relation to that of the main component of horizontal shift along the Camp Bird, and to differences in origin of the fissures. Most but not all of the fissures reopened in the walls of transverse dikes show the same offset as the dike. Thus the Smuggler, Ansborough, and other veins of Marshall Basin are offset with the dikes, but the St. Paul, which follows a dike near its crossing with the Camp Bird, cuts through the Camp Bird fissure. It must be supposed, therefore, that later fissuring in the blocks on the footwall side of the Camp Bird was strong enough in some places to break through to the hanging wall. However, as illustrated by the Hancock and some other veins in the footwall of the Camp Bird, a number of the northwest tension fissures failed to break through the Camp Bird and consequently the hanging and footwalls were fissured independently to some extent. As some of these fissures, such as the Hancock, contain early base-metal ore, and as the Camp Bird does also, the Camp Bird fissure is one of the oldest in the area. This evidence agrees with the conclusions reached in the section on structure and classification of the fissures. Although it has been commonly held that the main horizontal shift on the Camp Bird vein was approximately contemporaneous with the introduction of the gold-bearing quartz, the evidence of these numerous transverse veins as well as of the structure of the Camp Bird compound vein suggests that several back and forth horizontal shifts occurred, and that the major part of the horizontal shift took place before introduction of the gold-bearing quartz. In fact Spurr,[62] who came to this same conclusion, estimated "that the sum of the two movements which opened fissures for the sulphide vein and the later gold-quartz vein was not over 15 to 20 feet, as shown by the size of the openings in the Discovery shoot." According to this figure 40 to 45 feet of horizontal offset of the walls occurred before the first main stage of mineralization. At the time of Spurr's study the horizontal offset of the dike on the lower level was not exposed, and hence he had no way of know-

[62] op. cit. p. 142.

ing the total shift, although he stated that shredded fragments of veins were locally offset as much as 60 feet. Evidently only a part of this offset could have resulted from postmineral movement.

Many of the veins crossing Imogene Basin contain base-metal ore with only minor amounts of gold-bearing quartz, and some are mainly barren quartz and calcite. Gold-bearing quartz equivalent in grade to that of the Camp Bird has not been found in any of them. Causes of the concentration of gold in the Camp Bird vein have been discussed by Spurr,[63] and will be reviewed in a following section on effects of temperature and pressure on mineralization (pp. 248-259). Throughout the entire southeastern part of the Telluride and Sneffels districts the San Juan tuff was fissured contemporaneously with the introduction of the early base-metal ores. This correlation is illustrated in Ingram Basin on the Telluride side of the axis by the Black Bear vein, which contains both base-metal ore and gold-bearing quartz although it is allied in structure with the "flat" veins farther northwest. Fissuring along the Argentine vein and dike turned off mainly at the Black Bear vein because southeast of their intersection the walls of the Argentine dike are but feebly fissured. The fact that some veins in both Ingram and Imogene Basins contain only late barren quartz shows that fissuring in these areas continued until the latest stages of mineralization. On both sides of the axis the most striking examples of late quartz veins are found along the outer edge of the fissure swarm. Examples on the Sneffels side include the Muldoon vein between Sneffels and the Camp Bird mill, and a series of smaller veins extending southeast from here along the ridge between Richmond Basin and Fall Creek Basin. This concentration of late quartz is not due to the failure of the earlier solutions containing base metals to reach the outer edge of fissuring, because other veins such as the Monster and Highland Chief were formed during both stages of mineralization.

[63] Idem., pp. 126-137.

A certain amount of symmetry in the distribution of the vein matter of different stages suggests some general order in the growth of the fissure pattern in the two districts. The earliest stage of fissuring involved the walls of the dikes in all areas, excepting possibly at the extreme northwest, and at the same time opened many new tensional fissures in the San Juan tuff in areas bordering the caldera and close to the center line of the swarm. With continued downwarping the tensional rupturing of the San Juan tuff appears to have extended farther northwest involving chiefly intermediate belts on either side of the axis. The final stage of fissuring became strongest along the outer edges of the belts on either side. If this growth in the development of the fissure pattern had been perfectly symmetrical both in time as well as spacially, we would expect to find symmetrical distribution of the ores on either side of the axis. This is not so although there is a definite tendency toward such symmetry.

The most obvious lack of symmetry is in the distribution of the quartz or quartz-adularia veins containing native gold. Thus on the Sneffels side of the axis there is no counterpart of the belt of strong gold mineralization that extends from the Smuggler "Flat" southeast through the Japan-Flora and Tomboy toward the border of the caldera. A corresponding belt might be expected from the line of the Atlas and Cumberland southeast through the vicinity of the Yellow Rose vein in Imogene Basin. It is probably true that the Atlas vein shows the strongest gold mineralization of any northwest vein on the Sneffels side of the axis, but longitudinally the belt is poorly developed. Inasmuch as the fissures along this belt were opened early in the base-metal stage, in contrast to those of the Japan-Tomboy belt, the gold-bearing solutions that gained access to them were perhaps unable to circulate freely owing to the choking effects of earlier vein matter and gouge.

Such generalizations are not to be taken too strictly in the sense that gold and silver-lead ores are entirely restricted to certain belts, but they serve to emphasize that fissuring concurrent with the different stages of mineralization failed to take place with equal strength throughout the area of the downwarp. The shift in position at which stongest fissuring took place from time to time appears to accord with that expected on the supposition that the downwarp represents an early stage in the formation of a graben. If a more or less flat-topped block of the basement sank concurrently with the superficial downwarp, deformation in the shallower formations at later stages would tend to become more and more concentrated along positions above the sides of this block.

In an ideal example the rocks above the middle of the sagged block would therefore be subjected to a decreasing intensity of fissuring in later stages, and hence the veins would contain ores chiefly of the base-metal or silver-lead type. This expectation is partly borne out in areas at some distance from the margin of the caldera. The belt lying between the Atlas vein on the east side and the Smuggler "Flat" on the west contains ores principally of the silver-lead and silver and minor gold types. A boundary of the inner side of the gold-quartz zones would extend from the line of the Liberty Bell and Smuggler "Flat" southeast through the center of the Montana oreshoot in Middle Basin, and thence to the Camp Bird. On the east side of the axis this line extends from the Governor vein near Stony Mountain southeast along the Atlas toward the Camp Bird vein. Veins containing their principal values in gold extend outward as far as the edge of the fissured belt on either side of the axis, but of course not all veins fall in this category. North and west of Stony Mountain the area of silver and silver-lead veins widens still farther, whereas in the other direction toward the Camp Bird it apparently narrows. The particular exception to this generalization, already noted, is the ground beneath Imogene Basin.

In the Imogene Basin area it is probable that the earlier tensional rupturing of the San Juan tuff (preceding and during base-metal stages) had relieved the strains sufficiently so that few if any new tensional fissures were formed during the intermediate or gold stage. Some reopening of the base-metal sulphide veins seems to have taken place. During the last stage, however, when nearly barren quartz was deposited, the rocks in the basin were further fissured. Some of these veins contain a little gold, and if precipitation was controlled mainly by loss of pressure (see effects of temperature and pressure, p. 248), the higher-grade shoots would have been formed not far below the base of the Potosi volcanic series. This horizon is now eroded in this area. On the other hand, in the slightly reopened base-metal veins gold may have been precipitated mainly by reaction between the solutions and earlier-formed sulphides, and hence would tend to become more concentrated at deeper levels (see chemical factors, p. 259).

Conceivably the southeast extensions of the Yellow Rose and Pierson veins beneath Richmond Basin closer to the margin of the caldera, and near the eastern extension of the Camp Bird fissure, could have been more strongly fissured than their northwest parts during the gold stage. Also movement along the bounding faults of the caldera may have strengthened fissuring, as described in the following section on faults transverse to veins.

The prospecting of these veins at depth toward the head of Richmond Basin should, however, be considered an expensive and speculative enterprise. Factors in the economy of mining and treatment of the predominant base-metal ore must be balanced against a speculative enrichment of vein matter with gold.

Faults transverse to veins

Faults transverse to veins have both favorable and unfavorable effects on the localization of ore bodies. The belt of ring faults along the caldera border tends to terminate and split many of the individual fissures of the Telluride and Sneffels swarm. A number of the stronger fissures continue across the fault belt, but the individuality of many others becomes lost eventually in the more highly fractured ground. Although a few small shoots of ore have been mined well within the fault belt, the shoots found are much shorter than those in the unfaulted areas. In general the volume of commercially extractable vein matter decreases in proportion to the transverse faulting and fracturing of the rocks.

Individual oreshoots within or along the outer margin of the fault belt may, however, have been localized by the influence of transverse faults. Such an example is probably presented by the Barstow oreshoot, which was exposed in the bottom of Commodore Gulch just northwest of the edge of the outer marginal faults (pl. 1). This shoot extended for more than a thousand feet northwest of the outer fault, but appears to have extended deepest not far from the fault line. Very wide shoots of ore having this same relation to transverse faults are found in the Sunnyside mine, at the extreme northeast edge of the caldera. These shoots have been described and figured by Hulin.[64] It is reasonable to suppose that movements due to the activity of the faults intensified movements of the walls of the neighboring fissures, and caused recurrent openings. As a consequence later gold-bearing quartz as well as base-metal ore was deposited. The Barstow shoot was essentially a gold shoot, although base-metal and silver-lead ore predominated in places.

Prospecting of other northwest-trending fissures at depth in the same relative position along the fault belt is suggested by this example. The more favorable fissures are probably those in line with the more productive vein zones of the Telluride side, especially between the Black Bear and the Barstow. Other less productive vein zones northeast of the Barstow and as far north along the fault belt as the Camp Bird intersection may be considered proportionately less favorable prospects. Owing to the fact that

[64]Hulin, C. D., Structural control of ore deposition: Econ. Geol., vol. 24, pp. 41-43, fig. 12, 1929.

the border of the fault belt is more complex and less sharply defined northeastward, a less well defined localization of oreshoots by transverse faults is to be expected.

Several oreshoots a few hundred feet in length between transverse faults have been mined in the San Juan tuff at or above an altitude of 10,600 feet along the Handicap vein drift of the Treasury tunnel (pl. 1). Although the structural environment is not favorable for large bodies of ore, these shoots are indicative of the depth to which ore may extend along this belt. The tunnel is somewhat deeper than the bottom of workings on the Barstow shoot, and ore continues below the tunnel level. The fact that few shoots of ore crop out in the latites of the Picayune volcanic group in this area, suggests that these rocks were in a less favorable position for localization of ore than the underlying tuff. However, it is hardly safe to assume that most of the minor veins in the Picayune flows and breccias will become productive in the underlying tuff. The Imogene tunnel in Spirit Gulch near the border of the fault belt failed to disclose ore in the tuff although some minor veins are exposed in the latites above the tunnel line.

Ore channels at depth

During later stages of deformation adjustments between blocks outlined by dikes and later fissures probably extended deepest into the underlying formations along dike fractures or their intersections. At such places veins may continue productive into the sedimentary formations, especially where relatively sandy or other massive beds, rather than shales, underlie the tuff. Transverse structures of one kind or another, such as dikes, fissures, and sheeted zones, may have increasing influence on the localization of mineralizing channels in depth. If so, the oreshoots are likely to decrease in length. In prospecting, therefore, particular attention should be given to transverse structures regardless of the fact that at many places their intersections with the vein may have little apparent or even unfavorable effects upon the local mineralization.

Where the veins pass downward from the volcanic rocks into the sedimentary formations those transverse structures that resulted from rupturing of the San Juan tuff may not everywhere extend uninterrupted into the deeper rocks. Especially where shale layers intervene the shallower fractures may die out, but their places may be taken by other fracture systems controlled by the nature of the rocks and their deformation. Conceivably such deeper structures could be offset with respect to those above, but prediction of deeper structure is not possible. However, from past experience and from the structural conditions, the productivity of the veins must be expected to decrease markedly in the underlying rocks. Prospecting should at first be confined to vertical development near zones where feeding channels are likely to be found.

Volcanic and breccia pipes as feeding channels

Under the description of the Red Mountain district and its volcanic pipes evidence was presented to show that these structures doubtless controlled the rise of mineralizing solutions from depth. As bodies of intrusive quartz latite porphyry like those in the pipes are found in places somewhat outside the main fault belt, and, as the pipes may not everywhere reach to the surface, their influence on feeding channels may extend outside the Red Mountain district. A problem of this kind is presented by structural features associated with the different oreshoots of the Camp Bird vein; however, it has not been proved that these are related to buried pipes.

In Imogene basin above the mine, and directly above the two eastern oreshoots, the latitic rocks of the Silverton volcanic series are fractured and altered along a series of curved fractures of roughly elliptical outline (fig. 10 and pl. 1). The rocks are epidotized and somewhat indurated along the altered zones. Projection of the stronger curved zones downward intersects the Camp Bird vein along the root channels of the two eastern oreshoots to a depth of about 2,500 feet below the surface. Fractures of like trend

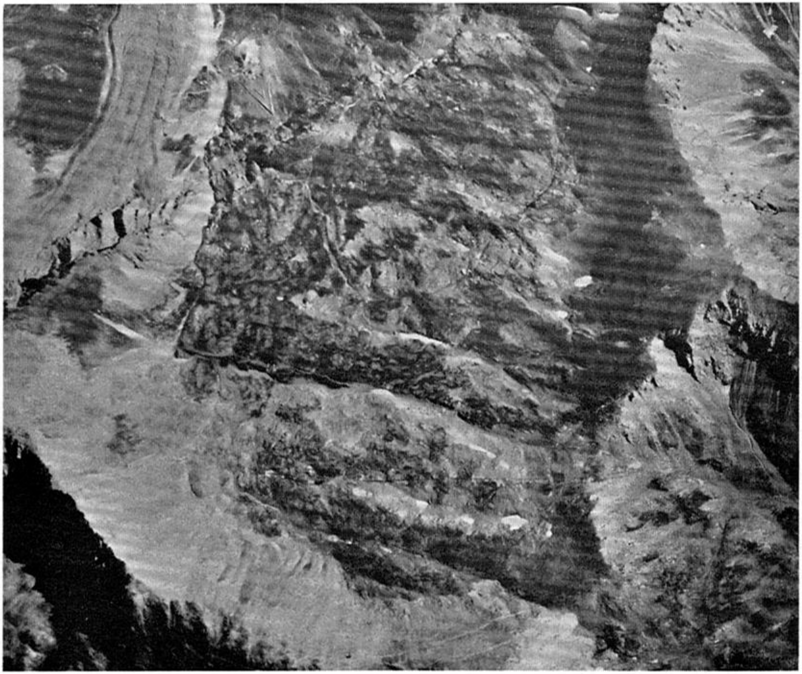

Figure 10.—Aerial photograph of the upper part of Imogene Basin, showing outcrop of the Camp Bird vein diagonally across upper left quarter. Traces of curved lines of sheeting and fracturing of elliptical form are visible above center, and a more poorly defined outline below center. North is about 35 degrees diagonally to the left from the sides of the photograph.

and with strongly epidotized and silicified walls intersect the vein at this depth in line with the trace of the principal oreshoots. Although no intrusive bodies have been found even at this depth, the possibility that these structural features are shallow expressions of buried pipes cannot be overlooked. An alternate possibility is that these altered fracture zones result from escape of vapors upward along the boundaries of prismatic blocks determined by minor fissure intersections (see also page 253). The effects of combined hydrothermal alteration and pressure may have tended to produce concentric shells of alteration analogous to the spheroidal alteration of jointed rocks. Whatever the explanation, such features may be significant in the prospecting of veins.

If the curved alteration zones are actually the expression of deep pipe outlines they should continue down through the plane of the Camp Bird vein, but if they represent shallow shells of alteration these should extend only as deep as the vein fissure from which the altering solutions or vapors escaped. At other places in the district, for example at the head of Savage Basin, the rocks are rather highly altered over restricted areas. Such places also probably represent the escape of mineralizing solutions from underlying channels, but whether or not these features are significant guides in the search for deep feeding channels to orebodies can be determined only by future development.

True manifestation of pipe formation is represented by the mineralized breccia pipe of Stony Mountain (pl. 1). This is several hundred feet in diameter, almost perfectly oval in plan, and has steep, sheeted walls like the volcanic pipes of Red Mountain but without evidence of accompanying intrusive activity. The body of the pipe is composed of much brecciated and altered gabbro-diorite of the Stony Mountain stock. The highly altered breccia consists mainly of ankerite, quartz, and sericite. The sulphides present are mainly pyrite and arsenopyrite, although small fissures around the rim contain a little sphalerite, galena, and barite. The mineral assemblage is similar in character to that of the neighboring veins to the south of Stony Mountain,[65] except for the predominance of the carbonate gangue in the body of the pipe. Hence it seems probable that the pipe was formed contemporaneously with the neighboring vein deposits, and may have fed some mineralizing solutions into neighboring parts of the Banner vein. The northern part of this vein in the Governor mine swings in strike toward the southern edge of the pipe. The Governor vein, which parallels the Banner on the east in the mine workings, consists chiefly of gold-bearing quartz, and hence is different in mineralogic character and time of formation.

The prospecting of this pipe at depth for possible bodies of ore within boundaries of the pipe could be accomplished by extension of the drift on the Banner vein or by diamond drilling. As there is very little if any indication of higher-grade ore concentrations near the pipe, such an exploration would be speculative. This pipe, however, offers further evidence that in depth, and especially near the borders of major crosscutting structural features, pipe-like channels may be a factor in the mechanism by which deeply derived emanations are fed into the shallower and more highly fissured rocks.

Effects of temperature and pressure

The control of temperature and pressure on zoning and precipitation of ore minerals is a less tangible factor than structure, though it should not be ignored in applying structural factors to prospecting. As has been mentioned in the introductory remarks on these districts, zoning is clearly exhibited by changes in mineral composition areally and in depth, and in the relative concentrations of base-metal and precious-metal shoots in different areas. In part this zoning is related to structural factors, such as the compounding of the veins, whereby ores of typical epithermal character are superimposed on ores of mesothermal affin-

[65]Moehlman, R. S., Ore deposition south of Ouray, (pt. 2): Econ. Geol., vol. 31, pp. 491-495, 1936.

ities. However, probably all ores should be classified as epithermal on the basis of environment, that is, deposited in volcanic formations within a few thousand feet of the surface under conditions of relatively low external pressure. As stressed in the description of the Red Mountain ore bodies, low external pressure in many places may have been a more critical factor than the cooling of the solutions in the deposition of ore minerals.

Sharply contrasted differences in the zoning of the ores with depth are characteristic of the region as a whole. The ore bodies of the Red Mountain district, telescoped within a vertical range of 1,000 feet or less, contrast sharply with veins like the Smuggler-Union and Virginius which show very little change to depths of several times this amount. In general zonal changes with depth become less pronounced as distance is gained from the caldera margin. This is not, however, an invariable rule, for an outstanding feature of the region as a whole is the scattered distribution of especially high-grade ores in shoots near the upper limit of ore deposition.

The expression "upper limit of ore deposition" may have little significance in some regions, for commonly a number of oreshoots crop out on an erosion surface whereas others fail to reach this surface because of some accident of erosion. It is rarely justifiable to infer that the ores ever had any well defined upper limit, or that the veins did not originally extend up to some former land surface. In the Telluride and Sneffels districts, however, the evidence is conclusive that the ores do not at any place extend far above the base of the Potosi volcanic series, and in some areas fail even to reach it. Because of the widespread distribution of the formation it may be safely concluded that the deposition of ore never extended to the land surface at the time of mineralization. The characteristic features of this upper limit of ore deposition are possibly critical in the evaluation of the effects of temperature and pressure on the deposition of ore minerals. The preceding analysis of structural conditions has shown that the nature of fissuring in the Potosi rocks was an important factor in restricting the size of veins. The absence of large veins in these rocks does not mean that no fracturing took place in them or that the outcrops of fissure zones are everywhere insignificant. The character of fracturing in the shallower rocks above the productive part of the Camp Bird vein may be seen for example at the extreme left in figure 10. In general such effects are much less noticeable on the ground than when viewed from the air. Commonly the Potosi rocks are shattered and the jointing much accentuated; silicification and alteration to clay minerals are especially noticeable along the fissure line. Quartz occurs as small veinlets or as crystals deposited in irregular cavities leached in the rocks. In places near the fissure zones the rocks are impregnated with pyrite, which may locally be oxidized or partly leached. The conditions above the veins are therefore not greatly different from those above the Red Mountain oreshoots, except for the degree of leaching and silicification, and the volume of rock affected by the alteration. The Potosi rocks over large areas are devitrified and altered to some degree by the formation of secondary quartz, clay materials, and calcite. Hence the breccias and flows of this formation were somewhat permeated by mineralizing hot solutions or heated ground waters beneath the plateau surface at the time of vein formation. The general physical character of the flows and breccias as well as this alteration indicates that these rocks were much more permeable than the underlying andesitic flows and tuffs, which are much less widely fractured and altered near the vein zones.

The upper terminations of the Camp Bird oreshoots are especially instructive in regard to possible factors controlling ore deposition below the base of the Potosi volcanic series. These shoots have been studied and described in some detail by Spurr,[66] and the writer has examined critical parts of the Discovery shoot in the vicinity of the Chicago tunnel. Along the vein for a total stretch of 5,000 feet the shoots all terminate upward in remarkably ac-

[66] Spurr, J. E., Idem., pp. 119-126, 137-148.

cordant flat tops at an altitude of 11,900 feet, just at the base of the Picayune volcanic group.

Spurr attributed this limitation of gold to a factor of porosity in the San Juan tuff, which he believed facilitated the escape of volatile constituents from the "ore magma." No attempt will be made to argue the question of whether the gold-quartz vein was deposited from the concentrated solutions postulated by Spurr, or from more dilute vein-forming solutions conforming to the more generally accepted views of geologists. Regardless of the nature of the ore-forming solutions, Spurr's inference that pressure was a basic factor in controlling the deposition of gold appears well founded in the light of the facts. On the other hand, the porosity of the San Juan tuff can hardly account for the restriction of the gold to the uppermost part of this thick formation, or, in some other veins, for the continuance of ore up into the base of the Potosi volcanic series. Furthermore, the rhyolitic and latitic flows and breccias, from all physical appearances, fracturing, (fig. 10) and general alteration, must have been and still remain a very much more permeable series of rocks than the San Juan tuff. Hence the vapors should have escaped upward through the pores of the overlying rocks rather than through the relatively tight walls of the fissures in the San Juan tuff.

By comparison with other examples of such discontinuities of ore in the deposits of this region, the writer believes that a discontinuity in the ore-forming processes, brought about by direct boiling or a rapid escape of vapors from the solutions, may account for the localization and distribution of ore. The leaching and kaolinization of the more porous fractured rocks and vein matter above the ore zone, the sharp boundary between ore and barren vein matter, and the localization of these features near a sharp change in the general permeability of the country rocks are believed to be significant criteria.

Beneath the lower massive flow of this group the two longer shoots were over 1,000 feet in length, but above the western one a small upward protuberance, only 150 feet in length, extended several hundred feet higher into the latite breccias of the Picayune volcanic group though not to the base of the Potosi series. The quartz vein material in this upper shoot extends to the base of the rhyolite, and is characterzied by much clay matter and limonite but very little gold. Above this the altered and leached rhyolite does not contain a well defined vein. The high-grade ore beneath the flat tops of the shoots continued down in the San Juan tuff to a maximum depth of 700 feet, and contained on the average an ounce or more of gold to the ton; but still deeper the ore channels contracted in length and the gold content diminished. Although the shoots have recently been explored and mined to a depth of 2,000 feet, much deeper than was considered practicable at the time of Spurr's examination, the fact remains that the relative grade as well as volume of ore decreases in depth. Recent work also affords additional proof that the upper limit of ore is remarkably flat and sharply defined. Spurr was unable to explain this upper limit solely on the basis of fissuring and the distribution of quartz, inasmuch as barren vein quartz of the gold stage extended higher than ore. He states[67] in regard to the western or Discovery shoot: "It will be noted that the main vein, where it crosses the upper andesite flow (in the Picayune volcanic group as here defined) is narrower than the underlying portion; it is also practically barren of gold, although the quartz which carries the gold below goes on up—but without the gold. Where the vein enters the bottom of the rhyolite, it is still farther constricted, and its outcrop is insignificant."

The restriction of the width and length of the ore channels where these break through the lower andesite flow of the Picayune group may have greatly accentuated the tendency for a flat top to the horizon of gold deposition in this particular vein. These restricted passages may have acted as outlet valves for the escape of vapors from the ore-forming solutions. If so the gold was evidently not in sufficiently volatile combination to pass upward with the

[67]Idem., p. 129.

more tenuous vapors, but in some places, such as the minor protuberance above the Discovery shoot, sufficient solution was carried upward with the escaping vapors to produce minor shoots of ore. The fact that the quartz of the gold stage continues above ore suggests either that the gold was deposited mainly from later solutions of this stage, as, indeed, is indicated by the petrographic study of vein matter, or, that gold was more readily precipitated from solution than siliceous material by the release of vapors. The downward extension of the rich shoots for 600 or 700 feet below this horizon of discontinuity may indicate either the depth to which strong ebullition extended in the trapped solutions, or it may have resulted in part from some escape of vapors through minor fractures in the hanging wall of the vein. In a previous section the formation of silica and such ferric-iron bearing minerals as epidote in the hanging-wall rocks of the Camp Bird vein has been described. These alteration effects may perhaps be considered characteristic of weak vapor-phase attack on rocks somewhat more basic than rhyolite.

Alternative explanations of the rich upper limits of the shoots involve abrupt cooling of the solutions by some means, or a supergene leaching and enrichment of the upper parts of the shoots. Certain conditions unfavorable to supergene leaching and enrichment may be briefly noted: the absence above the shoots of a large well defined body of vein matter that could provide a source of gold; the fact that the shoots are separated horizontally by barren tight stretches of the fissure in which no vein matter of any consequence is present; and the lack of evidence in general that gold migrates freely in zones of supergene enrichment.

If the deposition of gold be attributed merely to a near-surface cooling of the ore-forming solutions rather than to the partial loss of gas or complete evaporation, the sharply defined top of ore as well as the means by which cooling could have been accomplished are not readily explained. Lateral or convective circulation of cooling ground waters would be greatly hampered by the barren, tight stretches between shoots and by the narrow restrictions of the channels at the top. The formation and expansion of vapors are hence the most probable processes involving the abstraction of large quantities of heat under the conditions defined. The greatest cooling due to expansion might be expected to take place above the channel constrictions at the tops of oreshoots rather than below them. Hence it appears probable that temperature controls were subordinate to pressure controls or loss of gas in bringing about deposition of ore minerals.

The causes of the relatively high concentration of gold ore in the Camp Bird fissure as compared with nearby northwest-trending fissures are touched upon by Spurr.[68] The course of the fissure in the Camp Bird mine follows alternate stretches that strike nearly east-west and west-northwest. Owing to a large component of horizontal movement along the fissure the west-northwest stretches localized wide openings in which the ore was deposited. Most of the north west-trending fissures, on the other hand, were formed with very little displacement of the walls and this was mainly vertical. Consequently, even though gold-bearing solutions had gained access to the northwesterly fissures, such new openings as may have formed would tend to have a horizontal rather than a vertical extension, and the channels so provided would fail to offer a direct passage from depth toward the surface (see also chemical factors, pp. 259-261). The marked telescoping of the Camp Bird gold shoots affords further evidence of the by-passing effect of these steeply inclined channels. Spurr points out that if the volume of the Camp Bird gold had been distributed through a vertical range of 3,500 to 4,000 feet instead of 600 to 700, the grade of the ore would have fallen to that of the more persistent deep lodes, such as the Mother Lode of California. It is not at all improbable that at great depth the northwest-trending veins form the feeding channels of the Camp Bird fissure, although, as mentioned, the alternate

[68]Idem., pp. 122-126.

possibility that breccia pipes are also involved cannot be eliminated.

Some of the silver-lead and silver-lead-gold oreshoots of veins farther from the caldera margin may be compared with the Camp Bird shoot. One example of a silver-lead shoot is that of the Terrible vein, in which the main oreshoot was nearly 2,000 feet in length and about 500 feet in depth. This shoot consisted chiefly of galena and silver-bearing "gray copper" ore, the top of which extended for a short distance up into the base of the Potosi series. At the bottom the silver-lead content of the vein decreased appreciably over a greater part of the shoot length. In contrast to this vein the nearby Virginius silver-lead vein, with a sail-shaped ore body, was mined through a vertical interval of 2,200 feet without appreciable change in the value of ore. The explanation of the rather abrupt bottoming of the Terrible shoot is not apparent without more exact information on the changes in mineral composition and structure in depth. The vein in the Revenue tunnel drift, 1,200 feet below, is compound and consists chiefly of an early-stage quartz-rhodonite-rhodochrosite vein with predominant pyrite and sphalerite. At places there is some later quartz, mostly barren, but spotty showings of gold may indicate minor channels that were open during the gold stage of mineralization. As several veins of the Sneffels area were repeatedly opened during the main sulphide stage, with a predominance of galena in the parts that were opened latest, the silver-lead ores of the Terrible shoot may have been localized above a change in dip of the vein during the later stages of fissuring. The interpreation of primary zoning of the ore in depth is also applicable.[69] If, however, the silver-lead ore resulted from a later introduction of ore-forming solutions, the root channels probably lay at the northwestern end of the shoot rather than the southeastern end. There also appears to be a northern root channel beneath the Virginius shoot just southeast of the intersection of this vein with the Jump Off and Ansbor-

[69]Moehlman, R. S., op. cit., pp. 394-395.

ough dikes (pl. 1). It is reported that at the seventh level (alt. 10,050) of the shaft sunk at the end of the Revenue tunnel, tetrahedrite-bearing ore is present in the Virginius vein, but the oreshoot is evidently greatly reduced in length at this depth.

The Smuggler-Union and Humboldt veins together have been mined to a greater length than any other veins of the district. At the northern end and in the Humboldt ground the veins are capped with the rhyolitic flows. That the ore in these veins at all levels was very largely of primary or hypogene origin has been shown by Bastin.[70] The gold and silver content of the ores decreased very abruptly where the vein passed from the andesitic rocks of the Silverton volcanic series up into the rhyolite. This change is illustrated by assays said to come from the third level, but which may be shown as the 2 level of mine maps, as the top level is marked zero and the 3 level of the mine maps lies well below the contact. In vein matter ranging from 1 to 2½ feet in width in the andesitic country rock the gold content ranges from 0.12 to 1.40 ounces to the ton, and the silver content from 45 to more than 150 ounces. In vein matter ranging from 1 to 2.2 feet in width within the rhyolite the gold content ranges from a trace to 0.04 ounce, and the silver from 0.90 to 5.60 ounces. These relations according to Bastin were not exceptional, but characteristic of the vein under these conditions. He describes the vein in the two formations as follows:[71]

"An excellent exposure of the vein in the 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, and there was a single band of quartz 1 to 2 inches wide carrying a sparse scattering of sulphides.

"With this may be contrasted the appearance of the vein in andesite about 250 feet north of the shaft on the same

[70] Bastin, E. S., Silver enrichment in the San Juan Mountains, Colo.: U. S. Geol. Survey Bull. 735, pp. 79-95, 1923.

[71] Idem., p. 80.

level, where the vein is 5 feet wide. For 3 feet next to the footwall occurs altered andesite traversed by numerous narrow 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. . . . In spite of the stains of iron oxide in this ore the microscope shows no replacement phenomena or other features suggestive of enrichment."

He concludes with regard to the origin of the vein matter:[72]

"To summarize, the Humboldt mine workings develop portions of the . . . 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 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 may encroach directly upon primary ore. Microscopic study of the ores confirms these probabilities by showing that the silver occurs chiefly in argentiferous tennantite and in ruby silver (proustite) that are clearly primary. Microscopic evidence 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,

[72]Idem., p. 83.

even those rich in ruby silver, obviously offers encouragement for deeper exploration."

This evidence is in agreement with that obtained from the Camp Bird vein that the distribution of ore was controlled entirely by hypogene processes.

Although alteration in the rhyolite above the Humboldt oreshoots was less intense than above those of the Camp Bird, the vein zone is clearly defined at an altitude of 12,800 feet or about 200 feet above the top of ore. The vein at the surface is marked by a sheeted and fractured zone 12 feet wide. The outer 4 feet on either side consist of bleached and pyritized rhyolite, with a middle of hard silicified rock which has been crushed and streaked with clay materials. The altered rocks are stained lightly with iron and manganese oxides. Still higher on the ridge the rocks have been more generally though less intensely altered, owing to their general permeation with hydrothermal solutions or vapors.

The occurrence of relatively high-grade vein matter just beneath the rhyolite capping at the Humboldt vein appears consistent with the interpretation applied to the Camp Bird vein. Although the zoning in depth is evidently less pronounced at the Humboldt, the precious-metal content given by Bastin from the 2 level is appreciably higher than that of ore that was mined from deeper levels between 1916 and 1920 and averaged about 0.08 ounce of gold to the ton, and 12 ounces of silver. It appears likely that the greatest change in value of ore takes place in the upper few hundred feet of the vein and that zoning is less noticeable at greater depth. In 1898 Purington[73] commented that in the Smuggler-Union vein, then developed down to an altitude of 10,700 feet, no diminution of the value of ore had been experienced in the deepest workings. The part of the Smuggler-Union vein that had been developed deepest, however, cropped out below the altitude of the rhyolite so that no comparison is possible with the uppermost parts of the vein which have been eroded here.

[73]Idem., p. 833.

In view of the similarities and differences between some of the more feebly zoned veins of the outlying areas and the Camp Bird shoots, and the similarities in alteration processes in barren rocks above the upper limit of ore deposition, the factors controlling mineral deposition appear to differ mainly in degree rather than in kind. If temperature control is the dominant factor anywhere it would be in the outer zones where hypogene zoning is relatively feeble. The effects of pressure become more apparent in the Camp Bird shoot, which may be considered a connecting link to the Red Mountain chimney deposits where pressure appears to be the dominant control. This relationship suggests that in prospecting for oreshoots in areas bordering and within the margin of the caldera, the possible effects of pressure on the upper limit of ore deposition should be considered. The upper limit of ore deposition could conceivably be much lower along this border zone than in nearby outlying areas. The fall between the top of the Camp Bird ore at 11,900 feet altitude and the apparent tops of the Red Mountain chimneys on the valley floor at 11,000 feet and below indicates a relatively abrupt downward plunge of the zone of ore deposition across a belt about 2 miles wide.

Chemical factors

The possible influence of chemical factors in ore deposition has not been emphasized in the preceding discussions as it is believed that such factors are subordinate in the localization of veins. In processes of vein formation, however, chemical factors are important, perhaps especially in the deep, feebly zoned shoots where pressure and temperature changes become relatively feeble. Moehlman[74] has emphasized this phase of ore deposition in the San Juan veins and comes to the conclusion that "replacement was a much more important process in the formation of the veins of the western San Juan region than has been gener-

[74]Op. cit., pp. 489-503.

ally recognized." Also, as he points out, reaction between ore-forming solutions and previously deposited minerals may bring about precipitation when mere cooling will not. There is no doubt that such reactions are factors in the deposition of gold and silver, especially in compound veins where the earlier base-metal and later silver or gold stages are superimposed. For example, in the lower levels of the Camp Bird mine concentrations of gold are in places associated with specularite, sphalerite, and chalcopyrite which may have acted as precipitants, whereas in the upper levels some of the most striking concentrations of free gold are in quartz with but little associated sulphide in direct contact with the gold.

On the other hand, if reaction processes were the dominant control of mineral deposition, then the silver and gold introduced late in the sequence in the compound veins would tend to become precipitated by reaction at deeper levels. We would expect the silver and gold content of such tight veins, which did not provide some by-pass for the later solutions, to be concentrated at deeper levels. Specific examples of such action are not particularly obvious without resort to much comparative microscopic work. Also in many places later fissuring has provided adequate by-passes for the later solutions. Possible examples of reactive deposition of the ore minerals are exhibited by the Camp Bird and Smuggler-Union veins at lower levels, where the principal gold and silver values are directly associated with the earlier sulphides. This is perhaps the general rule in the eastern shoot of the Camp Bird mine. The existence in the Smuggler-Union and other veins of pockety high concentrations of gold and silver at great depth suggests too that such reactions only exceptionally produce high-grade ore, and that the volume of solution by-passed was relatively large. Another example of deposition by reaction and replacement may be furnished by the Red Mountain chimney deposits, where presumably conditions during ore formation were especially favorable for reaction between the earlier-formed sulphides and gangues and later solutions.

In some chimneys the higher gold concentrations were found at deeper levels in the chalcopyrite and pyrite bodies. That this association is not invariably the rule suggests that around other chimneys later fracturing by-passed the gold-bearing solutions to higher levels before much reaction could take place. In some of this ore gold occurs in crystalline form perched on other minerals in cavities.

Perhaps the best examples of the formation of veins by complex replacement processes are furnished by the quartz veins near Stony Mountain described by Moehlman.[75] The earliest gangue minerals deposited in the fissures and by replacement of the walls and shattered material were barite and manganiferous carbonate. The early sulphides were then deposited. The early gangue minerals were in turn replaced by the later quartz to form the bulk of the vein. The silver-bearing minerals were deposited in and near spaces remaining after the bulk of the quartz was deposited. Thus the solutions bearing most of the silver must have worked their way toward the surface through the more or less permeable vein matter that plugged the original fissures. These conditions would provide further restraint to the dumping of silver-bearing minerals in exceedingly rich bodies such as occurred in the highly telescoped chimney deposits. In general other silver-bearing quartz-carbonate veins of the San Juan appear to have had a similar history of formation. Many of these mineralogic problems are beyond the scope of this paper, however, and will be treated at greater length in a final report.

[75]Op. cit., pp. 491-495.