Nature of deformation across axis of sagging

The inferred nature of the deformation is shown in figure 8, a generalized section at right angles to the axis of the sag. The tilts of the formations and displacements of the blocks are very much exaggerated to clarify the diagram. The broken line P-P′ represents a nearly horizontal datum plane, such as the base of the Silverton volcanic series prior to deformation; the slightly inclined solid lines the attitudes of beds after deformation; and the steep lines the radial dikes of the Sneffels axis.

The diagnostic feature of the sag structure is the tendency for the faults to dip outward toward the borders of the sag, and for each succeeding block to be downthrown slightly outward from the main synclinal axis. This is the reverse of ordinary step-fault structure, such as that of the caldera walls, but is exhibited in a very pronounced fashion by the tilted blocks of the Red Mountain sag (section B′-B″, pl. 2, and fig. 3).

Blocks included between the older dike fracture planes are subjected to a distortion or distorting force during sagging; thus the block "abcd" is tilted and distorted to the shape "ab'c'd." This lengthens the diagonal axis of the block from ac to ac′, whereas the other diagonal is shortened to db′. The block is thus subjected to a rotational shearing strain, and the arrows at the four corners show the directions of maximum compression and tension. The result is essentially the same as that inferred with respect to the rotated blocks of Arrastre Basin,[55] except that these latter blocks were rotated mainly about a vertical rather than a horizontal axis.

Tensional cross-fractures tend to develop in the deforming blocks in the approximate direction shown by the heavy line (1), and shear fractures as shown by the lighter lines (2) and (3). The more highly tilted blocks at the outer part of the sag will have a tendency to yield by tension breaks that dip at relatively low angles such as (1),

[55] Op. cit., pp. 196-200, and fig. 2.

but near the axis of sagging there is insufficient tilt to develop these and the blocks will break along steeper fissures or partings already established.

The unsymmetrical features of the actual sag and the steeper border tilts tended to localize strongest deformation in certain belts parallel to the Sneffels axis. It is apparent from the figure that if the sag were exactly symmetrical, two belts of strongest tensional fracturing would develop, one along either border. Actually the strongest deformation occurred along the southwest border of the sag and formed a belt of sheeting and tensional fissuring one to two miles in width that extended from the edge of the caldera near the Black Bear and Tomboy mines at the southeast to and beyond the Liberty Bell and Virginius mines at the northwest. Within this belt lie the largest number of the so-called "flat veins" in the district. The "flat veins" do not all approach the ideal dips of tensional fracturing, for there is a tendency in actual deformation for the fissures to step from a lower-angle dip (1) to one of the steeper fractures of set (3) (fig. 8). The dips of fissures that may be arbitrarily considered as members of this class range from 50 to 65 degrees, but the fissures may steepen upward and even reverse their dip. The Smuggler "Flat" vein and the Liberty Bell vein, both at the northwest end of the belt, may be considered the closest approach to an ideal fracture of this class (pl. 2, section A-A′).

Because the Sneffels belt of sagging developed late in the structural sequence, its structures are alined diagonally to the curved dike and fissure systems. Furthermore, because of the strength of the older fissures, the younger flat tension fissures did not cross many of the older ones but terminated against them. This effect is shown most strikingly by the relations of the Tomboy, Japan, Virginius, Smuggler "Flat," Humboldt, and Liberty Bell veins to the Argentine-Montana and Smuggler-Union dikes and veins. In line with many of these "flat" veins there are zones of shearing or nearly vertical sheeting in the San Juan tuff. In places these zones extend across the older fissures and dikes. These suggest that during the accumulating strain, the rocks first parted along the steeper shear fractures but, as rotation of the blocks could not be fully compensated in this manner without closely spaced sheeting entirely across them, the accumulated strain finally resulted in supplementary breaks of tensional nature. This is of considerable significance in reference to spacing of the fissures.

The relative age of some sheeting zones is shown by the fact that pyritization and rock alteration is usually strong along them, whereas "flat" veins in the same zone contain principally minerals of later stages of mineralization that were accompanied by weaker alteration. The effects of timing of the "flat" tension break on local vein mineralogy will be considered further in connection with the spacing of fissures.

Theory of spacing of fissures

The origin of the "flat" veins and associated steeper fractures according to the theory of rotational shearing involves certain limitations to the maximum spacing of the rotating blocks. As shown by the vein systems of Arrastre Basin,[56] if the sides of blocks stressed by rotational shear were widely spaced the cross fissures were likewise widely spaced, whereas if the blocks were narrow the cross-fractures were correspondingly closer spaced. As the blocks in the Arrastre Basin have rotated mainly about a vertical axis, their horizontal dimensions are evident, but, as those of the Telluride and Sneffels districts have rotated about a nearly horizontal axis, there is no exposed or obvious limitation to the vertical dimensions of the blocks or to the depths at which the tensional fractures may have formed.

According to Becker's[57] partial theory of spacing (fig. 9, A), the blocks would be of such dimensions that they may rotate to afford relief of stress with the least expenditure of energy. This condition is ideally met, as shown

[56]Op. cit., pp. 207-209.

[57]Becker, G. F., Finite homogenous strain, flow and rupture of rocks: Geol. Soc. Amer. Bull., vol. 4, pp. 57-68, 1893.

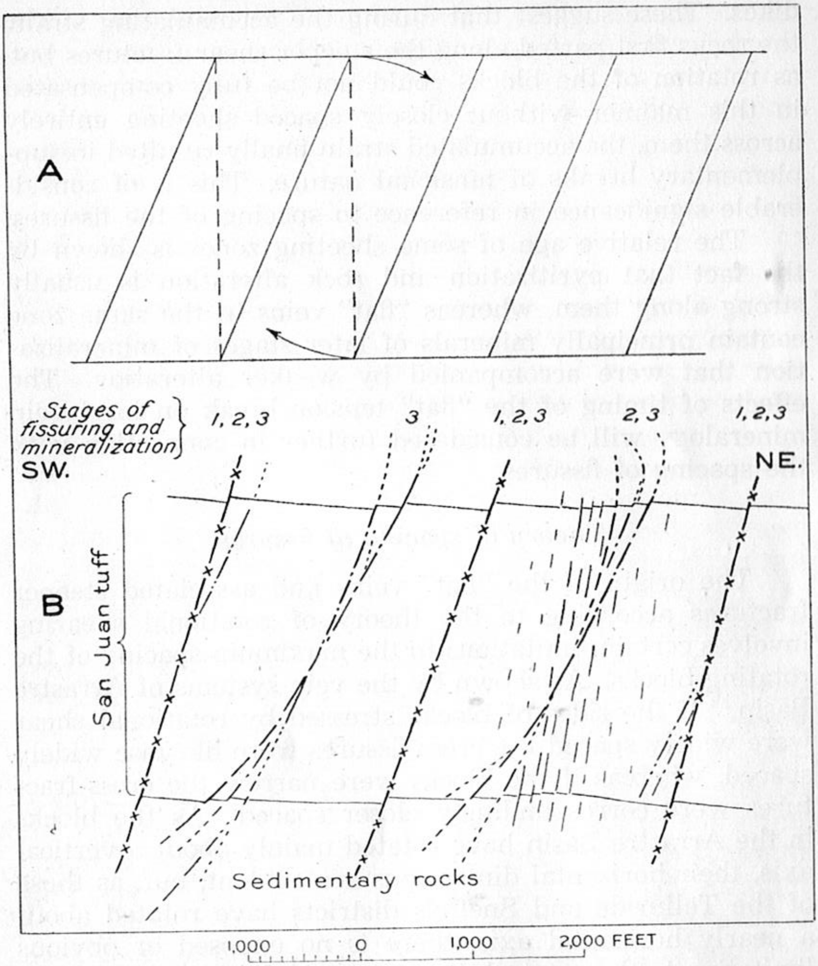

Figure 9.—Diagrammatic illustration of the theory of spacing of fissures. A. Maximum spacing of fissures under rotational strain to permit relief with least expenditure of energy. B. Diagramatic relations of fissuring in the Telluride district. Fissures with crosses are along the oldest fissures occupied by dikes. Other lines represent tension fissures ("flat veins") which would be opened during following stages (2 and 3) of rotation of blocks.

by the figure, when their width is such that the blocks overlap with their corners in a vertical line. Each block may then rotate without extending the vertical dimensions of the space occupied. If the spacing of the inclined fissures is greater than this maximum, then the rotating blocks must lift the cover. If the cover were not very heavy this could actually happen, but it may be inferred that the cover was not actually lifted very much in the Telluride and Sneffels districts. The initial sheeting of the blocks noted above may represent a counter-deformation produced by a slight lifting of the cover, but in order to evaluate this possibility the dimensions of the rotating blocks must be more closely defined.

By reference to the cross sections of the districts it would seem unlikely that an entire block of the shallower crust, some 8,000 feet in thickness to the base of the sedimentary rocks, could deform as a unit under rotational strains. Such a block is not a unit in its physical properties, but is divided into a number of parts by horizontal planes of stratification.

Among the weakest of the stratified layers are those which bound the massive or competent formations at their contacts with much weaker ones, as represented by the softer sedimentary rocks or the rhyolitic members of the volcanic formations. Knowledge of the general physical properties of the different rock formations leads to the inference that the San Juan tuff is by far the most massive, uniform, and competent of the volcanic rocks, excluding, however, the local thick bodies of massive latites in the Picayune group. The stratification of the tuff-breccia composing the San Juan tuff is too imperfectly formed and the clastic materials composing the rock sufficiently bonded so that slippage parallel to its own coarse layering becomes a negligible factor in the reaction of the formation as a whole to strains. This is bounded below by a comparatively thin layer of Telluride conglomerate, which in turn rests directly at many places upon soft shales and thin-bedded sandstones of the Mesozoic formations. The underlying beds of the Cutler and Hermosa formations are thus separated from the San Juan tuff by a relatively continuous and incompetent layer of beds ranging from several hundred to a thousand feet in thickness (table 1).

From these considerations it may be concluded that the tuff and any part of the underlying formations of equal competency could not undergo simple rotational deformation as a unit if any appreciable strain was generated parallel to the stratification of the rocks. One direction of maximum shearing strain as shown in figure 8 is nearly horizontal and hence parallel to these planes of stratification. Accordingly, a tendency would arise as the blocks rotated for dividing planes of shear to form within the most prominent of the weakly bonded layers that bound the main block of the San Juan tuff. Such layers lie either at the base of the tuff or of the Telluride conglomerate, and also above the tuff (fig. 9, B) at or near the relatively incompetent rhyolitic and latitic flows and breccias of the Picayune volcanic group, or in places near the base of the Potosi volcanic series. Therefore the competent blocks of tuff-breccia subjected to uniform rotational strain under the conditions of sagging had a thickness ranging from 2,200 to 2,700 feet, according to local thicknesses and minor variations in the weakness of the horizontal dividing layers in different parts of the districts.

The pre-Cambrian basement within which presumably the primary bending of the crust originated is separated from the San Juan tuff block by alternate layers of competent and incompetent sedimentary beds aggregating more than 3,000 feet in thickness. Hence minor faulting and fracturing of the basement rocks, as must have affected them during sagging, would be damped by these intervening layers, and the reaction of the San Juan block to bending strains would thus be governed mainly by its own competency and the effects of pre existing fractures in it.

On the assumption of average thicknesses cited and average dips of the tension fissures between 50 and 60 degrees, these fissures according to Becker's theory should be spaced from 1,000 to 1,500 feet apart. In general this deduced spacing of the fissures is in close agreement with that observed in most parts of the Telluride and Sneffels districts.

As an example, the belt of rocks southwest of the Smuggler "Flat" vein for a width of 6,000 feet comprises roughly four blocks bounded by veins, sheeted zones, and dikes that strike N. 40-45° W. The transverse Smuggler-Union dike and vein may be neglected in considering this spacing. The N. 45° W. fractures are represented by the Smuggler "Flat" vein, the Liberty Bell and Caruthers, the Dynamo vein and dike (a preexisting break), the northwesterly zone of fissuring and sheeting through the Valley View, and another zone about 1,500 feet farther southwest, which comprises a number of small, weakly mineralized steep fissures containing mainly late calcite. Fractures in this zone are closely spaced and prominent, as seen on the ground, and may be followed northwestward for more than 8,000 feet from the place where they cross Marshall Creek. As the fissures contain only late barren gangue for the most part, this zone was formed late in the stages of deformation and mineralization, and hence a productive "flat" vein is not to be expected within it. The Valley View zone and its extension to the northwest, as well as the Dynamo vein, contain veins of late-stage quartz with only local pockets of high-grade gold ore. The next important "flat" veins to the northeast are the Liberty Bell and Caruthers, splits of the same zone, and these contain silver-gold ores associated with much carbonate and quartz gangue. The Smuggler "Flat" vein contains a greater proportion of silver-lead sulphide ore as well as gold-bearing quartz, and mineralogically is the oldest of the veins. This succession indicates that the belt of fissuring widened southwestward as the degree of deformation and sagging increased, and as the composition of the vein solutions changed in the interim.

Another example is the belt between the St. Paul and the Ajax veins extending northwesterly across Savage Basin near the Tomboy mine. Its total width is 8,400 feet.

At the end of the period of dike formation this belt was divided into 3 or 4 blocks separated by prominent dike-filled fractures. It is now divided into 8 blocks, whose average width is 1,050 feet. The veins include from north-east to southwest, the St. Paul, the Coronado, an unnamed sheeted zone 1,000 to 1,500 feet farther southwest, the Tom-boy, Japan, Argentine, Columbia, Alamo, and Ajax veins. The average dips of the veins are somewhat steeper in this entire belt than in the one just described. The spacing corresponds closely to the theoretical figure. The earlier or dike-filled fissures nearly all contain early base-metal ores, though some contain later gold-bearing quartz as well.

The timing of the fissuring relative to the stages of mineralization is especially well illustrated by the large original block included between the Columbia and the Ajax dikes. This block was about 2,200 feet across at its widest part, and was later split into two blocks by the formation of the post-dike Alamo vein fissure, which dips from 50 to 75 degrees southwest. Although the preexisting dike fissures on either side of the Alamo contain early base-metal ore, the Alamo vein is filled entirely with late stage barren or low-grade quartz, and hence has been unproductive (compare with left side of fig. 9, B). The Columbia vein to the northeast contains small bodies of gold-bearing quartz of the second stage as well as base-metal ore of the first stage. The Ajax vein is composed mainly of base-metal ore, but at the widest parts of the block it might be inferred that later gold-bearing quartz would have been introduced. Where cut by the Meldrum tunnel near this position there is a late filling of quartz of the gold stage alongside the base-metal ore, but the grade of the quartz is evidently low either because of depth, or effects of the small channel in which is was deposited. The Argentine vein to the northeast of the Columbia follows a dike fissure and was well mineralized at several stages; hence renewed fissuring took place along it throughout the period of ore formation. The Tomboy and Japan veins both lie in parallel sheeted zones, but in steplike relationship. These "flat" fissures were evidently formed at an intermediate stage as they contain mainly gold-bearing quartz with adularia. The Tomboy sheeted zone is also occupied by an eastward dipping vein of pyritic ore, but this fissure did not relieve the increasing rotational stresses completely, and in later stages of mineralization the southwest-dipping Tomboy fissure was formed. The steplike relationship of the Tomboy and Japan veins suggests that relief of stress was divided longitudinally along these blocks between the parallel zones of sheeting. It could be inferred that another flat vein should have formed somewhat to the southeast of and overlapping the Tomboy, and along the parallel zone of sheeting to the southwest; however, a crosscut from the Black Bear mine to this zone failed to encounter any promising mineral occurrence at a position still farther southeast (pl. 1).

These examples are sufficient to indicate that Becker's theory of spacing of fissures may have some practical application in the search for hidden or obscure veins produced by tensional fracturing of the blocks, but the very late Alamo fissure proves that not every theoretically required position for a fracture will be occupied by a productive vein. Furthermore, the rotational strain may have been so largely relieved locally by the close spacing of more steeply dipping fractures that tensional rupture, when it finally occurred, may have been dispersed into a number of closely spaced small fractures that would be unfavorable for commercial concentrations of ore. There are also some other factors to be considered, which will be discussed briefly in the following section.

Interrelations of fissuring and mineralization to the different classes and trends of fissures

The foregoing section has dealt particularly with relations of fissuring between nearly parallel veins, without taking into account the presence of diagonally trending older fissures, and problems relating to the distribution of mineralizing solutions and their means of access to the fissures of different stages.

As the theory of division of the originally wide blocks separated by dikes presupposes that the rotationally strained blocks were bounded above and below by weak layers (fig. 9, B), it may be supposed that the later tension fissures were likewise bounded by these same layers, and hence would not directly tap the feeding channels of mineralizing solutions. Actually the ore in some "flat" veins is so distributed with respect to the older and steeper fissures along dikes as to indicate that the trunk feeding channels lay near or within the older fissures.

The way in which the solutions gained access to the younger fissures may be inferred, in part from observations of exposed structural features, and, in part from general considerations of rock failure under accumulating stresses. A comparison may be made between figures 8 and 9, and figure 3. The "antithetic" faults, cd, of figure 3 correspond to the tensional or "flat" fractures of figures 8 and 9; whereas, with the possible exception of east-dipping veins like the pyritic vein of the Tomboy, the "synthetic" faults, ab, are not commonly represented by actual low-angle faults across the Sneffels axis, but correspond structurally to the weakly bonded stratification planes in rocks below the base of the San Juan tuff. Hence this comparison would lead one to surmise that the "flat" tensional fissures of the Sneffels axis die out somewhere along the stratification of the sedimentary rocks and at some position not very far beneath the base of the San Juan tuff.

Under favorable conditions, however, the younger tensional fissures may doubtless extend for some depth below the base of the tuff with at least sufficient strength to permit the formation of local, if narrow, feeding channels. The forces that cause the final rupture of blocks may accumulate gradually, and in some places slowly enough to permit the development of sheeted zones; but the shock attendant upon the final rupture is vibratory in nature, and will in some degree be transmitted across the less elastic or "plastic" layers that bound the San Juan tuff above and below. As shown diagrammatically in figure 9, B, and as seen in cross-sections of veins (sections A-A′ and B-B′, pl. 2), the "flat" vein fissures actually extend upward into the rhyolites and latites above the San Juan tuff and commonly steepen in these higher formations. Their extensions are branching and some are strongly curved, as shown especially well by the "Flat" vein of the Smuggler-Union mine. To produce this effect the vibratory strains transmitted upward are relieved by the fracturing of a comparatively light cover of rocks, but on the other hand strains transmitted downward below the base of the tuff would be under much greater restraining pressures. Rupture much below the base of the tuff might not occur along some fissures, but, at places where an earlier parallel or diagonal fracture lies close by in the hanging wall of the tension fracture, the rupture might be expected to extend downward in a curve to join this older fracture plane. In general, such an extended fracture would dip at a smaller angle than the main tensional break, because strain could thus be relieved with the least expenditure of fissuring energy. The older fracture plane may be considered to bear essentially the same relation to the bottom part of the tension break, as the land surface does to the upper end of the break. We may conclude, therefore, that under the particular structural conditions existing in the district, the tension breaks in depth will tend to decrease in dip and in places may even die out along the stratification planes of rocks beneath the volcanic formations; whereas upward they will tend to steepen.

These conclusions are to some extent borne out by a number of veins that have been sufficiently explored to afford evidence; thus, the Smuggler "Flat" vein joins the main vein at places by a curved break of gentle dip, though it may also join by steeper nearly parallel breaks. The dips of the Virginius and the old Tomboy veins both decrease with depth even at some distance above the base of the San Juan tuff. The dip of the Alamo vein decreases perceptibly in depth near its northern extremity where it lies close to the footwall of the Ajax vein, and consequently the Alamo vein must intersect the Ajax vein within a depth of 400 or 500 feet. This intersection would lie near the base of the San Juan tuff. At higher altitudes toward the southeast, however, the differences in dips of the two veins are insufficient to permit of this interpretation, and either the dip of the Ajax vein must decrease in depth, or the fissuring must have penetrated beneath the base of the tuff for some distance in order to intersect a trunk channel.

The trend of an older fracture diagonally across the strikes of "flat" tension fissures is illustrated by the relation of the main Smuggler-Union vein to the Liberty Bell and Smuggler "Flat" veins. Here it is to be expected that the productive parts of the gently dipping breaks will extend deeper where they are close to the reopened feeding channels of the Smuggler-Union vein. Although exploration has not yet proved the extent of this difference it supports the expectation, for work on the Smuggler-Union and "Flat" veins near their intersection has encountered strongly mineralized ground well down into the conglomerate. This condition may be expected to extend even deeper if beds favorable to open fissuring are found beneath the conglomerate. Near the Stillwell tunnel some distance northwest of the Smuggler-Union, the Liberty Bell fissure where it enters the Telluride conglomerate is choked with mud or gouge and scarcely mineralized. Closer to the Smuggler-Union the Caruthers vein, a split of the Liberty Bell zone, was mined below the average depth of the Liberty Bell, but the conditions found are not entirely familiar to the writer.

According to these interpretations the earlier fissures must be the main or trunk feeding channels from below, although it is a common experience in the district to find that the "flat" tensional breaks contain ores of higher grade, or at least the more uniform ore bodies. This contrast results from the choking of older channels by gougy slip planes, and the "short-circuiting" of the later solutions toward the surface along the newer and cleaner tensional openings. The walls of an older feeding fissure have been subjected commonly to strong alteration (sericitization) that typically accompanies introduction of the early base-metal ore. During vibratory faulting movements the softened walls of the old fissure may be converted to gouge, which, if appreciable deformation results, may be spread across parts of the channel along diagonal breaks. Wherever a new fissure happens to intersect the older one, it will divert most of the mineralizing solutions; consequently, each fissure will ideally contain a larger proportion of ore minerals belonging to the stage during which it was first opened, whether two or three repeated ruptures occurred. This principle is illustrated in many veins of the district but with some special exceptions.

The principle is well illustrated by older fissures of the base-metal stage that contain by contrast only the narrow and discontinuous bodies of ore minerals and quartz that were formed during the later stages. Where this same late quartz fills fissures of late age it forms very massive and uniform veins. The somewhat different appearance of the late quartz in the fissures of several ages may lead one to think that the quartz veins are not equivalent in stage of development; but it seems likely that the greenish material that colors and accompanies the narrow bands of late quartz along old vein walls results from the partial replacement and recrystallization of sericitic gouge through reaction with vein solutions.

The subject of the appearance and composition of the veins on the Sneffels and Telluride districts will be treated more fully in the final report, but is beyond the scope of this paper.

Factors Controlling Ore Deposition and Their Application to Prospecting

Relation between wall rock control and regional structure

The problems of wall rock control of ore deposition in the San Juan Mountains have been discussed in many publications and private reports by geologists and mining engineers. The published discussions of this subject[58] need not be reviewed in this report; however, some emphasis on the relation between wall rock control and regional structure will bring attention to a somewhat neglected phase of the subject. Applications of wall rock control based upon a local determination of the "most favorable altitude" of ore deposition, which is projected far and wide as a basis of exploration, are not sound in principle. The partial success of this method is due to the uniformity of rock formations and structural conditions over large areas of this region. Nevertheless, the method takes little account of critical physical-chemical factors involved, and tends to restrict prospecting to long drifts without support of adequate vertical work.

The relationship between regional structure and rock deformation has to do primarily with the spacial relations and origins of the deforming forces and the localization of strains in rock units. The character of the initial fracturing in a rock mass is controlled not only by the physical properties of the particular mass, but also by its relative competence in the structural environment, by the localization of strains that cause final rupture, by the rate of application of the deforming forces, and many other factors. Some special features of these complex interrelationships may be illustrated by analyzing factors involved in the fissuring of the rock formations of the Telluride and Sneffels districts. The San Juan tuff is by far the most productive formation, the Potosi volcanic series essentially unproductive, and the sedimentary rocks beneath the tuff intermediate in productiveness, although mining development on veins in sedimentary rocks beneath the more productive areas is inadequate for direct comparison.

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[58]Purington, C. W., op. cit., pp. 774-776, 1898. ———, Ore horizons in the veins of the San Juan Mountains, Colo.: Econ. Geol., vol. 1, pp. 129-133, 1905. Ransome, F. L., op. cit., pp. 53-55, 1901. Spurr, J. E., The Camp Bird compound vein-dike: Econ. Geol., vol. 20, pp. 126-137, 1925. Moehlman, R. S., Ore deposition south of Ouray: Econ. Geol., vol.31, pp. 389-302, 1936. Burbank, W. S., Vein systems of Arrastre Basin and regional geologic structure of the Silverton and Telluride quadrangles, Colo.: Colo. Sci. Soc. Proc., vol. 13, no. 5, pp. 200-212, 1933.

From the basic data of production in these districts one might conclude that quartz latites and rhyolites in general are unfavorable rocks for ore deposition; however, the prospector would be at loss in another district, for example, the Creede district[59] of the San Juan region, where silver-lead veins are found mainly in rocks of the Potosi volcanic series. Hence the chemical and physical properties of quartz latite and rhyolite can hardly be the dominant control, even though under certain conditions they may constitute an unfavorable balance of control. At Creede the main veins are along strong faults that involved thick bodies of the crust, and the structural factors that controlled the faulting were distinctly different from those that controlled fissuring in the Telluride and Sneffels districts. Faulting along the veins in these districts was of minor degree, and the openings in which oreshoots were localized resulted from successive minor adjustments of shallow rock masses to sagging along a northwesterly rift zone. This sagging failed to attain the fully developed graben structure of the Creede rift, or of that shown by the northeast-trending rift in the Treasure Mountain area of the Silverton caldera.[60] The Sneffels zone of sagging, because of its structural setting in comparison with these graben structures, may be interpreted to represent an initial stage in the development of a graben (pl. 1, inset map).

Under conditions of incipient deformation the massive uniform body of the San Juan tuff was probably the main storage reservoir of fissuring energy produced by downbending of the shallower rock formations. By comparison with the tuff neither the Potosi volcanic series above it nor the sedimentary rocks beneath would be resilient enough to store equal energy in the form of strain. The conditions are comparable to those of a slab of resilient material embedded between layers of stiff mud, the whole

[59] Emmons, W. H., and Larsen, E. S., Geology and ore deposits of the Creede district, Colo.: U. S. Geol. Survey Bull. 718, pp. 85-97, 1923.

[60] Burbank, W. S., op. cit., pp. 166-167.

being subjected to bending under its own weight. Very little energy would be stored in the mud, but that stored in the slab would be partly released when the stress exceeded the elastic limit and rupture occurred. The released energy would fissure material in contact with the slab, but, away from the contact the forces would become dispersed in the plastic material. If the system were supported below, major faults could form only where some major plane of weakness in the supporting basement was activated at the time of rupture.

In the Telluride and Sneffels districts continuity between the shallower fissuring and such faulting as occurred in the pre-Cambrian basement existed mainly along the older dikes and fault fissures. Some faults that must extend deep into the basement extend upward into the rhyolite. These are found mainly near the border of the caldera, or around intrusive stocks such as that of Stony Mountain. The older dikes commonly split and assume curved and irregular forms in the rhyolite. During later stages of deformation, when the oreshoots were localized, the rocks of the Potosi volcanic series were but feebly fissured though widely fractured and jointed. The minor ore-bearing fissures originated evidently from forces applied mainly at the lower contact of the formation with flows of the Silverton volcanic series, which together with the San Juan tuff had accumulated strains during deformation. At most times, therefore, the rhyolite was protected from severe strains by the alternations of rocks between it and the basement. Until deformation had reached correspondingly more advanced stages of graben formation, as at Creede, the flows of the Potosi volcanic series could not have been fissured adequately to localize ore deposits.

From these regional comparisons it may be concluded that degrees of favorability may not be assigned to rock formations irrespective of their structural environment.

The effects of the Potosi rocks on ore deposition are perhaps not confined to such negative results as are caused by their poor fissuring. This formation to a depth of 1,500 feet or more formed the surface rocks of the volcanic plateau beneath which ore deposition took place. The porous breccias and flows were doubtless saturated in places with meteoric waters. The porous blanket effect thus produced by the Potosi volcanic series is described later under temperature and pressure controls of ore deposition, and may have been an important factor in localizing rich bodies of ore in the immediately underlying parts of some fissures.

Intrusive stocks are only minor factors in the structural control of mineralization in these districts. As might be expected, however, the Stony Mountain stock has had a noticeable but local effect upon fissuring and ore deposition. The control on ore deposition is mainly if not entirely structural because the later-stage gold and silver ores that were deposited close to and at some distance from the stock show no differences that can be attributed to temperature. The numerous radial dikes about the stock tend to cause splitting and deflection of later fissures. Veins within the stock are commonly narrow and irregular in strike and have not been very productive. The more productive gold and silver veins near Stony Mountain lie along the outer edge of the intrusive body, as represented by the Yankee Boy, Trust Ruby, Circassian, and Governor. The northwest-trending veins along either side dip steeply inward toward the intrusive mass, as though they may have been formed by a general settling of the surrounding rocks about the more rigid buttress of the stock.

Kinds of fissures

The two main kinds of fissures in the Tertiary formations have been described, but some fissures not readily classifiable and others subsidiary to the main kinds need brief mention. Under certain conditions, where the differences are of critical concern in prospecting, criteria for the recognition of the different kinds may prove to be inadequate, and hence resort should be made to diamond drilling to test the attitudes of fissures, the presence or absence of dikes along their walls, and other structural features. The first kind of fissure formed by reopening of a dike wall is most readily identified, but even such a fissure does not of course everywhere lie in the immediate wall of the dike. Fissures of the second kind, formed by tensional rupture of the San Juan tuff, are recognized by the fact that they commonly dip at lower angles than the first kind, and in places may strike diagonally to them. Near the central zone of the Sneffels sag, where all dikes and fissures are nearly parallel and where some dikes may not have penetrated the full thickness of the formations, the critical differences may become less apparent. In this position the dips of tensional fissures are steeper than along the borders of the sag and the spacing is correspondingly closer. Furthermore, close to the margin of the caldera the steepening of all fissures becomes particularly pronounced. Under these conditions the basis as well as the need for distinction may disappear.

The attitudes of fissures in the shallower formations are not safe guides for distinguishing average differences in dip; some of the gentler-dipping fissures steepen upward and even become reversed in dip. Also a third kind of steep fissure has formed in the hanging walls of more gently dipping fissures as the result of slight normal faulting. Examples of such "hanging-wall" or feather fractures are found in the hanging walls of the Smuggler "Flat" and Liberty Bell veins (pl. 2, A-A′). These rise almost vertically from the master vein and tend to feather out upward. They are not as common in this area as at Creede and other districts where the faults have considerable throw.

A few mineralized fissures of anomalous dip, such as the North or "Iron" vein of the Tomboy mine,[61] present special problems. These dip opposite in direction to the locally prevailing dips of the later tensional fissures. They may represent "synthetic faults" of the kind "ab" shown in figure 3, or the upward extension of deep-seated faults of a similar nature in the basement rocks. A third and more

[61]Ransome, F. L., op. cit., pp. 209-211.

plausible interpretation is that these are the lateral terminations of early steep fissures formed along the caldera margin, and are due to torsional stresses. If so, the North vein of the Tomboy may be the northwestward extension either of the steeper Handicap vein of the caldera margin or of a series of veins along this zone (pl. 1).

The influence of these and other kinds of fissures in by-passing ore-forming solutions at successive stages of mineralization has been discussed sufficiently in the text on structure of the veins and need not be repeated here. This discussion however applied more particularly to the ideal examples in the Marshall and Savage Basins, areas at a considerable distance from the margin of the caldera. In areas closer to the margin, as well as closer to the axis of the dike and fissure swarm, the tensional rupture of the San Juan tuff occurred at relatively earlier stages in the span of mineralization. Consequently many of the veins in these areas contain the early-stage as well as the late-stage ores. This fact may be illustrated by a brief description of the veins of Imogene and Ingram Basins, and of those in the vicinity of Sneffels.

First, the veins on the Sneffels side of the axis differ from those of Marshall Basin in their relations to the distribution and trends of the dikes. Southwest of Sneffels, in the area in line with the numerous dikes of the Stony Mountain stock, the close spacing of the earliest dike-filled fissures greatly modified the tendency for the San Juan tuff to become ruptured by evenly-spaced new tensional fissures. However, farther southeast in Imogene Basin the dikes become more widely spaced and the typical tension fissures are consequently better developed. Perhaps the best single example is the Yellow Rose vein (pl. 1). At its outcrop across the basin the dips of the walls range between 65 and 75 degrees northeast, opposite in direction of course to the corresponding tensional fractures on the other side of the axis. Where this vein is intersected in the lower Camp Bird tunnel it dips between 50 and 60 degrees southeast, and hence shows a pronounced decrease in dip near the base of the tuff. The average dip of the vein from the top to the bottom of the San Juan tuff may be estimated at 60 degrees. In contrast to this vein, the Pierson vein next to it following a dike wall is cut on the tunnel level almost vertically beneath the outcrop. The trend of the Yellow Rose vein is diagonal to that of the older dikes, for it starts near the wall of the Pierson at the head of Richmond Basin and extends across Imogene Basin to a position on the east side of Pierson Basin, where it intersects the next strong series of dikes paralleling the Pierson dike on the northeast. However, in this area, the angle of divergence between the dikes and the later fissures is nowhere so large as in Marshall Basin above Telluride. The strike of the Yellow Rose vein may be taken as representing the trend of the ideal tension fissures on this side of the axis; it is about N. 47° W., and hence essentially parallel to those of the Telluride side. This affords evidence that the trend-lines of post-dike tensional fracturing in the San Juan tuff were very little influenced by older dike trends, except in those places where the dikes were very closely spaced, or near the center line of the downwarp where most fissures are steeply inclined as well as parallel to the older dike lines.

The series of veins crossing Imogene Basin become more closely spaced toward the southwest and closer to the center of the sag, and their dips increase correspondingly to 70 degrees or more. There is little consistency in the alinement of these northwest fissures on the hanging and footwall sides of the Camp Bird vein, and some evidently do not cut through the latter vein. This had led to some belief that the horizontal displacement along the Camp Bird fault fissure may differ from place to place in the district. However, on the bottom (14th) level of the mine a vertical rhyolite dike transverse to the vein is offset west about 60 feet in the hanging wall, a displacement consistent with that of the dikes and veins of Marshall Basin. Hence the differences to be seen from place to place are evidently due to the timing of the transverse fissuring in