of maganese,[14] of which rhodonite is the most common. The carbonate of manganese, rhodochrosite, also occurs in these veins, and free gold and quartz of a late stage are locally associated with the base-metal ores, as in the Sunnyside mine. The veins of Poughkeepsie Gulch and Mineral Point likewise contain manganese minerals but are characterized chiefly by the occurrence of lead and silver in combinations with bismuth, and their main value has been in the silver content of the ore rather than in the base-metal content. Some ores of Mineral Point have been compared by Ransome with veins in the eastern zone of the Animas Valley in the vicinity of Maggie Gulch, as they are siliceous and contain argentine and other finely disseminated sulphides that are valuable chiefly for their silver content.

The structure of the northeasterly part of the area and its relation to the fissure and vein systems is known in a general way from the studies of Cross and Howe[15] on regional structure, and of Hulin[16] on the relations of structure to mineralization in the Sunnyside mine, and from Purington's description of the Treasure Mountain region.[17] The vein systems of the Sunnyside mine are part of the great northeast and northwest fault systems that border the sunken block, and local variations in strike and dip of the fault fissures and intersections of these systems and other north-south faults have been dominant factors in localizing mineralization. Hulin has further shown that movements on these faults are largely premineral, but that later movements during mineralization have been important factors in reopening fissures and localizing ore shoots. Still later reopenings have resulted in dilution of ore by large bodies of relatively barren rhodonite. Movements on the fissure and fault systems of Arrastre Basin have likewise

---

[14] The ores of the Sunnyside mine contain, in addition to rhodonite, two other anhydrous silicates, tephroite and alleghanyite; hydrous silicates such as friedelite; the manganese sulphide, alabandite; and a rare silicate of beryllium and manganese, helvite. Many of the silicates are more characteristic of deposits considered to have formed at moderately high temperatures. They will be described in a forthcoming paper.

[15] Cross, Whitman, and Howe, Ernest, op. cit. (folio 120), pp. 23, 24.

[16] Hulin, C. D., Structural control of ore deposition: Econ. Geology, vol. 24, pp. 15-49. (Diagram of sequence of mineralization at Sunnyside mine, p. 32; structural features, pp. 38-42.)

[17] Purington, C. W., Treasure Mountain, Colorado: Min. and Sci. Press, vol. 97, pp. 23-25, 1908.

exerted important control on the formation of ore shoots (see pp. 182-185), but the Sunnyside fissure systems differ somewhat from those of Arrastre Basin in that they lie close to and within the zone of marginal faults of the sunken block. The effect of faults paralleling the margins of the down-faulted blocks was a dominant factor in the Sunnyside area. In those parts of the Arrastre Basin area that are more distant from the marginal faults vertical and horizontal movements on radial fault systems were more effective than movements on other systems, which were relatively more inactive at increasing distances from the edge of the sunken block. Ransome[18] states that the intersection of the Forest and Old Lout fissures localized the rich bismuthiferous silver ore that formed the most profitable ore body of the Old Lout mine, in Poughkeepsie Gulch. The Old Lout fissure belongs to the north-northeast radial group, and the Forest fissure strikes N. 70° E. and dips 70° S. near the intersection. The north-northeasterly fissure system of Poughkeepsie Gulch and Mineral Point continues a mile or two beyond the area shown on plate III, to the mines of Engineer Mountain and vicinity, and the northeasterly faults of Treasure Mountain and Sunnyside Basin continue east to connect with adjoining systems of the Lake City region, but the relation between these more distant centers of mineralization and those of the Silverton quadrangle are not yet known.

WESTERN AREA

The western area of mineralization may be conveniently divided for purposes of description into two parts. One lies chiefly along the marginal faults and within marginal areas of the sunken block, and the other comprises the radially fissured zones outside the sunken block, occupying the western edge of the Silverton quadrangle and the eastern part of the Telluride quadrangle.

The first of these subdivisions extends from Ironton Park southward along the entire western border of the sunken block embracing the area bounded by Gray Copper, Cement, and Mineral Creeks, and contains certain unique features. How-

---

[18] Ransome, F. L., op. cit. (Bull. 182), pp. 192, 193.

ever, the northern part of this area is characterized by mineralogic and structural features indicating its relationship to the northeasterly veins of Poughkeepsie Gulch and thus the probable merging of these areas. The distinguishing feature of the area is the occurrence of stocklike ore bodies that are localized in part along the marginal faults of the sunken block, such as those of the Red Mountain mines, noted for their exceptionally rich silver ores. Nearly the entire western border of the sunken block over a width of several miles is broken by innumerable fissures that provided channels for the escape of volcanic vapors and solutions, which altered the Silverton volcanic rocks to an unusual degree. Ransome[19] has described the alteration that took place in the vicinity of the Red Mountain mines and on Anvil Mountain, showing that the rocks were altered in various degrees to aggregates of quartz, kaolin, sericite, barite, diaspore, epidote, rutile, pyrite, and other minerals. Where the rocks are not brilliantly stained at the surface by iron oxides, as on the Red Mountains, they are gray or white, and the different lavas are so changed from their natural appearance that many structural features and volcanic members were not differentiated on the Silverton folio map. This alteration has resulted from emanations earlier than those that deposited the valuable ore minerals, and because of its widespread nature it offers little clue to the most favorably mineralized zones. The exploration for and development of ore shoots in this region are hindered by difficulties of determining structure and in distinguishing between alteration produced by ore-depositing solutions and by earlier emanations, by the softening of the volcanic rocks by alteration, and by the presence of acid ground waters. The region therefore presents many unsolved geologic and mining problems.

The localization of ore bodies in the western area is dependent in large part upon structural features produced by marginal and radial faulting and fissuring, but in addition the fissuring and therefore the shape and location of ore shoots have been modified by the action of the volcanic emanations that preceded the deposition of ore. The important effect of

---

[19] Ransome, F. L., op. cit. (Bull. 182), pp. 124-131.

these pre-ore volcanic emanations become apparent from the nature of the Red Mountain ore bodies. These ore bodies have been variously called "stocks," masses," or "chimney deposits," but Ransome[20] says regarding their shape, "It is evident from the descriptions given of the Red Mountain stocks that the term 'chimney' applied to them is somewhat misleading. They are not simple vertical pipes of ore extending from the surface to indefinite depths but are separate bodies of irregular, lenticular, or spindle-shaped form, often completely enclosed by country rock, but linked with neighboring stocks by fissures which are often small and which carry little or no ore."

The origin of the spaces filled with ore, as suggested by Emmons and Ransome,[21] is probably due in part to complex intersecting fissure systems that were at one time channels through which the earlier volcanic emanations escaped. These emanations, perhaps in part fumorolic and in part acidic solutions, were capable not only of intensely altering the rocks near their channels but evidently of dissolving them and enlarging the spaces. The resulting porous and cavernous zones thus formed permeable conduits through which later mineralizing solutions ascended and deposited ore by filling and metasomatic replacement. However, this was not the only mode of formation of the spaces filled with ore, as some bodies of lead ore in the Guston mine occupy ordinary unenlarged fissures produced evidently by renewed movements along fault lines of the district. The more productive ore bodies in the Red Mountain district are grouped along lines of fracturing in a belt less than a mile wide and about 4 miles long, bearing about N. 20° E. The common ores consist of sphalerite, galena, tetrahedrite, enargite, chalcocite, stromeyerite, bornite, chalcopyrite, and pyrite, and the richest silver ores are associated with certain of the copper minerals. According to Ransome the ores found near the surface, consisting chiefly of argentiferous galena, changed at a depth of several hundred feet to highly argentiferous silver-copper ores, which in turn de-

---

[20] Ransome, F. L., op. cit. (Bull. 182), p. 107.

[21] Idem, pp. 104-108.

creased in value downward through the increasing proportion of low-grade pyrite.

The mineralization of other areas near the west edge of the down-faulted block was similar in some respects to that of the Red Mountain district, but at other places simple fissuring and fissure intersections have been more dominant factors in localizing ore shoots. The mines of Anvil Mountain, north and northwest of Silverton, are within similarly altered rocks, but the ore shoots of the Zuni and other mines depart somewhat from the extreme stocklike forms of Red Mountain. Furthermore, ore bodies near Gladstone, at the head of Cement Creek, partake of the nature of ordinary fissure deposits, and some, such as the Gold King, contain important shoots of gold ore. The principal ores here, however, are base-metal sulphides valuable predominantly for lead and silver, and some veins contain rhodonite, like those of the adjacent northern area outside the marginal faults. Some veins lying both east and west of the head of Cement Creek, veins on the ridge extending north from Anvil Mountain, and a few veins of the Bear and Sultan Mountain stock contain the tungstate of manganese, hübnerite, which is commonly either associated with late quartz and fluorite or occurs as incrustations in cavities of the earlier base-metal ores.

The region comprising the radially fissured sedimentary and volcanic rocks west of the sunken block is by far the largest of the mineralized areas surrounding that block. (See pls. III and IV.) The extreme northeastern portion, between Red Mountain, Telluride, and Sneffels, has been the most productive region of the San Juan Mountains and includes such veins as the Camp Bird, Liberty Bell, Smuggler Union, Tomboy, Virginius, and others, all of which have been mined to unusual length and depth. This series of dikes, fissures, and veins forms another radial group, bearing from N. 40° W. to N. 70° W., the main zone of which is 2 to 3 miles in width and has an average course of N. 45° W. The zone has a length of about 6 miles along the strike, from the edge of the down-faulted block near Red Mountain to the Stony Mountain-Mount Sneffels stock. This outlying stock of gabbro-diorite forms a center of igneous activity seemingly independent of the intrusives of the Silverton center, but andesitic dikes radiate from it much as they do from the Silverton center. Those extending southeastward can be followed continuously from Stony Mountain to the ridges adjacent to the Red Mountain Valley and appear to indicate intrusion simultaneous with the central activity of the Silverton region. The strength and continuity of the fissures throughout this distance also suggest that this outlying igneous center had an important control upon the connecting structural features. The veins nearest to the sunken block of the Silverton quadrangle consist chiefly of base-metal ores in a gangue of quartz, with some rhodonite and rhodochrosite. Nearly all the veins show many stages of reopening of the fissures, with deposition of several distinctive types of vein filling. The principal gold-producing vein of this group, the Camp Bird, contains base-metal ore, followed in order by mixed carbonate vein filling; fluorite; gold in quartz, adularia, and carbonates; late barren quartz; and calcite. This vein strikes about N. 80° W., diagonally across the N. 45° W. veins, most of which were not affected by the rich gold mineralization characteristic of the Camp Bird shoots. The Barstow vein, however, on the mountain slopes adjacent to the Red Mountain Valley, belongs to the N. 45° W. group and has been productive of both gold and silver from base-metal ore. The Tomboy vein, likewise in this group, was a large producer of free gold ore. Veins farther northwest, such as the Virginius, Montana, and Smuggler, contain chiefly mixed lead-silver or gold ores, and those most distant, such as the Liberty Bell, are of very low sulphide content and commonly produced silver in excess of gold. The complexity of the veins tends to mask any marked zonal belts of ore deposition, excepting at the southeast end of the belt where the heavy base-metal ores are clearly developed to their strongest degree. The Liberty Bell constitutes at least one individual vein in which the base-metal content of the ore definitely increased toward the east. The Stony Mountain stock, like the large stock near Silverton, appears to have played but little part in the distribution of metals, as the veins of this region contain chiefly silver ores with a late stage of finely divided sulphides and a little free gold in quartz, more like the distant facies of ore deposition in the southern area of the Silverton Quadrangle. There are, however, small bodies of somewhat variant base-metal ore with barite and manganiferous minerals near the Stony Mountain stock, indicating its local but minor effect on ore-depositing processes. Thus the conditions in this area likewise suggest that the sources of the ore-depositing solutions were chiefly very deep reservoirs of crystallizing magma, probably concentrated mainly nearer the marginal faults of the sunken block, but extending toward the outlying satellitic bodies.

Much less is known about the fissure systems and distribution of different facies of mineralization in the region west of Mineral Creek and south of this northwesterly group of veins. In the districts just south of Telluride, on Silver Mountain and adjacent ridges, the veins show unmistakable mineralogic affinities to the veins just described, but the dominant direction of fissuring in the canyons south of Telluride is more nearly due east. The dominant directions of fissuring in the Telluride quadrangle are indicated by a few veins, the strikes of which were recorded by Purington on the Telluride folio map. These have been included on plate IV. Purington[22] enumerates three systems in the eastern part of the quadrangle—namely, N. 87° W., N. 53°-63° E., and N. 25°-51° W. He states that the east-west and northeast systems are best developed in the central and southeastern portions of the quadrangle, and that the northwesterly veins are best exemplified in the northeastern portion, which has just been described. The dominant east-west system in the Ophir Valley region continues 8 miles or more west of Ophir to the intrusive centers of the Mount Wilson group, holding this strike with remarkable consistency. South of this on the ridge north of Ice Lake Basin and terminating in U. S. Grant Peak, to the north, zones of mineralization have a northeasterly direction.[23]

---

[22] Purington, C. W., Preliminary report on the mining industries of the Telluride quadrangle, Colorado: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, pp. 765-767, 1898.

[23] Idem, p. 766.

Throughout this region the sedimentary rocks underlying the volcanic formations are a much more important factor in structure and ore deposition, and not far west of Ophir they become the dominant surface rocks. Because of lacked of detailed data on different phases of mineralization it does not seem advisable to attempt a review of the veins and ores of this region. Purington's conclusions regarding the origin of this fissuring in the eastern part of the Telluride quadrangle, however, are significant. He states:[24]

> "It has been said that the fissuring is of dynamic origin; also that the joints penetrate all rocks and consequently are later than any in the district. It cannot from present evidence be asserted, however, that certain of the fissures may not be earlier than the latest volcanic flows and diorite stocks. By far the major part are of recent origin. From all observed phenomena it seems probable that the fissuring was made by forces acting at time intervals not far removed from one another. Since the fissuring is later than all the rocks of the quadrangle, volcanic disturbances whose product is now visible cannot be cited to account for it, but it is entirely possible that later disturbances of volcanic nature, which did not result in surface flows of lava, have produced a straining to the point of rupture in the tract under consideration. It is thought, with great reason, that in the area directly east and northeast of the Telluride quadrangle there are centers and necks of volcanic eruption. Such evidence as has been collected in the present investigation points to those quarters as the source from which pressure came."

Origin of the regional structure

The above descriptions of ore areas about the sunken block of the Silverton quadrangle subsidence are necessarily not complete nor perhaps even accurate in all respects, because of difficulties in generalizing about very complex phenomena of mineralization in a region so large, but the features described are believed to show the close structural relation between the outlying areas and the centralized Silverton area. The remarkable symmetry and the relations between different structural features offer substantial evidence that the regional structure is the result of some comparatively simple and systematic failure of the crust, and in the following paragraphs an attempt is made to show that the forces producing this structure were probably generated by the upthrusting of igneous bodies and by gravitative adjustments that followed their upward surge.

---

[24] Idem, pp. 769-770.

The fissure systems are now known in a general way for much of the Silverton quadrangle, and for several smaller areas the fissure systems are known in great detail, but in the central sunken block data on the systems are meager. Such data as are available have been compiled on plate IV, showing the entire Silverton quadrangle and the eastern half of the Telluride quadrangle. With the exception of larger crosscutting intrusive bodies, which are shown stippled, all structural features, including dikes, faults, fissures, and veins, are shown by lines, and the two areas in which fissure systems are known in greatest detail are outlined. By comparing these detailed areas with adjacent regions mapped on topographic maps of 1/48,000 scale, it is apparent that the paucity of fissures shown west of the sunken block is not real but simply illustrates lack of knowledge in these regions. The same may be said of part of the central sunken area, particularly the western border, which is known to be broken by numerous fissure systems; but the east-central part adjacent to Storm Peak is not strongly fissured. The courses of those fracture systems that outline the major part of the central sunken block are show by heavy lines on plate IV and at the south are projected beyond their actual present extent to the central part of the quartz monzonite stock, where they must have united originally.

If the principal radial systems of fissures are projected inward their focal concentration near the center of the Silverton quadrangle suggests their origin in some common force. The most apparent structural features that might be the cause of this fissuring are the intrusive bodies and the down-faulted block. Aside from theoretical considerations there is ample evidence that subsidence of the central block alone cannot account for all the radial fractures nor certain other structural features to be described. Many radial fissures contain dikes that are clearly older than faults initiated during the sinking of the block. About the best examples are the radial rhyolite dikes and sheets of the northeastern part of the Silverton quadrangle, many of which are fissured and displaced by the marginal faults. Furthermore, many andesitic dikes in the southern and northwestern areas occupy simple tensional fissures along which there had been little or no faulting preceding the dike injections. Not all the intrusion preceded the subsidence, however, for, as shown on page 159, the large quartz monzonite intrusions of the southern area followed or accompanied the subsidence and faulting, but there is a sufficient number of earlier intrusions to indicate that the major structural pattern was in existence before the subsidence was well under way.

As only the western margin of this block is strongly fissured, and on the whole the central portion is less strongly fissured than the surrounding regions, it is highly improbable that the great surrounding zones of radial fractures distributed through a volume of crust many times that of the sunken block could have been produced by radial pressures generated by its subsidence without the stresses developed causing intense fissuring or crushing of the central block itself. It thus seems unlikely that stresses producing the earlier fractures were the result of forces transmitted horizontally through the volcanic rocks from some central point; on the other hand, if the stresses were chiefly vertical, and the maximum force were applied near the center of the Silverton quadrangle, radial fissuring might readily result from tensional stresses developed by bulging of the earth's crust.

The theory of radial tension fractures produced by intrusion of igneous magmas will not be discussed in this paper, but examples and the theory of these fracture systems have been described in geologic literature.[25] The convex fracture systems of triangular symmetry that bound the sunken block are probably the result of most direct relief along radial lines of the tensional stresses induced by upward bulging of the crust. These fractures evidently belong to the same system as other concentric bow-shaped fractures that lie outside the margins of the sunken block, and the fact that they form in large part the boundaries of the sunken block appears to be incidental to the later igneous history. Although doubtless

---

[25] Hills, R. C., U. S. Geol. Survey, Geol. Atlas, Spanish Peaks (folio 71), 1901; Weed, W. H., idem, Little Belt Mountains (folio 56), 1899; Chamberlin, R. T., and Link, T. A., The theory of laterally spreading batholiths: Journ. of Geology, vol. 35, pp. 319-352, 1927.

there are other concentric fissures and dikes that have not been traced, several very prominent curved fissures lie within or close to the areas that have been mapped in detail and are shown on plates III and IV. One of the most remarkable of these curved fractures lies in the northwestern area about 4½ miles northwest of the margin of the central block. This has been traced in a northeasterly course for over 4 miles and dips southeastward. In addition to vein material, which has been partly developed in the Wheel of Fortune mine, the fracture contains several igneous dikes and one injected mass of clastic debris. These show not less than four tensional openings of the fracture, each opening accompanied by forceful injection of igneous or clastic material from deep in the crust, before the deposition of vein matter. Several curving fractures in the southeastern area, extending 4 or 5 miles from a point near the eastern end of the quartz monzonite stock to the upper part of Cunningham Gulch, likewise contain igneous dikes and dip northward toward the central area.

A region in which numerous concentric fractures were formed about igneous centers is that of the Tertiary plutonic districts of western Scotland. The sheets of igneous material filling these concentric fractures dip inward toward the center of the volcanic complexes, and the name "cone sheets" has been applied to them because they presumably have the form of a series of inverted concentric cones with a common apex at the top of the underlying central intrusive body.[26] Thus as a rule those occurring closer to the center have steeper dips than the more distant ones. It seems possible that the concentric fractures and dikes of inward dip about the Silverton center are of the same origin, but their dips (60°-85°) average much steeper than those of the cone sheets of Scotland. The concentric dikes of the Silverton center are also very subordinate to the radial dikes, but in the Scottish complexes the cone sheets occur typically in great abundance with comparatively few radial dikes.

---

[26] Anderson, E. M., (The Tertiary and post-Tertiary geology of Mull, Loch Aline, and Oban): Scotland Geol. Survey Mem., pp. 11-12, 1924. Richey, J. E., Thomas, H. H., and others. The geology of Ardnamurchan, Northwest Mull, and Coll: Scotland Geol. Survey Mem., pp. 56-58, 1930. Richey, J. E., Tertiary ring structures in Britain: Geol. Soc. Glasgow Trans., vol. 19, pp. 42-140, 1932.

The great volume of the crust within the sphere of influence of the Silverton center, which has an area at the surface of not less than 250 square miles and possibly more than 300 square miles, suggests a very deep-seated source of the forces involved in the deformation. The fact that the concentric dikes are very subordinate to the radial dikes may be the result of the great depth at which the central igneous body lay. In most of the Scottish centers the depth of the main magma reservoir has been estimated at not more than 3 to 5 miles. Cone sheets appear to be less commonly developed about igneous centers than radial dikes, and with the possible exception of these occurrences near Silverton, they have not been described specifically from any locality outside of Scotland. However, in order to avoid definite implication of their origin the dikes of the Silverton center will be called simply concentric dikes until further study can be made of their distribution and attitude. Some of these concentric dikes appear to have limited or deflected many of the radial tension fractures that intersect them and thus are of importance in considering the continuity of fissure systems. The radial fracture systems south of the Animas River are concentrated chiefly between the marginal faults of the Animas system and the concentric dikes that lie just south of the Arrastre Basin region (plate III). Similarly, in the area northwest of the sunken block an apparently greater concentration of fissures is found east of the Wheel of Fortune concentric dike, on Potosi Peak, than west of it.

Another feature of the Silverton center that is comparable to the Scottish centers is the annular distribution of the intrusive igneous bodies along the marginal faults of the central sunken block. However, intrusion evidently failed to penetrate the shallow layers of the crust sufficiently to develop fully the ring dikes and intrusives so characteristic of the shallower volcanic complexes of Scotland. But because of the distribution of ore deposits with relation to the marginal faults and other evidences of hydrothermal igneous activity, there can be no doubt that had erosion penetrated deeper in the Silverton quadrangle, igneous bodies that almost completely encircled the sunken block would have been exposed.

The ring structures of Scotland are attributed to a different set of fractures that developed independent of and in part subsequent to the cone sheets, which they intersect in places at obtuse angles, as they tend to dip outward from the igneous center and in opposite direction to the cone sheets. No such relation is apparent in the Silverton quadrangle, but it is not surprising here that the very steep concentric tension fractures produced by bulging of the crust should nearly coincide with later fault lines that outlined the sinking block. It seems probable that at depths not now exposed there would exist an outward inclination of the margins of the annular igneous bodies, for both the radial dikes and the ore deposits occur in greater abundance in the crust just outside the sunken block than within it. There are, however, some stretches along the western margin of the sunken block which are possible exceptions to this inference.

The bounding fractures of the sunken block were greatly modified by later forces of a different kind, which were generated by the sinking of the central block. (See pp. 182-185.) Only the simplest types of fracturing believed to be interpretable have been mentioned, but it is certain that other very complex stresses developed and that not all the fractures belong to the systems mentioned; nor is it probable that all are of tensional origin. It is well known that in the formation of torsional stresses by bending strong shearing stresses are developed, and such stresses may well account for additional and complex fracturing diagonal to the radial and concentric systems. Furthermore, as is shown by the fissure systems of Arrastre Basin, the later sinking of the central block evidently caused the generation of outward thrusting and shearing stresses, which further modified the earlier-formed fissure systems and produced new systems of shear and tension fractures. These later forces, which thus modified and reopened many of the earlier tension fractures, were of great importance because of their effect upon and development of openings in which ore bodies were formed. These latest systems are described in connection with the fissure and vein systems of Arrastre Basin (pp. 195 et seq.).

Conclusions on the sequence of regional structure may be summarized but must be considered tentative and subject to revision, as mapping of other areas in detail will doubtless add much to our knowledge of the complex fissuring in this region. Because of the many igneous intrusions that apparently were injected at times not far separated from one another throughout every part of the Silverton and Telluride region, the inference may perhaps safely be made that an essentially continuous layer of molten magma underlay the crust at a time just preceding the start of the structural cycle. Current geologic opinion as to the depth of such magmatic reservoirs and the minimum thickness of the earth's crust would indicate that this layer probably was not less than 10 miles below the surface, and possibly at somewhat greater depth. The pressure that was inherent in this molten layer finally caused bulging and fracturing of the crust at a position near the central part of the Silverton quadrangle.

Some speculation may perhaps be warranted as to the reason why the magma finally broke through this particular section of the crust. A great thickness of volcanic rocks accumulated in a basin that occupied the central part of the Silverton quadrangle and extended eastward toward Lake City. This basin may represent an actual down-warping of the crust caused by deep transfer of magma and filling of the depression by material from surrounding volcanic vents. This downwarping, however, took place at a much earlier period in the volcanic history than the development of the structure under consideration. Nevertheless, it is possible that just as the upwarping later caused tension at the surface, an early downwarping may have induced tensional stresses in the bottom layers of the crust sufficient to weaken it below the strength of the surrounding parts and thus localized the surgence of later magmas. The further possibility that the intersection of two dominant sets of regional fractures localized the surgence of magma cannot be critically examined until the structure of a much larger area of the surrounding country is better known.

It seems probable that one of the earlier sudden upthrusts of igneous material developed the bow-shaped outlines of the central fracture system drawn in heavy lines on plate IV. However, more detailed knowledge of fracture systems in the interior block might modify this conclusion. As three or four injections are found in some of the tension fractures, it seems evident that the upthrusts occurred in numerous stages, and radial and concentric tension fractures were thus developed and enlarged gradually, until sufficiently large blocks of the underlying crust had foundered, with consequent escape of molten rock to the surface and loss of magmatic pressure. With vents to the surface established and the margins of the central block weakened by the foundering of crustal blocks, a cycle of subsidence began, and the weight of the central block caused it to break along the lines shown on plate III. Expansion of the upper part of the block by fissuring probably caused the formation of an arch as the rocks subsided, so that pressures were exerted outward from this central region, as seems to be manifested in the shearing and faulting along early tension cracks. The downward drag of the sinking block would also develop shearing stresses paralleling the marginal faults. Those parts of the central region that had been subjected to the greatest uplift would necessarily have been the most fractured and weakened. This result seems to accord with conditions found along the west margin of the block, where small bodies of rhyolite were evidently first dropped into gaping tension fractures during up-warping and later intensely fissured by shear and compression developed during subsidence. The weakest parts of the central block, as represented by its corners, were thus intensely fractured, and it was near the two western corners that the greatest igneous and hydrothermal activity centered. Moreover, it is perhaps significant that in the outlying regions those areas that lie directly outward from the corners of the central block exhibit the weakest fracturing. This relationship is perhaps further evidence that the convex triangular outlines of the marginal fault systems were developed early and exerted important control upon early tension cracks as well as upon the later subsidence.

VEIN AND FISSURE SYSTEMS OF ARRASTRE BASIN

GENERAL FEATURES

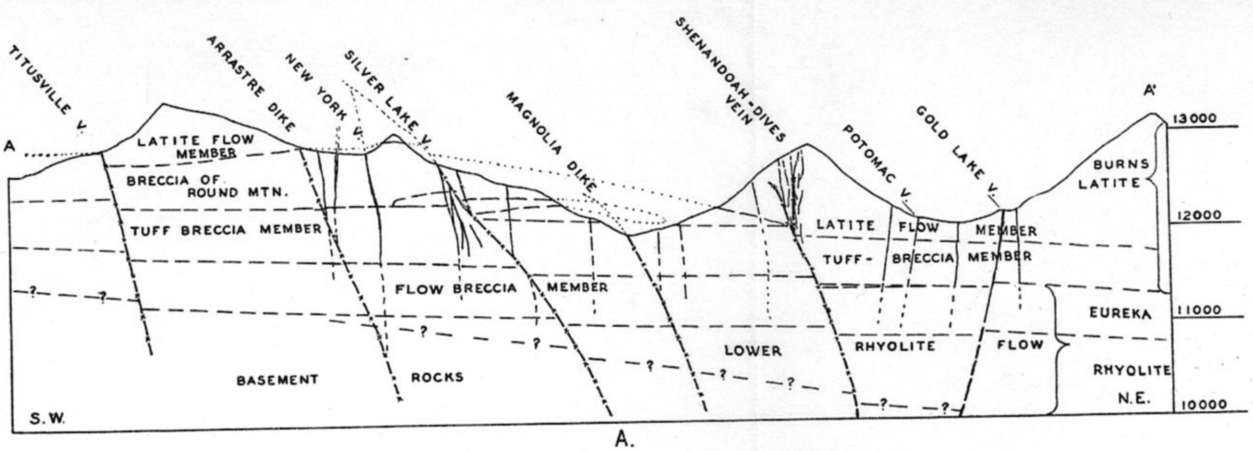
The vein and fissure systems of Arrastre Basin have been mentioned in the preceding text in their relation to the major structural pattern of the Silverton quadrangle, and with the perspective afforded by that review it is the intention in this section to discuss chiefly those structural features that were instrumental in localizing the ore bodies of this special area.

Two principal types of tensional fracturing were developed during the surgence of underlying molten magma, and resulted in radial and concentric fissures, many of which were intruded by dikes of igneous rock. The Arrastre Basin area (plate I) lies to the north of a zone of curved fractures that contain igneous dikes belonging to the particular group of fractures called concentric dikes (cone sheets?). These dikes do not appear on plate I, but their relation to the Arrastre Basin area may be seen on plate III. Eastward from the Animas Valley drainage slopes south of Silverton to the crest of Spencer Peak the dikes are of andesitic composition, and at the peak they strike about N. 80° E. The curving sheet of granite porphyry about 800 feet south of the peak swings from the strike of N. 70° E. to about N. 45° E. where it crosses Cunningham Gulch. It will be seen from this that the two dikes crossing Arrastre Basin with an average strike of about N. 80° E., called the Arabian Boy and Arrastre dikes, probably were also intruded into tension fractures essentially parallel to those farther south and likewise belonging to the system of concentric dikes. Intersecting these N. 80° E. fracture systems there are several dikes intruded along radial tension fissures that trend about N. 45° W. Those shown on plate I include the Silver Lake, Magnolia, and Shenandoah-Dives (Mayflower) dikes, all of which at the surface have a northeasterly dip of 60° or more. The Silver Lake and Magnolia dikes represent one intrusion of igneous material into complementary fissures en echelon. The coexistence of these two directions of tensional stress when dikes were injected into the country rock is shown by the fact that the Silver Lake dike turns eastward in a curve where it crosses the first of the N. 80° E. dikes and tails out, whereas the Magnolia dike begins with a similar sickle-like curve north of this termination and crosses the Arabian Boy dike with its normal N. 45° W. trend, but upon reaching the Arrastre dike it again turns into a N. 80° E. course parallel to this dike and probably continues beneath the talus deposits of Dives Basin. The Mayflower dike could not be traced at the surface to its intersection with the Arabian Boy dike, but underground it is known to extend to a position nearly beneath the crest of Little Giant Mountain, As the dike does not occupy the extension of the Dives fissure in the center of Dives Basin it appears that the tensional stresses responsible for the N. 80° E. fractures now filled by the Arabian Boy and Arrastre dikes may likewise have interrupted or turned the Mayflower dike fissure. It is thus assumed that both the N. 45° W. and the N. 80° E. tensional fractures began to form essentially simultaneously, although it is known that all the intrusions of dike material did not occur at the same time. The Mayflower dike may extend even beyond the Arrastre dike at somewhat greater depths than the level of Dives Basin, but it is apparent from the relations described that the N. 80° E. tension zones greatly weakened or deflected the radial tensional fractures, so that dikes occupying such fissures tended to tail out or change strike as they approached and passed these crossings. This fact has a direct bearing upon later fissures in which certain ore bodies are found.

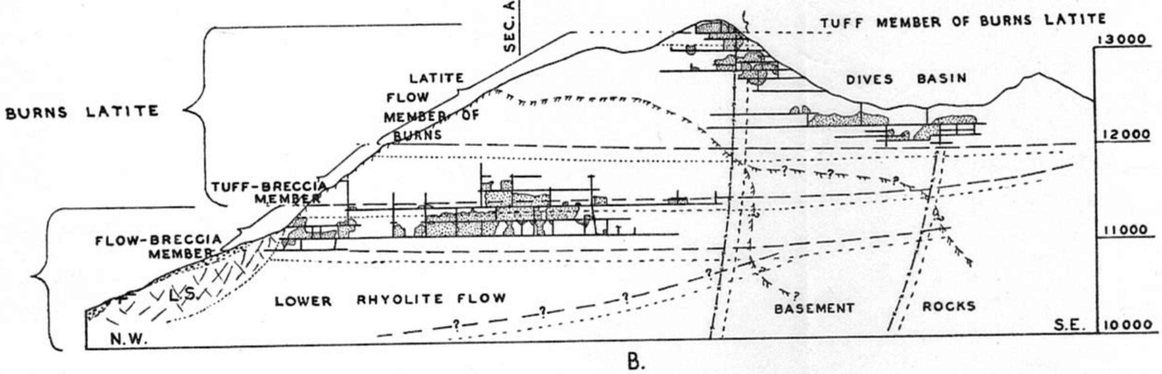
At the crossing of the Magnolia and Arabian Boy dikes there is no detectable offsetting of either one by the other; but at the crossings of the Silver Lake dike and of the Shenandoah Dives fissure zone with the Arabian Boy dike, there is an appreciable offsetting of the N. 80° E. dike by the N. 45° W. fissure systems. This offsetting, which happens to be in the same relative direction at both crossings, is clearly caused by forces of later origin than those producing the earlier tension fissures. It also seems that these forces resulted from some differential lateral pressures originating to the northwest near or within the subsiding block, because the nature of the fissuring described below accords with the movements and energy transmitted from that direction. These later fissure and fracture systems, which include nearly all the fissures shown on plate I, are generally concentrated along or parallel to the northwesterly dikes north of the point where these dikes approach and cross the concentric dikes. Near and to the south of the concentric dikes the tendency for complex feathering of the fracture systems is very marked. This difference indicates the close control of later differential movements by the early tension fractures and zones of tension north of the dikes; but beyond and to the south of the blocks most strongly broken by early tensional stresses later crustal movements caused the development of new lines and patterns of fracturing.

Because the later systems of fractures were the result of somewhat gradual development and because older fracture surfaces already existed in the rocks, it is not possible to classify all the fissure systems of even so small an area as Arrastre Basin upon a uniform basis. The lines of stress generated in the crust are deflected by these older fracture surfaces which thus have an important influence on the development of fissures of the later generations. It is possible, however, to recognize and classify certain types of fissuring that are of importance in the localizing of ore shoots, and in some degree to determine the effects of different kinds of rocks and of earlier fracture surfaces upon the general character of these fissure systems.

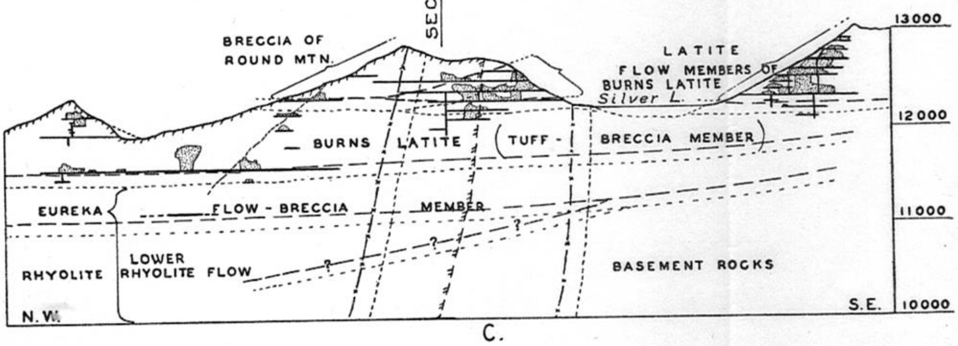
The fissures that are filled with vein material, which may be called vein fissures, generally fall into two broad classes—those consisting primarily of openings formed along older fractures or surfaces of discontinuity, such as dike walls and tension fractures, represented by the northwestern portions of the Shenandoah-Dives and the Silver Lake lodes; and those whose course and pattern are not controlled directly by older surfaces of discontinuity, but which are produced by the same forces in essentially continuous bodies of rocks, illustrated by the New York, Stelzner, Iowa, and Royal veins and by the southeasterly extensions of the Shenandoah-Dives and Silver


A
A'
TITUSVILLE V.
ARRASTRE DIKE
NEW YORK V.
SILVER LAKE V.
MAGNOLIA DIKE
SHENANDOAH-DIVES VEIN
POTOMAC V.
GOLD LAKE V.
LATITE FLOW MEMBER
BRECCIA OF ROUND MTN.
TUFF BRECCIA MEMBER
FLOW BRECCIA MEMBER
LATITE FLOW MEMBER
TUFF-BRECCIA MEMBER
BURNS LATITE
EUREKA
RHYOLITE
LOWER RHYOLITE FLOW
BASEMENT ROCKS
S.W.
N.E.
13000
12000
11000
10000

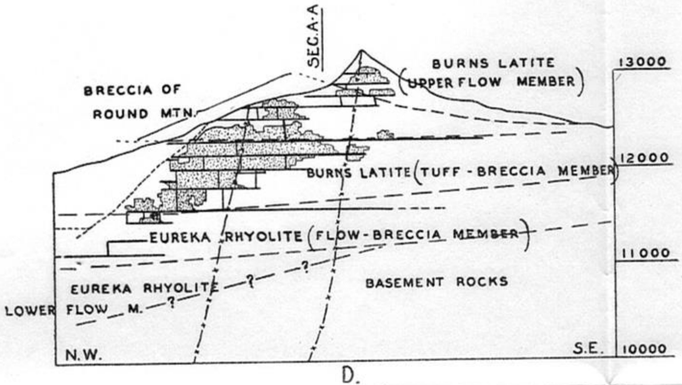
A.


SEC. A-A
TUFF MEMBER OF BURNS LATITE
BURNS LATITE
LATITE FLOW MEMBER OF BURNS
DIVES BASIN
TUFF-BRECCIA MEMBER
FLOW-BRECCIA MEMBER
EUREKA RHYOLITE
L.S.
LOWER RHYOLITE FLOW
BASEMENT ROCKS
N.W.
S.E.
13000
12000
11000
10000

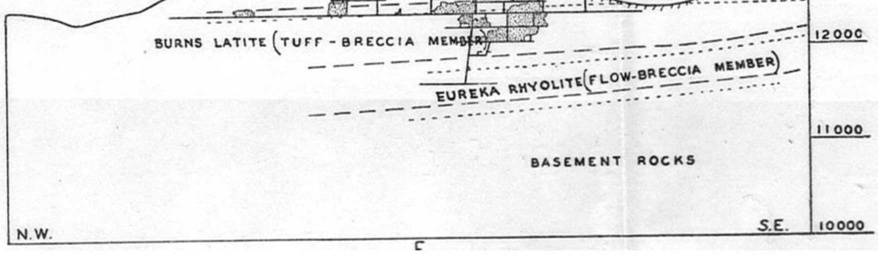
B.


SEC. A-A
BRECCIA OF ROUND MTN.
LATITE FLOW MEMBERS OF BURNS LATITE
Silver L.
BURNS LATITE (TUFF-BRECCIA MEMBER)
EUREKA
FLOW-BRECCIA MEMBER
RHYOLITE
LOWER RHYOLITE FLOW
BASEMENT ROCKS
N.W.
S.E.
13000
12000
11000
10000

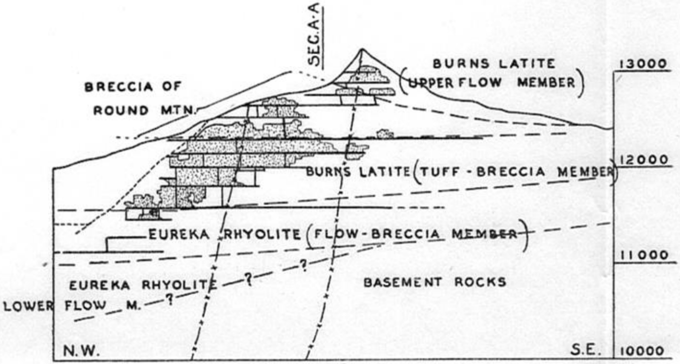
C.


SEC. A-A
BRECCIA OF ROUND MTN.
BURNS LATITE (UPPER FLOW MEMBER)
BURNS LATITE (TUFF-BRECCIA MEMBER)
EUREKA RHYOLITE (FLOW-BRECCIA MEMBER)
EUREKA RHYOLITE LOWER FLOW M.
BASEMENT ROCKS
N.W.
S.E.
13000
12000
11000
10000

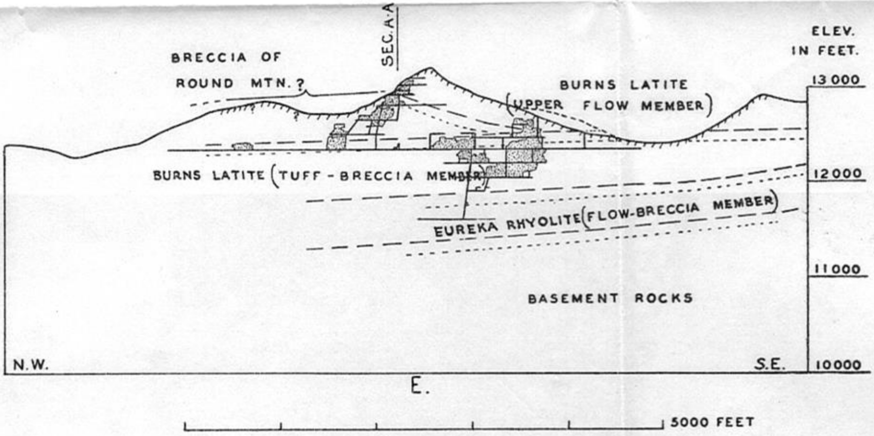
D.


SEC. A-A
ELEV. IN FEET.
BRECCIA OF ROUND MTN.?
BURNS LATITE (UPPER FLOW MEMBER)
BURNS LATITE (TUFF-BRECCIA MEMBER)
EUREKA RHYOLITE (FLOW-BRECCIA MEMBER)
BASEMENT ROCKS
N.W.
S.E.
13000
12000
11000
10000

E



D.



E.

Note. Except for parts of Shenandoah-Dives section, underground position of formation boundaries is based upon projection and assumption of average thicknesses. Actual position of boundaries may thus vary several hundred feet from that shown. Boundaries with question marks are highly speculative.

PLATE V. Geologic and mine sections. A. Geologic section from Titusville mine to King Solomon Mountain, (see Plate I for line of section). B. Vertical projection along the Shenandoah-Dives vein. Plane of projection about N. 46½° W. C. Vertical projection along the Nevada-Silver Lake-Royal Tiger vein. Plane of projection about N. 45° W. D. Vertical projection of the New York vein. Plane of projection about N. 45° W. E. Vertical projection of the letter G or Titusville vein. Plane of projection about N. 70° W. Line above mine sections indicates intersection of geologic section A-A′. Abbreviations, m., member; L. S. landslide debris. Eureka flow-breccia member includes also the medial tuff member of the Eureka rhyolite. The dashed formation boundaries represent their approximate positions in the west or southwest walls of the veins, and the finer broken lines their positions in the east and northeast walls. The hachured lines show the extent of the dikes along the outcrop or along the vein fissures.