Lake vein fissures beyond the limits of their respective dikes. Although more detailed and rigid classifications of the different vein fissures of Arrastre Basin could be made, these two types of fractures are of primary importance, for it appears likely that the control of wall rocks upon the openings is quite different in each type. The shapes and sizes of mined or partly developed ore shoots in these different classes of vein fissures are illustrated in plate V.

Vein Fissures Formed by the Reopening of Old Fissures.

Vein fissures formed by the reopening of old fissures are of two kinds—those formed along and near the walls of dikes that fill preexisting tension fissures; and those along preexisting fractures that were only partly dike-filled or that contain no dike material. The principal vein-fissures of this general class are the Shenandoah-Dives, Silver Lake-Nevada, and Titusville or Letter G veins. Dikes have not yet been found along the Black Prince-Gold Lake lode nor along any of the older fissure systems of Little Giant Basin, but certain master fissures, such as the Black Prince, may be early tension fractures that were not filled by dikes. Veins of east-west trend occur along the dikes of Arrastre Basin, but in general the east-west lines of fracturing were not sufficiently reopened to form productive veins.

Shenandoah-Dives vein

Along the Shenandoah-Dives vein, which was accessible to underground study, an andesitic dike commonly from 15-20 feet wide has been exposed for a length of about 4,800 feet along the workings, and through a vertical range of about 1,700 feet to its highest exposure on the surface. It may not accompany the vein fissures above an altitude of 12,500 to 12,700 feet, but unquestionably it extends to great depths below the present lowest workings. The southeast boundary of the dike beyond the present deep workings is not known, but owing to the possible effect of the N. 80° E. concentric dike crossings, the dike may not extend beyond these crossings at the present depth of development. The southeasterly extension of the Shenandoah-Dives fissure into and beyond Dives

Basin is strong and of constant trend and may indicate a much greater extension of the dike along this lie of fissuring at depth. The limits of the dike as shown on plate V-B are largely hypothetical, as the workings from Dives Basin below the North Star mine were not accessible. For this reason two interpretations of the limits are indicated, as the different possibilities are of critical importance in judging the probable presence and character of ore bodies toward the east. This particular problem is further discussed below.

The net result of postdike displacements along the Shenandoah-Dives vein can be estimated approximately from vertical displacements of several horizontal boundaries between formations and from horizontal displacement of the Arabian Boy dike. The net vertical displacements are between 125 and 140 feet, and the horizontal shifting of the cross dike on Little Giant Peak is of about the same amount. Striations on the walls of fissure systems of the Shenandoah-Dives lode clearly show, however, that movements producing this net result were very complex and ranged from movements directly down the dip to essentially horizontal movements along the strike of the fissures. The number and exact order of these different movements have not been determined, and it is doubtful whether to do so would be possible. Nevertheless, certain important movements can be differentiated. In both the Shenandoah-Dives and Silver Lake fissure systems there was before ore deposition a combined horizontal and vertical shift that was sufficiently strong to fracture the walls of the dikes and produce the complex system of footwall fractures found on the south of Little Giant Mountain and west of Silver Lake. Many striations on the immediate hanging walls of the Shenandoah-Dives ore shoots in the northern portion of the vein system show a vertical component of shift generally in excess of the horizontal component, and post-ore horizontal shifts appear insufficient to account for the total displacement. Consequently it would seem that relative movements of walls prior to those that took place during and after ore deposition were the chief cause of the large horizontal component of shift. Also the complex fracture systems found to the southeast and referred to above show that the main horizontal component must have been earlier than ore deposition, as many shear and tension fissures resulting from this movement exhibit essentially all stages of mineralization. On the other hand, some crustal adjustments during and after mineralization involved horizontal components of shift. In Dives Basin certain veins show nearly horizontal striations along the walls of late post-ore faults, and similar striations were seen upon barren quartz of late age. Thus in general the evidence favors an alternation of horizontal shifts and gravity adjustments of fault blocks. The cycle seems to have been initiated by a strong shift of the northeastward dipping hanging walls of the Shenandoah-Dives and Silver Lake dikes toward the southeast, as if from some differential pressure originating at the north. This shift was both accompanied and followed by down-faulting of the blocks, during which the hanging wall slid downward and somewhat eastward relative to the footwall. Perhaps several similar but less intense cycles of this nature took place throughout mineralization. The fact that east-west zones of fissuring were not appreciably opened by these movements suggests that the crust was under radial compression. The subsiding crustal block of the Silverton quadrange may have generated pressure radially outward from the center, while the gravitative adjustments accompanying such compression caused more widespread crustal subsidence about the margins of the strongly down-faulted block.

With movements of the nature described changes in strike or dip of the fault surfaces have an important influence on localization of highly fissured or open ground favorable to the formation of ore shoots. Certain ore shoots of the Shenandoah-Dives system have a comparatively low-angle pitch toward the north. The structural features controlling the limits of the ore shoots are of at least two kinds—gougy slip planes generally parallel to the strike of the lode, that were relatively impermeable to the mineralizing solutions, and certain changes in strike or dip whereby the amount of open space was reduced below the minimum width allowable by methods of mining. Changes in proportion of the different facies of mineralization in openings are of course important factors in delimiting ore, as a large opening filled with quartz and sulphides of comparatively low grade may offset the value of a later introduction of higher-grade material in small openings. However, if the enriching stage of mineralization happens to introduce gold accompanying chalcopyrite, as at places in the Shenandoah-Dives vein, the filling of comparatively small openings may greatly enrich the ore. It is apparent, therefore, that even if the character of mineralization could be correlated with each separate stage of fissuring, it would be difficult by this method to predict the value of ore, for even microscopic openings may account for a considerable proportion of the value of the vein matter. For this reason and because of incomplete data on the mineralogy and paragenesis of the veins, the discussion is of necessity confined largely to the structural control of openings, with little regard to whether these are filled with high-grade or low-grade vein matter.

The gougy fault or slip planes that have a slightly flatter dip than the dike and form so conspicuous a feature of certain parts of the Shenandoah-Dives lode are seen when traced upward to pass gradually from the hanging wall to the footwall of the dike and when traced horizontally to pass from one wall of the dike to the other (fig. 1). Certain ore shoots are limited on the hanging wall or footwall by the gouge planes, but in places ore is also found on both sides of the gouges with slabs or horses of altered rock between them, so that under these circumstances the gouge and altered rock may easily be mistaken for bounding walls of the lode or vein system. When an ore shoot whose hanging wall is limited by such a gouge plane is stoped upward it is found that this gouge may change its dip and flatten in such a way as to pinch off the high-grade ore at the top of the shoot and then pass into the footwall. Vein material above this gouge plane in the upward continuation of the fissure system may be wide but too low grade to be profitable, or the immediately overlying portion of the fissure system may be too tight for valuable concentration of vein matter. The function of these gouge planes and of the movements that produced them appears, therefore, to have been in control exerted upon permeability in different portions of the fissure system, and perhaps only incidentally in the production of large open fissures. Some post-ore movement has occurred along these faults, but they rarely break through and crush large bodies of vein matter or offset them in such a manner as might be expected if they were chiefly of post-ore origin.

Changes in strike of the dike and fracture system combined with the relative horizontal shift of the walls appear to have been a factor in producing zones of open and tight fissuring. Ore shoots developed by the main level of the Shenandoah-Dives suggest that slight changes in the average strike have resulted in open zones alternating with comparatively tight ones (fig. 1). If this were the only factor in the production of favorable or permeable fissures, we might expect, providing the change in strike occurred throughout a large vertical extent of the dike and fissure system, that these shoots would have at least as great vertical as horizontal dimension; but this is not generally true. It seems probable, however, that in addition to the limitation of the vertical extent of the shoots by the gouge planes, other factors may have been involved. Irregular warping of the dike fissure in the vertical as well as the horizontal plane would naturally greatly complicate the shape of openings caused by differential movement of the walls. With the reservation that perhaps sufficient data are not at hand to permit a final conclusion regarding causes of their shape, the suggestion is made that broken and fissured ground of considerable vertical extent was produced chiefly by the early horizontal component of shifting, and that downward slipping of the hanging wall before and during mineralization formed gouge planes that acted like baffles and tended to divide the open zones into a series of channel ways of comparatively low dip which had a greater horizontal than vertical extent. At places where the vertical zones were not tightly sealed by the limiting gouge planes or baffles the channels extended upward in more nearly vertical elongation and afforded openings through which portions of the ore-depositing solutions rose more directly toward the surface. Such shoots appear to exist in the upper portions of the Shenandoah-Dives vein system. An illustration that is somewhat diagrammatic but is based on actual conditions in the mine as well as they could be interpreted is given in figure 1, showing the effect of changes in strike and of gouge planes on localization of shoots.

Under the conditions existing along dike walls or other surfaces of discontinuity that were refissured, the nature and physical properties of the wall rocks have a minimum effect on the fracture systems formed and on the nature of open spaces. Original variations in the dike fracture would have the most important control on later openings. While although these variations may to some extent depend on the uniformity or lack of uniformity which the enclosing rock possessed, the portions of those dikes under consideration evidently occupied fissures determined by the average properties of great thicknesses of the crust and broke through the basement rocks and the overlying lavas with little apparent change in the general nature of the fracture. It will be seen from plate V, B, that the ore shoots worked from Arrastre Gulch in the northern portion of the Shenandoah-Dives mine occur partly in the flow-breccia member of the Eureka rhyolite and partly in the basal tuff-breccia member of the Burns latite and that at most places one or both walls of the vein are formed by the andesitic dike. The condition where both walls of the vein consist of dike rock is probably subordinate, and if the general nature of the vein is indicative, there is no ore localization that can be attributed directly to the chemical or physical nature of the different walls. If the wall rocks were the chief factors in controlling the richness and width of ore shoots we would be forced to conclude that the combination of Eureka rhyolite and dike rock was the most favorable condition; but it is far more likely that local structural conditions were the main factors.

If the foregoing deductions are correct, the principal changes that may occur at moderately greater depth are those related to changes in the mineralogy of the vein, or those

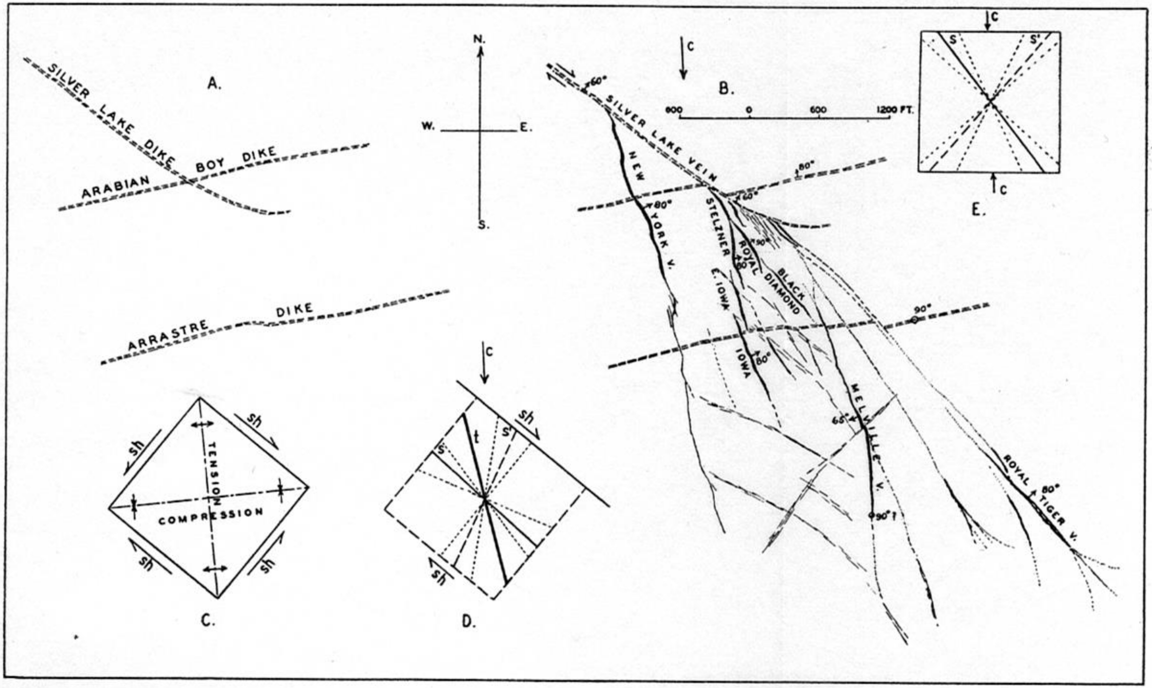

Figure 2. Silver Lake vein system.

A. Relation of Silver Lake and other dikes before displacement.

B. Relation of Silver Lake vein system to displacement of the dikes.

C. Axes of tension and compression and direction of maximum shearing stress (sh) in a body subjected to pure shear.

D. Interpretation of stresses and resulting fractures near Silver Lake vein: c, regional compressive stress: sh, shearing stress: s,s', shear fractures: t, tension fracture.

E. Interpretation of regional stresses in hanging wall of Silver Lake dike: s,s', shear fractures; **c,** regional compression.

caused by important changes in dip and strike of the dike. As shown in the cross sections, it appears more likely from the general nature and origin of the early tension fractures that the dike will steepen rather than flatten in depth, a factor likely to be more favorable than otherwise. Changes in mineralogy are likely to be important, but not enough evidence is at hand to permit prediction of such changes. Structural changes that may occur in depth as a result of greater pressures existing in the walls of open spaces and the possible reactions of different kinds of rock to these greater pressures are difficult to predict on the basis of our present knowledge of the physical properties of rocks in the San Juan region. This is one of the most important geologic problems related to deep mining, and possible methods of attacking these problems will be mentioned briefly in the concluding part of this paper.

Silver Lake vein

The Silver Lake vein, as may be seen from plate V, C, and figure 2, also occupies fissures along the walls of an andesitic or latitic dike that followed the same system of early tension fractures as the Shenandoah-Dives. The underground workings were not accessible, so that first-hand knowledge cannot be given as to the nature of fissuring that localized ore shoots along the Silver Lake dike. Descriptions of the mine fail to mention the occurrence of any dike alongside the vein, but it may be followed on the surface almost continuously, from the ridge just northwest of Silver Lake to the gulch below the Nevada mine. The dike was not actually traced beyond this point, but it probably continues much farther to the northwest. As the vein follows the foot wall of the dike so closely throughout this distance at the surface, it is probable that the vein fissuring, like that of the Shenandoah-Dives, was controlled by later movements along and near the dike walls. The net amounts of both horizontal and vertical movements along the Silver Lake dike can be approximately determined from displacements of the Arabian Boy and Arrastre dikes and from vertical displacements of recognizable zones in the volcanic formations. The horizontal component has been estimated at about 200 feet and the vertical component at about 100 to 150 feet, but the latter figure is less accurate because of the rapid variations in the geologic formations along the Silver Lake vein. The position where the dike leaves the vein and turns into the hanging wall in an easterly curve is indicated on the longitudinal section of the stopes by the hachured line, but the extension of this limit in depth is of course hypothetical. The stopes of the Silver Lake vein itself north of the point where the dike leaves the vein are not extensive if the data shown on plate V are complete, and according to Ransome,[27] ore from this vein is generally of lower grade than that mined from other fissures of the Silver Lake system, to be mentioned later. The average dip of the Silver Lake lode as determined from mine maps and other observations is about 60°. Probably the lack of irregularity along the strike and dip provided conditions rather unfavorable for extensive openings along the explored parts of the vein. If, however, the dike steepens in depth, the deeper portions of the dike walls would be more likely to possess irregularities favorable to openings comparable to the Shenandoah-Dives system. Here, as in the Shenandoah-Dives, changes in the wall rock should have but little influence on fissuring, inasmuch as it is controlled by the pre-existing surfaces of the dike walls. On the other hand, if the dike fails to steepen appreciably within 1,000 or 2,000 feet the chances for favorable fissuring within limits of practicable exploration are small. Such change or lack of change in dip of the dike might be determined by diamond drilling from the deeper workings and crosscuts.

Letter G or Titusville vein

The Letter G vein system includes several mines, as the Buckeye and Titusville,[28] and others that are to the northwest of the area shown on plate I and outside the special area described in this paper, although the workings of the Buckeye and Titusville extend underneath this area. Neither the Buckeye nor the Titusville mine could be examined in detail, but the surface above the Buckeye within the area mapped on

[27]Ransome, F. L., op. cit. (Bull. 182), p. 153.
[28]Ransome, F. L., op. cit. (Bull. 182), pp. 160-161.

plate I was studied briefly. It was found that at this mine the fissure system followed the walls of two or three dike injections of a compound nature, intruded side by side along the same line of early fissuring. It is probable that this dike system follows early tension fissures of the same age as those described for other parts of Arrastre Basin. The fact that the dikes have a strike of about N. 70° W., which is intermediate between the radial tension fractures and concentric dikes of Arrastre Basin, introduces some uncertainty as to the origin of this fracture system, but it may have been determined by torsional stresses. A vertical component of displacement of 100 to 125 feet was found near the Buckeye mine, but there were no means in this vicinity of determining the amount of horizontal movement. Stopes along the vein system are shown in plate V, E, and it is probable that the fissuring is of the same general nature as that along the northern parts of the Silver Lake and Shenandoah-Dives mines and was controlled by preexisting fracture surfaces, represented by the walls of the several dikes. If this is true, a change of formation in depth should not in itself affect appreciably the nature of the fissuring.

Little Giant Basin veins

Although perhaps most of the vein fissures of Little Giant Basin belong to another class, it is possible that some of the master fissures in the northern part of the basin belong to the group into which dikes were intruded, or that they opened during the early stage of the tension fissuring but were not filled by dikes in those portions exposed at the surface. Only shallow underground workings were accessible, and no dikes were detected, but completion of the study of this area may afford further data on this problem.

The principal fault fissure of the northern part of Little Giant Basin extends northwestward from Gold Lake through the Gold Lake, Black Prince, and Esmeralda claims, and then turns westward down the gulch toward the Iowa-Tiger mill. This fault fissure near Gold Lake dips about 80° W., but farther to the northwest it flattens to a dip of 55°-60° S.W., and thus dips in an opposite direction to the Shenandoah-Dives dike and vein. The hanging wall of this fault has moved down 50 to 125 feet vertically relative to the footwall with the displacement apparently increasing toward the north from Gold Lake. The horizontal component of displacement was not determined exactly, but to judge from the apparent offsets of cross dikes in Dives Basin along the continuation of this fissure system, it may have exceeded 150 feet. The horizontal movement appears to have been in the same relative direction as that of the Silver Lake and Shenandoah-Dives, but here the footwall of the fissure system moved southeastward relative to the hanging or west wall. From this relative movement we might infer that the southeasterly portion of the fault fissure would be the most open, and that the portion that curves toward the west down Little Giant Gulch would be comparatively tight, owing to pressure of the footwall against the hanging wall. In general, this inference seems to be borne out by the facts, as the widest body of vein material is exposed near and just below Gold Lake. South of Gold Lake the nature of the fissuring changes, becoming more like that of the southeasterly portions of the Silver Lake and Shenandoah-Dives systems, and is characterized by a strong tendency to feathering of the fissure systems. This type of fracturing does not belong in the class under consideration and will be described below.

The curving of the main fault westward toward the Shenandoah-Dives fault at the north suggests that the two may join beneath the talus deposits of Arrastre Gulch, and if their relative dips are maintained the two faults would necessarily connect in depth. On the cross section of plate V, A, the interpretation is therefore made that the master fissure of Little Giant Basin is a branch of the early tension fissure into which the Shenandoah-Dives dike was intruded. It was assumed in constructing the section that the Shenandoah-Dives fissure steepens in depth, and under these conditions the junction of the two would be at a greater depth than obtained by simply projecting the surface dips downward.

Vein Fissures Formed in Continuous Bodies of Rock

The vein fissures to be described next, although produced by the same forces as those that reopened the vein fissures along dike walls, have certain distinctive features. They were formed in relatively uniform or continuous bodies of rock, in contrast to those along boundaries between dikes and wall rock or along older fracture planes. The reaction of these uniform bodies of rock to fracturing more closely resembled the theoretical reactions of continuous bodies subjected to simple stress, and for this reason the vein fissures in them may be designated fissures formed in continuous bodies of rock. Such bodies are represented in Arrastre Basin by the portions of the formations that were not fissured strongly during the early stages of tensional stress, when the Silverton region was domed, and also those bodies that formed the relatively sound walls of the dike fissures of this early stage. According to this definition a large proportion of the fissure systems shown on plate I belong to this class, but those along dike walls and other fractures, where the rocks were appreciably broken or sheeted by the early systems of fractures, are excluded. In the following discussion, however, only a few of the more extensive of these fissures, especially those occupied by ore bodies, will be described.

Certain factors that controlled characteristics of the fissuring were the strength and other physical properties of each body or layer of rock under the conditions of stress that caused failure. The properties of the wall rocks were comparatively much less important where fissures formed along dike walls or followed preexisting tension fractures. This difference between the two classes of fissures is therefore fundamental in its application to mining problems and search for new ore bodies, for in each class quite different emphasis must be placed upon the principles of rock failure in attempting to predict the position of ground favorable to mineralization. This statement implies two rather sharply defined classes of fissures, but as a matter of fact the fractures developed in continuous bodies of rock were subject to still later movements, which somewhat modified the shape and dimensions of the original fissure. For many specific examples later modification of this kind is not sufficient to nullify the differences emphasized, and for some examples it increases the need for this distinction.

Silver Lake system

The Silver Lake system of fissures will be described first, because they are the most typical of this group and because more information is available on the underground workings of these mines. Only small parts of the extensive workings of these mines were accessible to first-hand study, but some of the shallower workings were open for short distances, and a study of these workings together with the published observations by Ransome[29] afforded a fairly complete picture of the ore bodies. The writer also had access to Ransome's original field notes on file at the Geological Survey and to mine maps that furnished other data than those appearing in published accounts.

Figure 2, B, shows the relations between the Silver Lake vein and dike and the veins occurring in the footwall, as represented by the New York, Stelzner, Royal, Iowa, Melville, and others. It has been long recognized that there were some important differences between the footwall veins and the master fissure of the Silver Lake lode, although differences in strike and grade of ore have been emphasized heretofore rather than fundamental difference in origin. Ransome described these lodes in two groups and observed that the miners then supposed that the Silver Lake lode was younger than the footwall lodes. His statement[29a] regarding the relations between the veins is as follows:

> "As the lodes of the second group approach the junction with the Silver Lake vein they become poor. Their courses are deflected toward the west, as indicated in the sketch. The country rock in the V near the junction is usually shattered and traversed by numerous quartz stringers. Some of these are irregular, but there is often noticeable a radiation of the stringers outward from the angle of junction. In some instances a breccia has resulted, the fragments being cemented by quartz and themselves altered into aggregates of quartz, sericite, and other secondary products by the action of the vein solutions. A close study of all exposures of such conjunctions of the veins of the two groups failed to show any evidence of different age. The filling of both sets of veins is continuous, as it would be in synchronously filled branches of a single fissure, or is separated by a clay gouge due to subsequent movement."

---

[29]Ransome, F. L., op. cit. (Bull. 182), pp. 145-159.
[29a]Idem, pp. 147-148.

Some of the most productive ore bodies northwest and west of Silver Lake were those of the New York, Stelzner, Royal, and Iowa, and these veins differ in certain important respects from the Silver Lake lode, in that they have been less disturbed by postmineral movement, and the ore was commonly frozen to the walls. They range from mere stringers or seams of gouge to a width of 10 or 12 feet, and generally dip from 75° NE. to vertical. Their intersections with the Silver Lake vein thus pitch northwest, as shown by the stope map of the New York vein in plate V, D. The ore bodies were usually more regular and of higher grade than those along the Silver Lake dike and have been stoped more or less continuously within the bounds of the larger ore shoots. The Melville vein shows more movement and gouge formation along the walls than the other footwall lodes. It dips southwest, in an opposite direction to most of the veins of this group, but toward the south it steepens to a more nearly vertical dip.

The structure of the Iowa vein shows that some opening occurred during ore deposition, as there was brecciation and reopening along certain bands of vein material. Movements along the vein walls of all veins of Arrastre Basin are known to have continued intermittently from sometime preceding the start of vein formation to sometime subsequent to the deposition of the latest vein material. Evidence has been presented above to show that the major movements along dike walls preceded ore deposition, and as the footwall fissures at Silver Lake contain essentially all stages of vein material, it is probable that they were likewise opened during this earliest and strongest rock movement. As the footwall veins contained a greater proportion of massive sulphides carrying silver and gold, which were deposited later than the low-grade sulphides and quartz, it probably follows that later movements along the different fissures were more effective in opening these footwall veins than in producing openings along the dike itself. This is not due to the amount of this movement but to its special nature and indicates that the footwall veins were formed by simple tensional openings of the country rock and did not share in the extensive differential movements along the walls of the Silver Lake dike.

That this is probably the correct explanation of the differences in grade and nature of the veins becomes apparent from a theoretical consideration of the mechanical origin of the fracture systems. Figures 2, A and B, which illustrate the relation of the dikes near Silver Lake both before and after their displacement, show that shearing stresses must have been induced in the continuous body of rock southeast of the termination of the Silver Lake dike by this shifting movement, and that rotational stress or a shifting direction of shearing force would also be induced in the footwall of the dike by the friction and pressure of the moving hanging wall block. In a body of rock subjected to nonrotational stresses, as in figure 2, C, the axes of tension and compression are at right angles to each other and the planes of maximum shear occur at about 45° to these axes; but, as rotational stresses are commonly generated during actual failure, it is necessary also to consider the combination of different stresses existing in the rocks at Silver Lake and their effects upon this simple relation.

The volcanic rocks just north of Silver Lake and in the hanging wall of the Silver Lake dike are divided or sheeted by numerous essentially vertical shear planes, most of which strike about N. 25°-40° W., but joints of another less prominent and more irregular set strike northeast. The small movements along the walls of these joint fissures and their conjugate relations to one another indicate that they were probably produced by a compressive stress applied to the rocks approximately in a north-south direction. In the area shown on plate I, only the northwesterly joints are prominent enough to be mapped in most places; for some reason the conditions favored their strong development. Figure 2, E, thus illustrates the relation between shear fractures and a simple compressive stress applied to bodies where the maximum relief is in an east-west direction. These relations are closely comparable with the ideal condition illustrated by figure 2, C, where an axis of compression lies at right angles to an axis of tension. The shear fractures represented by the lines S and S′ in figure 2, E, as represented by the sides of the parallelogram and marked by the arrows (sh). By observation it is known, however, that the planes of greatest shearing deformation in different materials vary with the properties of the material and with the rate of application of the force. Actual limits in the variation of the position of these conjugate shear joints seen north of Silver Lake are indicated by the dotted lines in figure 2, D or E. At Silver Lake the stresses that caused the conjugate joints were probably the result of radial compression induced by subsidence north of the Animas fault, and these stresses probably at the same time caused the shearing along the Silver Lake dike.

If the regional compression is combined with a shearing or rotational stress, as shown in figure 2, D, the planes of maximum shearing and tensile stress deviate from their position characteristic of the states of nonrotational shear or compression. As shown by the actual position of the footwall lodes, this is a minor change except where the planes of maximum movement are approached; here the tendency for the major fractures to become deflected toward the west is very noticeable. The change in strike and the tightening of the New York, Stelzner, and Royal veins as the Silver Lake fault is approached are described in the quotation from Ransome. The weakness of the ground between the main fault and the footwall fractures at this junction and its proximity to the moving hanging wall probably account for local brecciation and the tightness of the footwall fissures.

As these footwall tension fractures, except close to the Silver Lake fissure, make a considerable angle with the plane of this major fissure and with the direction of shifting of its walls, the footwall fractures would tend to open by tension during the movement along the Silver Lake fault. Furthermore, if, as appears probable, some relief from compressive stresses was afforded in an east-west direction, slight rotation of these blocks would permit the openings to be still further enlarged. Relaxation of the compression sufficient to permit settling of the hanging wall of the Silver Lake fault, which probably occurred, as in the Shenandoah-Dives, chiefly after the early epoch of horizontal shifting, would also tend to open farther both shear and tension fractures in the footwall. This may account for the fact that some of the conjugate joint sets in the immediate footwall are slightly opened and contain fillings of quartz, galena, chalcopyrite, and other sulphides. A few northwest fissures, such as the one near the south termination of the Iowa ore shoot, were sufficiently opened to encourage mining. Similar fissures were encountered in the underground workings of the Iowa mine, but commonly these northwest and northeast fractures do not contain large ore bodies.

The country rocks of these veins, as seen from plate I and the longitudinal section of the New York vein (plate IV, D) consist of the tuff-breccia member of the Burns latite, the latite breccia beds of Round Mountain, and the massive and fluidal facies of the Burns flows. The Eureka rhyolite underlies the region at depth and was found in the lowest workings on the New York vein. Most of the productive shoots of the veins lay between walls of the breccias or of the massive and fluidal facies of the Burns flows. Only shallow parts of the underground workings were open, so that correlation of the different rocks with variations in the fracture systems was not possible. The fact, however, that some of the other ore shoots behaved like that of the New York vein and did not extend downward as strongly into the underlying Eureka rhyolite, suggests that the latite breccias and flows reacted more favorably to the various stresses than the Eureka rhyolite.

It is well known from studies of structural material that the kind of fracturing and the angles between the planes of fracture vary with different kinds of material. Certain brittle bodies, such as concrete or hard brick, fracture with acute angles facing the direction of compression, but more elastic and plastic materials fracture with less acute or obtuse angles facing the direction of compression. There is considerable variation in the physical properties of the different volcanic rocks of the San Juan region, and it has been a common experience to find that certain rhyolite flows contain comparatively tight and essentially barren fracture zones, whereas andesitic or latitic rocks along the same line of fracturing contain wide and productive ore bodies. This may perhaps be explained by the postulate that continuous bodies of the rhyolite flows underwent sufficient elastic and plastic deformation under the impact of earthquake shocks and crustal stresses to yield and change their shape by small deformations distributed through large masses of rock, whereas more rigid or brittle rocks failed to distribute the strain and therefore broke along different and coarser systems of fracture. The amount of open space afforded by each single fracture would of course be much greater in the andesitic rocks, which had but few fractures as compared with the many small ones formed during the distributive yielding of the rhyolitic rocks. Under certain other conditions, as along zones of shear, the elastic or plastic yielding of rocks tends to simplify the final fracture (see pp. 209-211).

It may be that only certain kinds of rhyolites are unfavorable under the conditions described. Nevertheless, in view of the fact that deep explorations beneath the New York ore shoot from the Unity and Last Chance tunnels did not find large ore bodies, it seems safe to conclude that the upper portions of the Eureka rhyolite flows here are unfavorable rocks under the particular conditions of fissure formation described above. It would not be justifiable to assume from the evidence now available that the deeper flows of the Eureka formation were likewise unfavorable, but it is possible that field and laboratory studies of the elastic properties of the different rocks in their relation to fissuring might provide a firmer foundation upon which to base such speculations.

The Royal Tiger lode, which probably forms the southeastward continuation of the zone of shearing along the Silver Lake dike, is somewhat different from the lodes that would result from movements controlled by dike walls. Ransome[30] said that the Royal Tiger vein presented several characteristics foreign to the Silver Lake lode, but these differences are structural rather than mineralogic. The vein fissures have an average dip of about 80° NE. and thus are much steeper than the normal dip of the Silver Lake vein. At places the lode is

[30]Ransome, F. L., op. cit. (Bull. 182), pp. 159, 160; also field notebook.

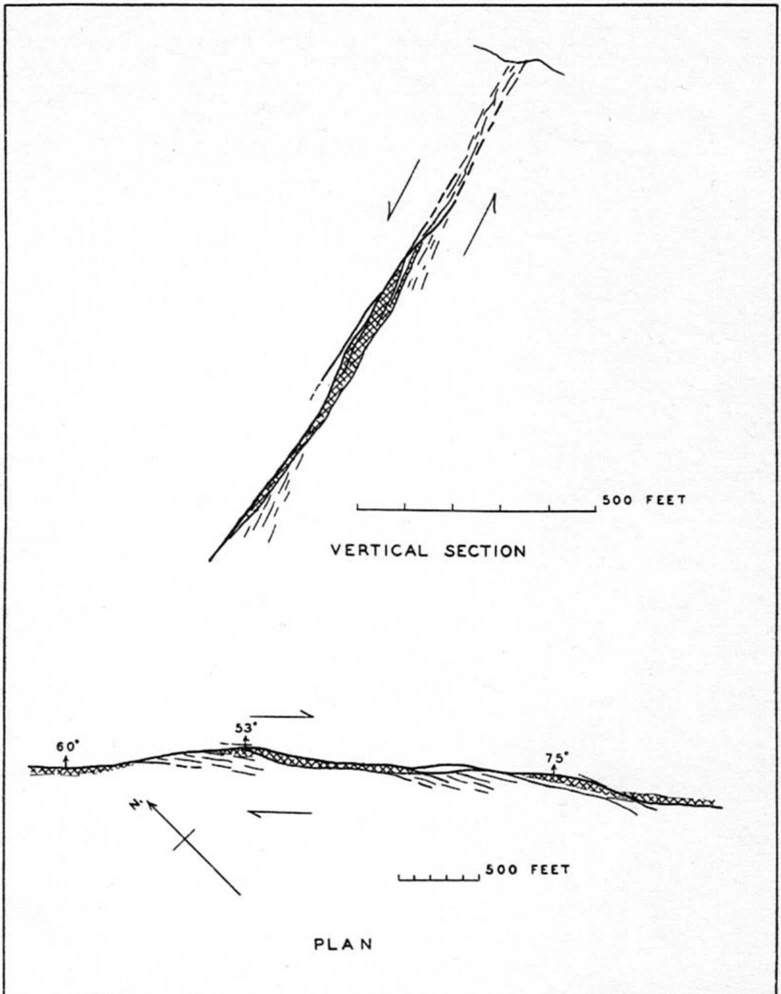

Figure 1. Plan and vertical cross-section of the Shenandoah-Dives vein and ore-shoots, representing somewhat diagrammatically relation of ore shoots to changes in strike and dip, and to gouge planes (heavy lines). The Shenandoah-Dives dike (Mayflower dike) is omitted to simplify, and width of ore shoots and vein exaggerated. Ore shoots indicated by cross-hatching.

divided into two branches separated by a distance of 30 or 40 feet, but where these branches come together the lode consists of two main veins separated by irregular stringers traversing blocks of shattered country rock. At other places the lode consists of stringers in a wide zone of shattered rock. There is less gouge than in the Silver Lake lode, but there may be gouge on both foot and hanging walls of the lode. Lodes of this kind are believed to be characteristic of fissuring along zones of shearing in continuous bodies of rock where the shears are not initially localized along dike walls or other preexisting fracture surfaces. The nature of the diagonal fissuring and shattering of the country rock is discussed in the following section on vein systems of Dives Basin.

Shenandoah-Dives system

The Shenandoah-Dives vein system, like that of the Silver Lake, consists of two parts—one, already described, that follows the walls of the dike and another that includes the upper parts of the vein north of Little Giant Mountain and the greater part of the entire vein system southeast of Little Giant Mountain. On plate V, B, the known extent of the dike is indicated by the underground workings from the Arrastre Gulch side and by its outcrop up to an altitude of about 12,500 feet. Beyond these known locations the extent of the dike is entirely conjectural, and the concealed limits suggested on the section are only two of many possibilities and are based upon the assumption that the cross dikes (concentric dikes) may have deflected the dike from its normal course. It is probable that the dike is not present in the North Star workings but this assertion is based solely on evidence that dike rock could not be found at the surface near these workings. Examination of the Dives workings at an altitude of about 12,200 feet in Dives Basin showed that there is no dike along the vein fissures. The uniformity in strike and strength of the lode southeastward from Little Giant Mountain suggests, however, that the dike may occupy the vein fissure at some depth below Dives Basin. The main lode southeast of the known limits of the dike is therefore like the southeastward continuation of the Silver