions could move freely, and as there were no minerals present that were efficient precipitators of tellurides, practically no deposition took place. The large vug, which had been formed by the corrosion along a fracture of a large mass of basalt in the Cresson blowout, admitted a large amount of solution but allowed it to escape very slowly, so that stagnation, saturation, and deposition were favored and one of the richest shoots in the district was formed. The ore shoots along intersections of fissures and in large bodies of shattered ground, as well as along accessible open stretches of simple fissures or sheeted zones, are subject to the same explanation, in that solution arrived faster than it could be removed.

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[52] Patton, H. B., and Wolf, H. J., Preliminary report on the Cresson gold strike at Cripple Creek, Colo.: Colorado School of Mines Quart., vol. 9, No. 4, pp. 10-11, 1915. Patton, H. B., The Cresson bonanzas at Cripple Creek: Min. and Sci. Press, vol. 115, pp. 381-384, 1917.

To what extent the lowering of temperature influenced the deposition of tellurides is not clear. It is conceivable that the earliest of the telluride solutions reached the upper parts of the fissure zones before their temperatures were lowered to the stability range of the tellurides, and the fact that in many mines productive ore shoots have been relatively shallow although the vein or fissure zone continues to much greater depth would encourage such a view; but the occurrence of the rich shoot between levels 27 and 30 in the Portland mine shows that the solutions were still rising in large quantity after their temperatures had lowered sufficiently to permit deposition at that depth. Although, theoretically, there was a depth below which the temperature was never low enough to permit the deposition of tellurides, there is no evidence in the deepest workings studied that that depth has been closely approached, and if this were the only factor to be considered mining might be extended far below the present workings; but temperature has been of much less influence than geologic structure.

The reason for the restriction of certain ore shoots to relatively shallow depths appears to be that undersaturated solutions can travel long distances without deposition until they meet favorable conditions such as those mentioned in the last paragraph but one. The solutions, rising from below the subcraters, followed the upward extensions of reopened prevolcanic fissures and spread along available branches; but the small dimensions in the lower parts of the subcraters and the pressure of the overlying rock as well as horizontal compression doubtless kept the fissures prevailingly tight and prevented deposition of ore in commercial quantity. Eventually a level was reached where favorable openings permitted the deposition of ore in appreciable quantity, along and adjacent to the main fissure zones, but pressure was still sufficient to prevent the formation of large open stretches along minor zones. Only small amounts of solution could escape along these minor zones, and any minerals deposited by them were thinly scattered or at best formed discouragingly small shoots. At still higher levels, where the pressure of overlying rock was much less, both the shear zones and the associated tension fractures could develop large and connected open stretches, and large shoots could form, connected by short to rather long stretches of low-grade or even barren veins or fissures. The solutions could reach openings along minor or local fissures of moderate vertical extent but connected with the main fissure zones or trunk channels by simple branch fissures or intricate networks of fissures. These conditions are well illustrated by the Portland and Cresson mines, the two deepest mines of the district, which are described in considerable detail on subsequent pages.

It follows from this discussion that deep ore shoots of commercial size and grade are most likely to be found along the trunk fissure zones of the deepest subcraters. These deep ore shoots are even more likely to be separated by low-grade or barren stretches along the vein zone than those at shallower levels, and the limit of downward exploration is likely to be governed by the ratio of costs of deep mining to the amount of gold recovered from the deepest shoots already mined and by structural conditions that encourage the search for another shoot of similar value. Thorough consideration of the local processes of fissuring should go far toward settling the question whether to cease or to continue deeper exploration, and such considerations are included in the local mine descriptions.

The third stage of deposition, which was comparatively insignificant, included at least one substage in which solutions were still rising from a volcanic source and others in which the solutions may have been of superficial origin. The work of the rising solutions is represented by cinnabar, which, as stated on page 301, coats pyrite and was evidently deposited as a result of reaction between the solution and pyrite in the Dante collapse breccia. The confinement of the cinnabar to a small disseminated deposit in the central part of this open breccia is striking and not easily explained, but it would seem that the solution entering the bottom of the water-filled breccia rose as directly as possible toward openings in the top and that the small amounts of mercury brought in could be precipitated by pyrite along this course before any appreciable amounts could escape or diffuse into the surrounding part of the breccia. The absence of any tellurides in the deposits prevents the determination of any relations between them and cinnabar.

The origin of the druses of quartz, calcite, and fine-grained pyrite is not clear. They may represent the end products of small remnants of solution from below, or water from the surface that has migrated far below the limit of oxidation along the more open veins and barren fissures. According to the second view, considerable quantities of this fine-grained pyrite merely imply that pyritic breccia or other rock had been strongly leached along open fissure zones since the second stage of ore deposition, and that the iron was carried downward as sulphate until, below the level of oxidation, it was reduced again to sulphide and redeposited. The reducing agents, however, are not in evidence. Zinc blende and perhaps the other sulphides could precipitate pyrite or marcasite, but they are too scarce to account for this late pyrite where it is found.

The crusts, miniature stalactites, and droplike forms of yellow chalcedony found in vugs here and there throughout the district and prominently developed in the Dante collapse breccia coat all the other minerals and have evidently been deposited by water that found its way from the surface. The stalactites and related forms indicate deposition by dripping water in empty cavities and may have formed shortly after the drainage of the ground.

Alteration of country rock

Alteration of the breccia and intrusive rocks and their impregnation by pyrite, sericite, and dolomite may have taken place to some degree from the time of the explosive eruptions that formed the breccia until the earlier stages of vein formation. Although the emanations that produced this alteration doubtless rose along the deepest trunk channels, they spread more extensively through the shallower parts of the breccia than the later, ore-forming solutions, and therefore the distribution of bleached breccia is not a close guide to the location of mineral channels. Unbleached breccia signifies freedom from attack by these emanations but does not necessarily mean that there are no promising veins in its vicinity; on the whole, however, unbleached breccia is not likely to occur near the largest and most persistent mineralized zones.

The granite, in contrast to the breccia, has undergone little bleaching. It is considerably impregnated by pyrite in places but not necessarily near ore shoots. The more persistent and productive veins in granite are bordered by bleached rock that ranges from a mere streak to a layer several feet in thickness. The dikes along mineralized zones have been bleached to some extent, but much of this bleaching has resulted from attack by descending sulphate waters.

Oxidation

The work of oxidizing water descending from the surface through the veins, pyritic breccia, and other rocks has been principally to decompose the pyrite and, with the resulting ferric and ferrous sulphates and sulphuric acid, to dissolve and remove dolomite and calcite, and either to dissolve such minerals as analcite, sodalite, nephelite, and even feldspars or to convert them into clay. The basaltic rocks, which contain the largest percentages of analcite, were the most readily altered, and the clay and any related secondary zeolite minerals developed in them largely account for their tendency to slake or crumble where exposed in mine workings and at the surface. Any of the other rocks are likely to slake where the attack by this descending water has been intense. Where the ingredients of clay were dissolved and carried downward in or beyond the oxidized zone, they were, in part at least, deposited by replacement of carbonate veinlets and grains, particularly in basaltic dikes. The ferric sulphate could attack the carbonates and even clay and deposit red or brown ferric oxide in their places.

Much of the iron from pyrite, together with small amounts from the original minerals in the altered rocks, and practically all of the replaced carbonates were carried down into the reservoir of ground water, and in places, particularly along ore zones, some of the iron sulphates were probably reduced again to pyrite or marcasite, as stated on Page 307, although the process of reduction is not clear. Where watercourses were opened by mine workings below the level of oxidation, the water began to deposit calcium carbonate and red or brown iron oxide, either as stalactites, stalagmites, and wall coatings or, where the volume was great, as in the Roosevelt drainage tunnel, as beds of travertine and iron oxide, particularly along the edges and the more shallow places along the streams. Small amounts of black manganese oxide accompanied the travertine. Where the ground water, after traveling long distances along fissure zones and faults, found natural outlets in the form of springs, the springs formed similar deposits of iron oxide and travertine, as is illustrated by a spring emerging along a fault in the valley of Wilson Creek southeast of Little Pisgah Peak. Obviously these deposits, whether at the surface or underground, are no indication of ore, even though some of them may be found along productive veins. They merely indicate present watercourses, whether along open parts of veins and other old fissures or along fissures opened since ore deposition. As the productive veins commonly occur along the more open parts of fissure zones, watercourses are likely to be found along them, but other watercourses are present far from any productive ground.

Where the circulation of air in the mine workings is poor and the ground water emerges faster than it can be oxidized, the iron is deposited as the green ferrous sulphate or the white ferric sulphate, in stalactites, stalagmites, or wall coatings. Where the water emerges so slowly that it is completely evaporated, white coatings or efflorescences of gypsum, epsomite, and probably other sulphates are formed. These, like the deposits of iron oxide and calcium carbonate, have no definite significance regarding the presence of ore.

The effect of oxidation on the ore deposits has been mainly to remove the carbonate and pyrite and to leach the tellurium from the tellurides, leaving free gold, either in fine specks and flakes or as pseudomorphs after telluride crystals, in a soft mass of iron-stained quartz and clay, with small to considerable amounts of fluorspar and perhaps celestite. Some of the tellurium was redeposited as green oxide, and some of the iron as the green iron-rich clay mineral nontronite, which was a conspicuous associate of oxidized ore in the upper levels of the Cresson mine.

Although most of the gold remained in the leached, oxidized ore, a little was evidently dissolved and redeposited either nearby or at a considerable distance. The small specimen of crystallized gold from Big Bull Mountain, shown to us by Joe Page, of Victor, in December 1933, and the few occurrences of wire gold mentioned on page 309 suggest such a process, but the total amount of redeposited gold, though it may be striking in a few spots, contributes only a negligible part of the output of the district.

LOCAL DESCRIPTIONS

As the prime object in the recent study has been to evaluate factors influencing the persistence of ore in depth, the deepest accessible mines have been the most thoroughly studied, and their descriptions constitute the bulk of the remaining part of the report. Time has not permitted examination of several of the smaller mines, parts of which may have been accessible, but it is hoped that the mine descriptions that follow will contain suggestions to those operating other mines, regarding both shallow and deep developments.

Although mines have been productive throughout the district, only eight have been worked down to or below the present drainage tunnel, and they are limited to the deeper parts of subcraters within the southern part of the composite crater and to the major fissure zones in granite adjacent to it. These are the only mines of immediate concern as regards any proposed deeper drainage tunnels. A few mines in the northern and northeastern parts of the district have water on their lowest levels, but they are so far above the altitude of the present drainage tunnel that their unwatering should depend on the driving of connections with the deeper levels of the nearest mines already drained or, if the inflow of water is