of them contain the richer shoots of copper-silver sulphides and the ore bodies as a whole are small and pockety in form. It may be suggested, therefore, that the difference was caused by less uniformity in pressures on the ore-forming solutions outside this narrow belt, and that, as a consequence, ore precipitation occurred at higher or lower levels in accordance with local structural and groundwater conditions that affected pressure along the fissure openings.

The factors involved in the above discussion of environmental conditions are obviously too complex to permit very definite conclusions, but there can be little doubt concerning the existence of a former meteoric basin above the Red Mountain Valley. The younger rhyolite flows and tuffs of the surrounding areas are comparatively porous rocks, and have been much altered to secondary clay materials, carbonates, and quartz. This widespread alteration of the rhyolites could hardly have taken place unless these rocks had been permeated with mineralizing waters beneath much of the former plateau surface onto which the numerous fissures emerged. Waters from such widespread groundwater blankets must have found their way into structural basins such as that of the Red Mountain sag.

Composition and origin of the solutions.—Two types of solutions are indicated by the products of rock alteration and ore deposition in the Red Mountain district. As inferred by comparisons with the solfataric and fumarolic areas of today, one was of the sulphate type and probably varied from place to place in its degree of acidity or alkalinity; the other was of the sulphide type and commonly though perhaps not always alkaline. Among the different minerals formed by reaction between the sulphate type of solution and the volcanic rocks, the kaolin minerals, including kaolinite, dickite, and nacrite (?), are the only ones that definitely indicate acidity of the solutions. In places alunite and dickite are found in close association, as in the National Belle mine. Day and Allen[39] state that in the hot springs of Lassen Peak "complex aggregates of alunite with

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[39] Op. cit., p. 141.

opal and kaolin . . . in the sediments suggest . . . that the three substances are contemporaneous products of the action of sulphuric acid on feldspars or volcanic glass." However, the range in conditions under which alunite will form is not known. The strongly silicified rocks that surround the main channels of alteration in the Red Mountain district are closely associated with dickite and other kaolin minerals, which occur filling or lining cavities in the siliceous material. Outward from these channels the intensity of alteration decreases and clay minerals, such as beidellite, are found associated with other products of rock alteration, including chlorite, sericite, and calcite. Hence solutions of strongest acidity traversed the main channels, and it was near these channels that the strongest leaching of the rocks occurred. In some of the silicified masses large caverns connected by many ramifying channels were formed. In places these open caves were later crustified or filled with the ore minerals, but these minerals in turn were locally embedded in kaolin or veined with it. In other places pyrite and sericite veined the dickite, or the sulphides were deposited around breccias of kaolinized and silicified rocks, so that there is no evidence of an invariable time relation between deposition of the sulphides and such alteration products. Presumably the other type of solution, which deposited most of the sulphides, sericite, and more coarsely crystalline quartz and carbonates, were alkaline; however, it seems uncertain that sulphides were all precipitated from alkaline solutions, for in places enargite and particularly pyrite are intimately associated with the kaolin minerals and alunite. Finely divided pyrite is also intergrown with alunite.

Enumeration of these complex relationships may suggest that no cleancut separation between the ore bodies and the kaolinized rocks existed, but in general the kaolinized and silicified rocks form casings about bodies of very massive sulphides. It is with these masive sulphide bodies that the more alkalic gangues are commonly and intimately associated.

The deposition of the sulphides in and near channels formed by advance and intermittent attack of acid waters on the volcanic rocks implies some very close association in origin of the two types of solutions involved. The simplest explanation is that one solution was formed by vaporization and recondensation from the other. As the acid-sulphate type of solution was sufficiently undersaturated near the channels to effect considerable leaching of the silicate rocks, this power of combined leaching and silicification, which was inherent in the formation of the open spaces, is obviously the key to the place and mode of its origin. Silicification and attendant formation of solution channels decrease very markedly in depth in all the chimney deposits explored to the bottom of their productive parts. This is one of the most significant relationships between the casings and the ore bodies themselves (see p. 189). In depth, low-grade pyritic ore or barren pyrite continues downward beyond the productive ground, but mainly in narrow veins or replacement bodies, and the casings of silicified rock as well as the number of pre-sulphide caves are said to be relatively insignificant. In the National Belle mine the pre-sulphide caves are most strikingly developed in the upper levels but do not occur in the lower ones.

If the power of the acid-sulphate type of solution to leach and silicify decreased in depth as it did outward from the main channel, then it must be supposed that these powers were either of local origin or were derived from above. The relations between ore and altered rock are most satisfactorily accounted for if it is supposed that the original sulphide ore-forming solution vaporized at this position, and that the vapors penetrating and condensing in the surrounding walls formed an undersaturated acid condensate.

Chemical reactions by which hydrogen sulphide waters may be oxidized to sulphate-bearing waters have been mentioned by Day and Allen[40] in discussing the origin

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[40] Op. cit., p. 139.

of the acid springs of Lassen Peak. Graton and Bowditch[41] have also described conditions indicative of the formation of acid-sulphate waters by vaporization of normal ore-forming solutions. None of the chemical reactions called upon by any of these authors have been proved experimentally to occur under conditions free of the influence of direct oxidation by air or meteoric waters, but there is much evidence that sulphates do form at great depth beneath the surface. The writer has described such occurrences in the Bonanza[42] district, and has shown that iron was oxidized, in igneous rocks at even greater depths in the Uncompahgre district.[43] Since these chemical reactions have not been studied at temperatures and pressures such as exist beneath fumarolic areas, the argument must rest mainly upon the geologic evidence, as has been presented by Butler,[44] that sulphates do originate in hypogene solutions under conditions free from the influence of surface oxidation.

Control of ore deposition.—The derivation of the sulphate type of solution from recondensed vapors of the sulphide-bearing ore solutions together with concurrent changes in the locus of vaporization provide controls adequate to account for many puzzling features of ore deposition in the chimney deposits. The local evidence of concurrent action of sulphate and sulphide solutions harmonizes with this origin of the sulphate solutions. It may be inferred that the fumarolic vapors emanating from the sulphide solutions were locally recondensed in the finely porous wall rocks and proceeded to corrode them. These new solutions, forced upward and outward by the driving power of the vapors, could carry away the more soluble rock con-

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[41] Graton, L. C., Nature of the ore-forming fluid: Econ. Geol., vol. 35, (Suppl.), pp. 331-337, 1940; also
———and Bowditch, S. I., Alkaline and acid solutions in hypogene zoning at Cerro de Pasco: Econ. Geol., vol. 31, pp. 687-691, 1936.

[42] Burbank, W. S., Geology and ore deposits of the Bonanza mining district, Colorado: U. S. Geol. Survey, Prof. Paper 169, pp. 82-85, 1932.

[43] Burbank, W. S., A source of heat-energy in crystallization of granodiorite magma, and some related problems of volcanism: Am. Geophys. Union, Trans., 17th Ann. Meet., pt. 1, pp. 237-240, Nat. Research Council, 1936.

[44] Butler, B. S., Some relations between oxygen minerals and sulphur minerals in ore deposits: Econ. Geol., vol. 22, pp. 233-245, 1927.

stituents, but quickly became saturated with the less soluble silica and alumina. These less soluble constituents were deposited in exchange for additional amounts of the more soluble constituents and thereby formed the silicified casings of the channels. These casings, which now consisted chiefly of finely divided quartz, or jasperoid, and kaolin minerals, tended to insulate the walls from further attack. Vaporization was continuously forced upward by this reduction of local porosity, by the filling of the channel space with ore, and by the slumping of the overlying weakened rock masses; hence, wherever the pressures were uniformly maintained. vaporization and the concurrent leaching and silicification of the walls kept pace with the deposition of the ore.

In positions where the pressures were closely controlled, the process of ore formation followed that of further attack by the vanguard of acid vapors, and the deposition of ore minerals proceeded from lower levels upward in the general order of their precipitation as shown by paragenetic relations. Crusts of the sulphide minerals show the same general order of growth as the minerals in the massive ore. Where the channels became filled by earlier-stage minerals, the later sulphides such as galena were deposited mainly as cappings, or, where further disturbances afforded access, as veins and replacement deposits in the walls of the chimneys. This distribution is illustrated by the Guston chimney and others that contain rich solid inner chimneys of copper-silver ore. Some of the late galena was deposited in cracks or by replacement within the earlier ore down to comparatively deep levels, as might be expected if the original channels became clogged with the earlier minerals. In other mines the later minerals encrusted the interiors of open channels that never were completely filled.

In places this balance was apparently not as well maintained. Some sulphide masses are shattered or crackled and veined by aggregates of the clay minerals. It may be inferred that the locus of vaporization shifted up or down erratically thus exposing sulphide bodies to the intermittent attack of sulphate or acid solutions and vapors. Lowering of the vapor pressure and descent of the locus of vaporization could have been caused by renewed fissuring in areas not well protected by meteoric water blankets, or by disturbances in the basins above. It may be inferred that chimneys located near the borders of the basins, or entirely outside them, would be more subjected to such erratic changes in the confining pressure.

What followed the completion of sulphide deposition seems to have varied greatly in different places. In some pipes the outcrops of mineralized chimneys are strongly leached and the sphalerite and galena are oxidized to sulphates and carbonates; in others the massive ore crops out but has undergone only minor and extremely shallow oxidation. The temporary leaching of sulphide during mineralization has been mentioned. In some places there is evidence of a strong attack on sulphide bodies by acid solutions or vapors after the deposition of galena. This is illustrated by the National Belle mine where the lower limit of leaching is a very sharply defined boundary coinciding with the bottom of oxidized ore in the open caves. Large masses of the silicified and originally pyritized rock forming the walls of the caves in the upper 150 feet of the pipe are almost completely leached of their sulphides, but such small relict masses remain as to show evidence of the action. Unlike the results to be expected from the leaching action of percolating meteoric waters, even the finest disseminated grains of pyrite and enargite are leached without leaving a limonitic residue to stain the silicified masses. These consequently have their original white, gray, or black color except for local limonitic stains at the surface and around residual cores of sulphides. The nature of the material remaining in caves in the silicified rock has been described (p. 187).

If the leaching of the iron and copper sulphide minerals resulted from the action of meteoric waters, it probably took place below rather than above ground-water level, because of the absence of limonitic residues.[45] It is

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[45] Locke, A., Leached outcrops as guides to copper ore, pp. 51-52, Williams and Wilkins, Baltimore, 1926.

suggested, however, that the leaching of disseminated sulphides in the upper part of the National Belle pipe may have taken place during late stages of hypogene mineralization. Hydrothermal leaching of these rocks would also provide pore space and increased permeability which would enhance the normal percolation of oxidizing ground waters. This may account in some degree for a general tendency here as well as in other areas adjacent to the district for highly oxidized ores to occur only at positions close to what may represent the upper limits of hypogene ore deposition.

Suggestions for prospecting

The ore channels in the eastern parts of the Red Mountain district have a more irregular distribution both vertically and laterally than those along the bottom of the main sag; in fact, only small and scattered bodies of lead and copper-silver ores similar to those of the Red Mountain valley have been discovered. These are found mainly below an altitude of 11,500 feet. Some of the highest small deposits at altitudes near 12,000 feet consist mainly of pyrite, sphalerite, and enargite, whereas lead-bearing ores are found hundreds of feet below this level and only a few thousand feet distant.

The entire upper part of Red Mountain No. 3 above an altitude of 12,400 feet consists largely of silicified and kaolinized rock in which there is little or no evidence of sulphide mineralization. If the rocks were formerly impregnated with pyrite, the crystal casts have been destroyed or filled beyond recognition. Large natural caves are common on some slopes, and these are partly filled here and there with kaolin minerals somewhat stained with limonite. Casts of pyrite crystals appear near some fissures at an altitude near 12,200 feet, and are heavily charged with limonite. It is concluded therefore that the sulphide solutions rising beneath Red Mountain No. 3 must have vaporized mainly or entirely below an altitude of 12,000 feet at essentially all stages of mineralization. Ores if present must lie at deeper levels. An exploratory crosscut from the Genessee-Vanderbilt tunnel to a position beneath the north slope of Red Mountain No. 3 encountered bodies of pyrite and enargite ores as well as one containing appreciable covellite. The tunnel however does not penetrate beneath the areas of strongest hydrothermal leaching and silicification along the south and west slopes of Red Mountain No. 3. The altitude of the exploratory tunnel at the portal is 10,725 feet, and hence within the horizon of possible mineralization.

Although much scattered work has been done in prospecting ground east of the Red Mountain Valley belt of high-grade chimneys, most of it has not tested ground lying at depth beneath surface areas of particularly strong hydrothermal leaching. One of the areas of strongest leaching and silicification is that surrounding the south and west slopes of Red Mountain No. 3. Exploration beneath this area holds the most promise of determining whether ore underlies such areas. The extensive silicification and cavern formation on this mountain indicates a very large volume of solutions compared with other mineralized pipes of the district. The temperatures and pressures at depth must have been such that any mineralizing solutions would have evaporated and deposited their lodes far beneath the level of the barren caves. This inference is borne out by the fact that the walls of the caves show little or no evidence of the former presence of appreciable quantities of sulphides. It is of course possible but improbable that even at the depth of ore deposition much or all of the soluble sulphides were later removed by post-ore hydrothermal leaching. Whether or not much leaching has taken place can be determined only by actual exploration.

There is no sound basis for prediction of the metal content of the original sulphide solutions at depth beneath Red Mountain No. 3. In comparison with the Congress and Carbon Lake chimneys the position of the pipe relative to the Red Mountain Basin indicates that the ore might resemble that in these chimneys, and hence would consist largely of pyrite and enargite, with galena. The Genessee-

Vanderbilt tunnel, which has penetrated to within 1,000 or 1,500 feet of the probable center of the pipe, cuts a small body of ore containing covellite. The possibility that the solutions were barren at depth seems remote.

The structure of the pipe on Red Mountain No. 3 most closely resembles that of the National Belle pipe. The east side of the pipe (fig. 7) is occupied by a lens-like body of quartz latite porphyry. The interior is composed of altered pyroxene andesite and locally of altered breccia. The silicified and cavernous rim around the border lies somewhat outside the probable envelope of the original volcanic pipe. The most strongly silicified and cavernous part of the rim forms a horseshoe-shaped mass surrounding the southern half of the pipe. Where the outer contact of the silicified rim is exposed on the south and east slopes of the mountain it dips from 45 to 60 degrees inward toward the pipe center. Outside this contact is a kaolinized and locally pyri-

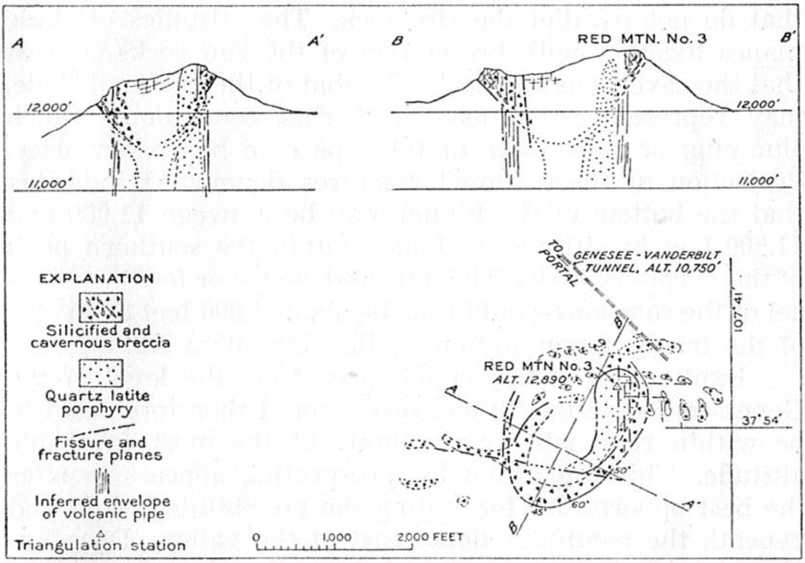

Figure 7.—Generalized geologic plan and inferred cross-section of the altered volcanic pipe on Red Mountain No. 3.

tized envelope of unbrecciated andesite, but the rim itself is composed of a silicified breccia identical in general character with that of the National Belle chimney. The fracture of sheeting planes striking parallel to this rim have dips either parallel to the inward dipping contact, vertical, or outward from the center at angles of 50 to 60 degrees. All these sets are recognizable in some places. In addition there are conjugate sets of steeply dipping fracture planes that do not parallel the rim rock. The attitudes of these planes together with brecciation of the rim rocks suggest that the cavernous rim rock, like that of the National Belle, may represent a funnel-shaped ring zone along which slumping or subsidence of the pipe core has taken place. Projection of these funnel fractures downward indicates that the bottom of the funnel may lie between 11,000 and 11,500 feet in altitude, and just within the southern hook of the porphyry body. This inferred center or feeding channel of the solutions would thus lie about 1,000 feet S. 45° W. of the triangulation station on Red Mountain No. 3.

Exploration of this center area from the level of the Genessee-Vanderbilt tunnel level would therefore seem to be within reasonably close limits of the most favorable altitude. This suggestion for prospecting appears to offer the best opportunity for testing the possibilities of ground beneath the mountain slopes east of the valley. Deep exploration in other areas east of the valley does not appear to offer as favorable opportunities, particularly with respect to the possible volume of ore-bearing ground; however, a favorable outcome of the suggested test beneath Red Mountain No. 3 might warrant further exploration beneath other silicified pipes of the district.

Exploration along the Red Mountain Valley belt has of course been more intense in the past and few if any of the more promising pipes have been overlooked. There are, however, a few smaller pipes in the district that have been only partly explored. Prospecting should be governed by the common structural forms of the pipes and relations of ore bodies to them as summarized above. If the theory of formation of the deposits is correct, then ore chimneys are not likely to be found in unaltered pipes, or beneath ground that has not been somewhat silicified and kaolinized. It does not follow, however, that the strongest silicified cappings of the ore chimneys should always crop out, for the bulk of the silica dissolved at depth may have been reprecipitated just above the ore body, although some channel or fractured zone providing means of egress of the spent solutions is essential and should be characterized by appreciable alteration.

TELLURIDE AND SNEFFELS DISTRICTS

General features

The Telluride and Sneffels districts, which occupy the high divide area between the San Miguel and Uncompahgre drainage basins, include the highly productive vein deposits of the northwest exterior sector of the Silverton caldera.

The structural features of this area are rather simple as compared with those of the Red Mountain district. Many of the vein fissures belong to the radial system of the main caldera, and to those connecting with the radial system of the Stony Mountain center. Some veins that follow dike walls are mineralized for horizontal stretches of 25,000 feet or more, though not retaining commercial grade throughout. The Smuggler-Union vein has been mined for about 8,000 feet horizontally and through a maximum vertical range of 2,300 feet.

Structure has had an obviously important control in the localization of the more productive belts of mineralization, but in the control of individual oreshoots the factors become increasingly complex and obscure. The larger more highly productive belts conform to definite parts of a radial zone of downwarping which may have taken place at the same time as the much more pronounced annular sag of the ring-fault belt. The oreshoots result from favorable openings produced by internal adjustments of blocks to this deformation.

Because of changes in composition of the ore-forming solutions with time, the timing of the fissuring was a critical factor in determining the grade of ore. This timing is expressed by compound structure[46] of the veins, which shows corresponding changes in composition or proportion of ore minerals in the different fissures opened successively. As first noted by Purington,[47] each part of a compound vein may be characterized by the recurrence of the common base-metal sulphides, but in different proportions and with varying differences in the gangue minerals. Commonly the relative bulk of the base-metal sulphides decreases in the material of each succeeding main stage. There are in general three main stages: the early quartz veins with base-metal sulphides, the gold- and silver-bearing quartz or quartz-carbonate veins, and the late relatively barren quartz and carbonate veins. The principal sulphides in all ore-bearing veins are pyrite, sphalerite, chalcopyrite, and galena. Enargite, so abundant in the Red Mountain ores, is absent in the vein deposits. The gangue minerals associated with quartz include sericite, ankerite, rhodochrosite, rhodonite, barite, calcite, fluorite, adularia, and kaolin or clay minerals. Adularia and kaolin are found only or chiefly in the gold-quartz stage of mineralization. Quartz and sericite are the principal alteration products in the vein walls, and epidote and chlorite are present locally, as in the deeper levels of the Camp Bird mine. The silver content of the veins is derived chiefly from argentiferous tetrahedrite, tennantite, and galena, although in veins lying farthest from the caldera the hypogene silver minerals also include pearceite, and possibly stephanite and argentite.[48]

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[46] Purington, C. W., Preliminary report on the mining industries of the Telluride quadrange, Colorado: U. S. Geol. Survey, 18th Ann. Rept., pt. 3, p. 799, 1898. Spurr, J. E., The Camp Bird compound veindike: Econ. Geol., vol. 20, no. 2, pp. 115-152, 1925. Hulin, C. D., Structural control of ore deposition: Econ. Geol., vol. 24, pp. 15-49, 1929. Burbank, W. S., Structural control of ore deposition in the Uncompahgre district, Ouray Co., Colo.: U. S. Geol. Survey Bull. 906-E, pp. 248-252, 1941.

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[47] Idem, p. 799.

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[48] Bastin, E. S., Silver enrichment in the San Juan Mountains, Colorado: U. S. Geol. Survey Bull. 735, pp. 65-129, 1923.

The areal zoning of the ores is complicated by the compound nature of the veins, but in general the complex base-metal ores predominate in the inner zones and silver-lead or silver-gold ores in the more distant zones. Barite is common in the silver-lead veins, although rare in the innermost base-metal ores, and appears in the Red Mountain chimneys. Gold-bearing quartz is found in all parts of the Telluride and Sneffels districts, but its concentration in the higher-grade shoots is erratic.

The continuity of the veins and gradations in mineralogy suggest a common source of the ore-forming solutions from depths beneath the caldera and beneath the axis of the dike swarm connecting it to the Stony Mountain and Mount Sneffels stocks. The most abrupt change in mineral composition of the ores occurs between the innermost vein deposits and the Red Mountain chimneys. Although this is suggestive of a difference in orgin of the solutions, the change may be related to depths of derivation or to pressures prevailing during mineralization. The gabbro-diorite of Stony Mountain and the dikes extending southeast to the caldera border are much older than the veins, whereas the quartz latite porphyry and rhyolite of the Red Mountain district may have been intruded just preceding mineralization. It may be inferred from these relations that the Red Mountain ores were derived from relatively shallow sources, whereas the outlying vein deposits were derived from increasingly deep magmatic sources, and that these changes in depth were most abrupt along the caldera walls. If so, iron, copper, and arsenic were concentrated especially in the shallower magmatic reservoirs and at lower pressures, although possibly at relatively high temperatures. On the other hand silver and lead appear in greatest relative abundance in ores derived from deeper sources. However, silver and lead appear in considerable local concentration in some chimneys of the Red Mountain sag or "basin" belt. It could be inferred either that these metals were here derived from greater depths during later stages of mineralization, or, that they were also concentrated at shallow depths but in lesser amounts. The absence of important concentrations of silver and lead in many chimney deposits just east of this narrow belt may have resulted from relatively low prevailing pressures and the consequent rapid cooling and crystallization of rocks, factors which sealed off the deeper sources and impoverished the later stages of mineralization. As Buddington,[49] Bowen,[50] and others have pointed out, time is an essential factor in controlling the differentiation of igneous rocks, the concentration of volatiles in them, and in "permitting residual volatiles to concentrate metallic elements."

Dike systems

The dike systems that radiate from the Red Mountain fault zone and the Stony Mountain center (pl. 1) form roughly a thick biconvex lens-shaped swarm. The average strike of the middle line is N. 45° W. Some dikes along the southwest edge of this swarm, such as those of the Ajax-Smuggler-Union and the Argentine-Montana groups, are strongly curved from N. 50° W. to N. 20° W. This results evidently from curvatures in the lines of stress produced by intrusion of certain radial dikes of the Stony Mountain and Mount Sneffels centers concurrent with the development of radial tension stresses about the caldera. On the other hand, the Columbia and Dynamo dikes, also along the southwest border of the swarm, exhibit comparatively little curvature. Along the opposite side of the swarm the dikes curve from a strike of N. 40° W. near Red Mountain to N. 60° or 65° W. near Stony Mountain.

The distribution of dikes within the swarm is not uniform. Near Stony Mountain the number increases markedly, indicating an affinity of the dike magmas with those of this gabbro-diorite stock. Across the widest part of the swarm a central belt 10,000 feet in width, which occupies

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[49] Buddington, A. F., Correlation of kinds of igneous rocks with kinds of mineralization: Am. Inst. Min. Met. Eng., Lindgren Volume, pp. 356-357, 1933.

[50] Bowen, N. L., The broader story of magmatic differentiation briefly told: (Lindgren Volume), pp. 115-118, 1935.

parts of Imogene and Savage Basins, contains few if any dikes exposed at the surface. In mine workings, however, a few narrow dikes are found in some fissures of this central belt, and consequently at still greater depths the number and sizes of the dikes may be expected to increase correspondingly.

The dips of the dike-filled fissures, in connection with their distribution at the surface, suggest that they are tension fissures produced by slight warping of the crust. In general the dikes of the southwest half of the swarm dip southwest, whereas those of the northeast half dip steeply northeast (pl. 2, sect. A-A′). As will be shown later, the ore-bearing fissures are rather definitely related to a slight and intermittent downwarping of the crust. The conclusion is reached, therefore, that at least some of the radial dike systems of the caldera result from downwarping rather than upbowing of the crust. This interpretation differs from one originally suggested by the author,[51] but it does not invalidate the general interpretation of structural disturbances around the caldera, except to the extent that differential forces acting upon rock bodies near the caldera might result from inwardly directed (centripetal) rather than outwardly directed pressures.

The dikes are mostly andesites, but some are of rhyolitic composition. There are two broad textural groups of andesitic dikes, those of notably porphyritic texture and those of finer more even texture, either microscopically porphyritic or amygdular. The age relations do not altogether conform to textural features, and some other factor such as composition may have more significance. The rhyolite dikes are clearly late. They center around Stony Mountain, and also farther southeast along the fault boundary west of Red Mountain. Special examples of rhyolite injections are those of the Wheel of Fortune fissure, which is intruded by both andesite and rhyolite dikes, as well as clastic dikes. The rhyolite of this dike is pre-ore, but one

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[51] Vein systems in Arrastre Basin: Colo. Sci. Soc. Proc., vol. 13, no. 5, pp. 181, 183, 184, and 187, 1933.

that crosses the Black Bear vein east of the mine shaft is said to be post-ore. A rhyolite dike encountered on the fourteenth level of the Camp Bird mine is offset by the vein fissure and is pre-ore.

Faulting and fissuring

The vein fissuring as well as most faulting along the dike walls is later than dike injection, although it has not been possible to determine whether the generally small displacements are entirely post-dike. As in Arrastre Basin[52] the fissure systems are of two general classes, those that follow preexisting fractures, such as the walls of dikes, and those that do not but were produced by forces acting in more nearly continuous bodies of rock. In both classes of fissures the slight displacements ranging from a few feet to a few tens of feet are generally along normal faults, with the downthrow to either side of the axial line of the dike swarm.

As shown by fault striations in some places and by the offsetting of some cross-structures, there was a component of horizontal movement along many fault fissures. This is particularly strong in fissures such as the Camp Bird that lie at a considerable angle to the general trend of the dike and fissure swarm. There is no general rule that will account for the directions of these horizontal offsets, and hence it appears likely that they result from purely local adjustments of fault blocks to the regional deformation.

The veins show ample evidence that they were enlarged periodically by renewed openings and offsets of cross-structures; hence faulting, though slight, continued at least to the end of vein formation, and to a slight extent thereafter. No large post-ore faults have come to the author's attention.

Succession of structural events

The succession of structural events is too complex and obscure to be determined with absolute assurance. If, as

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[52] Op. cit., pp. 184, 185.

appears very likely, faulting and fissuring were continuous though periodic processes from the formation of the first dike or fault to the last postmineral slip, the movements of individual fault blocks became more complex with continued deformation. On theoretical grounds each new block outlined during one stage of fracturing established a new control over subsequent stages, and the more numerous the stages, the more difficult it is to assign single fractures to any particular stage. It is clear, however, that the deposition of the high-grade ores took place fairly late in the sequence of fracturing, and therefore was governed by the accessibility of fractures formed or reopened during several stages. A succession of selected events may therefore be stated with some assurance, though with reservations as to its usefulness.

This succession beginning with the dike injections is as follows:

(1) Intrusion of the few "spiral" dikes or cone sheets related to the main caldera and the outlying intrusive centers.

(2) Intrusion of the curved andesitic dikes that join the Stony Mountain stock to the margin of the main caldera. This represents the probable initiation of the radial downwarping of the Sneffels axis.

(3) Intrusion of straight radial dikes of the Mount Sneffels-Stony Mountain center, followed perhaps by straight andesitic dikes and fissures of the main center. These straight radial dikes may indicate that early torsional stresses developed between the outlying and main centers had been relieved.

(4) Intrusion of rhyolite dikes along parts of the dike swarm. These evidently represent the initiation of a broader northwesterly axis of sagging, which controlled subsequent fissuring.

(5) Development of the Sneffels axis of sagging along a straight N. 45° W. belt about 6 miles in width. Mineralization began approximately at this time. The succession of ore-bearing fissures resulted from subordinate stresses

that were induced by this sagging. The different stages of vein deposition have been enumerated and briefly discussed elsewhere.[53]

Some of these events may be discussed at length in a later report, but emphasis will be placed now upon features bearing more particularly on localization of the vein deposits.

The succession in age relations of the different dike systems, (1) to (4), is based solely upon relative ages of the dikes, and of course does not apply to later fissuring that followed the different dike walls during period (5). A special example of this limitation is the Camp Bird fissure vein, which has been commonly interpreted as one of the latest veins of the district. In the Camp Bird mine, however, this vein is compound and contains ore shoots of base-metal sulphides that correspond in age to the earliest vein stages, represented mainly by northwesterly veins,[54] whereas its large shoots of gold ore, introduced at a late stage of reopening, show that later movements along this vein were more pronounced than along many northwesterly veins. Further evidence of these later movements is presented by the fact that the Smuggler and a number of other veins are offset where they are crossed by the Camp Bird vein. The Camp Bird probably represents an old line of weakness, contemporaneous in origin with the cone or spiral fractures. This belief is not based solely upon the form of the fissure or upon the vein stages mentioned, but also upon the existence of a dike that strikes N. 85° E. in line with the Camp Bird vein northeast of Telluride (see pl. 1). The exact alinement of this dike with the main westerly trend of the Camp Bird fissure farther east appears to offer adequate evidence that the two are related in origin. This dike, furthermore, is older than the straight northwesterly Dynamo dike, which cuts it about 2,000 feet northwest of the Bullion tunnel of the Smuggler-Union mine.

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[53] Burbank, W. S., Structural control of ore deposition, Uncompahgre district, Ouray County, Colo.: U. S. Geol. Survey Bull. 906-E, pp. 244-252, 1941.

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The Sneffels axis of sagging

Probably the most critical structural feature of all is the radial axis of sagging, which coincides approximately with the northwesterly axis of the dike swarm. This will be called the Sneffels axis of sagging. The center line extends northwestward from about the position of the Camp Bird mine (section B-B′, pl. 2) and continues approximately through the Stony Mountain and Mount Sneffels intrusive stocks. The approximate magnitude of this downwarp is shown by altitudes along the lower boundary of the Silverton volcanic series (Sections A-A′ and B-B′, pl. 2). The axis of the sag may lie a little northeast of the axis of the radial dike swarm, but the sag is unsymmetrical and the tilts are greater along the southwest than along the northeast side of the swarm. At the southwest the tilting of the Silverton flows is from two or four degrees, whereas at the northeast it averages between one and two degrees. Although in individual blocks the tilt on either border may exceed these amounts, the general effect is so slight as to be unnoticeable except on reasonably detailed areal maps. The total depth of the sagging is from 200 to 500 feet across a span of about 6 miles. This corresponds to an even tilt of 1° 48′ on each side of the trough. Actually the tilts of nearly all individual blocks exceed this amount except in the bottom of the sag. This results in part from concentration of the tilt along the sides of the sag, and in part from the inward rotation of individual blocks, as will be illustrated below.

In order to show that this sagging of the basal member of the Silverton volcanic series is probably late and not an expression of an old topography, it may be pointed out that the rhyolitic and latitic members of the Picayune volcanic group, which averages about 150 feet in thickness, extend nearly across this structure, and comprise a number of very thin flows that must have been so fluid that they would have been confined to the very bottom of the sag if the structure had been of pre-Picayune age. There is insufficient information from which to choose a datum plane younger than the Picayune.

The latest epoch of sagging along the Sneffels axis probably extended from the time of intrusion of the rhyolite dikes to the end of the period of mineralization. It may be supposed to coincide in time of development with the sag of Red Mountain Valley, but there appears to be little definite evidence in support of this supposition. It is true, however, that the belt of strong alteration along the Red Mountain sag widens at its intersection with the Sneffels axis.

By relating the structure of the veins to this sagging, it may be inferred either that the development of the sag was an intermittent or periodic process, or, that the forces accumulated gradually and were relieved by periodic fracturing and adjustments of fault blocks.

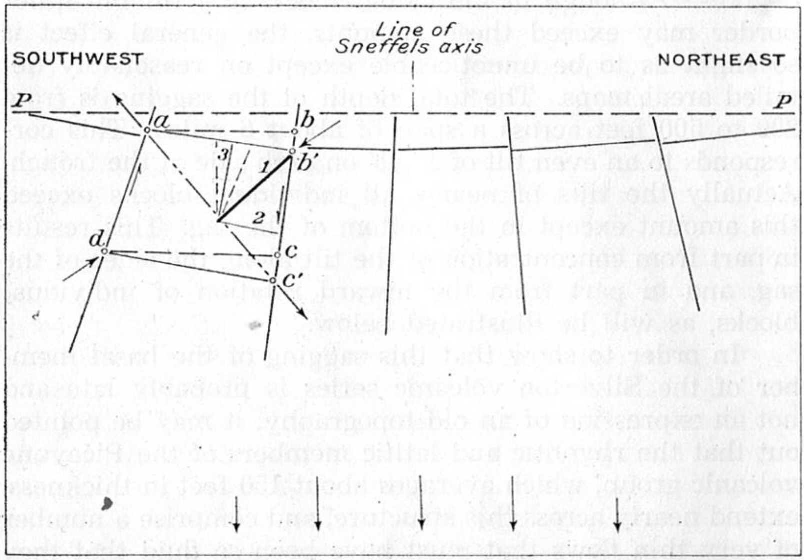

Figure 8.—Diagrammatic section across the Sneffels axis of sagging. The forces acting during the tilting of the blocks, and the principal types of fissuring are shown.