plate 3 of Professional Paper 54. As already intimated, these fissure zones, both within and outside of the main crater, are believed to have resulted mainly from mild regional compression and shearing and to a minor degree from the settling of newly consolidated breccia, upward thrust of later explosive eruptions or of rising lava, and internal expansion due to the forcing of molten rock into certain fissure zones. Any one or more of these forces may have acted in different parts of the breccia, and the resulting systems of fissures should differ accordingly; but some sets of fissures are equally attributable to two or more of these forces, and the interpretation of their origin is correspondingly difficult. However, as the distribution and continuity of ore shoots both downward and horizontally depend upon the character and therefore the origin of the fissures containing them, the interpretation is a necessary basis for conclusions regarding continuity. The bases for interpretation are therefore considered in the next few paragraphs, which doubtless are the most difficult to read in the entire paper.

The fissure systems along which the complex crater was developed must have influenced the direction and distribution of fissure systems formed later by forces from below or from the outside. Their approximate positions are shown in figure 10. The generalized arrangements of fissure systems that would be expected to result from the different internal and external forces mentioned above are shown diagrammatically in figures 5 and 6 and 11-16.

Effects of internal forces.—Fissure systems attributable entirely to contraction and upward thrust in and above any of the subcraters should have patterns resembling those in figures 5 and 6. Contraction fissures due to settling would be developed especially in the upper, flaring parts, and the most conspicuous of them would strike about parallel to and dip toward the nearest crater walls. Some of the fissures in different parts of the district, especially the fissure zone filled by the Isabella dike, suggest such an origin. Further shrinkage or disturbance of the rock between parallel major fissures could produce minor transverse fractures. Settling in the lower, more constricted parts of the subcraters would tend to develop fissures or shear zones closely parallel to the comparatively straight, steeply dipping walls of the crater and minor fissures dipping toward the walls; but the gradual narrowing of the subcrater with increasing depth and the tendency of its wall to close in, together with the increasing load of overlying breccia, would counteract or even exceed the effects of shrinkage, and the directions of fissuring would eventually become more dependent on the resultant of these

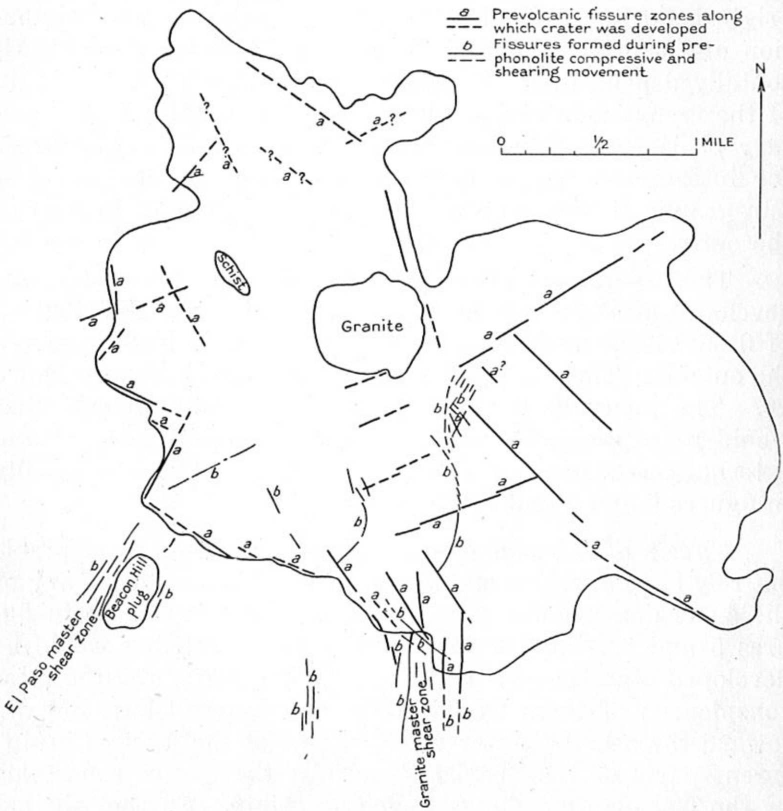

Figure 10.—Principal prevolcanic fissure zones that controlled development of the Cripple Creek crater; also principal fissures developed during subsequent, prephonolite compression.

compressive forces. Two conjugate sets of fissures with strikes at angles of somewhat less than 45° to this resultant force would be possible, but no fissures clearly attributable to such a cause have been noted.

Upward thrust caused by a rising column of lava or an explosion would develop shear zones along the prevolcanic fissures beneath the subcraters and extend them upward for some distance into the overlying breccia, but the shear zones on reaching the upper flaring parts of the crater would spread complexly, sending oblique branches upward toward the receding walls and forming transverse fractures in the slabs between the branches. The prevailing dips of the branches would decrease upward and would form a considerable angle with fractures due to contraction and settling. The "flats" in the Forest Queen and adjacent mines (fig. 47) are attributable to such a movement. If the upthrust were concentrated at some point such as the intersection of two fissure zones rather than along a fissure zone, it could develop a radiating or diverging set of additional fissures similar to those in the northeastern part of the district. (See p. 376.)

Internal expansion of the breccia mass implies the intrusion of additional material, presumably along prevolcanic fissures and their upward extensions in the central part of the mass, and a consequent outward push that would open fissures about normal to the edges of the intruding body, and therefore with a transverse to radial arrangement, to conform to its elongate, ellipsoidal, or spherical shape. Such fissures would be likely to curve toward any older fissures nearby, and older fissures crossed by the intruding mass would be reopened, relieving the local strain without the formation of new fissures. The resulting pattern is illustrated diagrammatically in figure 11, which is a simplified illustration of the structural relations of the main syenite mass. Intrusive masses that bulge considerably are likely to produce local conjugate "flats," or fissures with small angles of dip, which are illustrated by intersecting flats in the El Paso mine, west of the Beacon Hill plug. The more accessible fissures formed by these outward thrusts would be filled with dikes branching

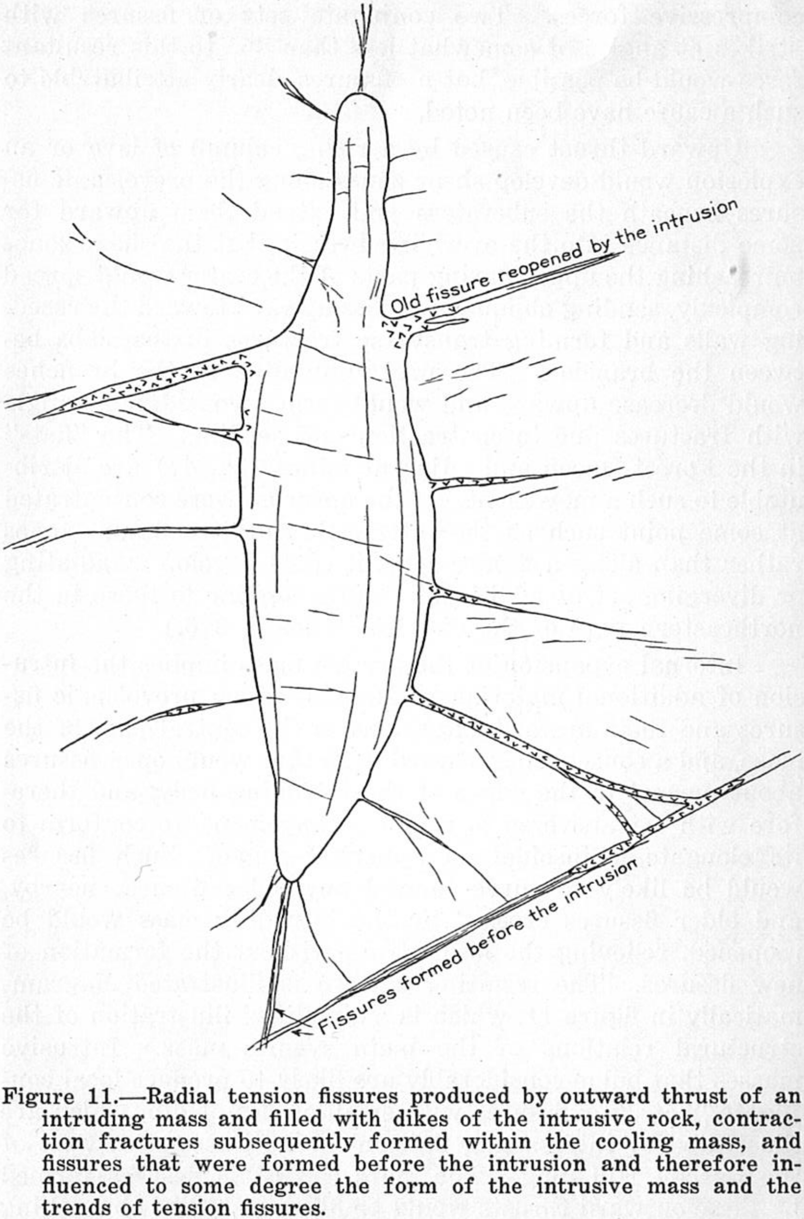

Figure 11.—Radial tension fissures produced by outward thrust of an intruding mass and filled with dikes of the intrusive rock, contraction fractures subsequently formed within the cooling mass, and fissures that were formed before the intrusion and therefore influenced to some degree the form of the intrusive mass and the trends of tension fissures.

from the intrusive body. Subsequent contraction of the solidified dikes would reopen these fissures to some extent and develop longitudinal and transverse fractures within the dikes, and similar contraction within the main intrusive body would develop fractures parallel and normal to its sides.

Effects of external or regional forces.—Mild regional compression and shearing could produce several fracture patterns, which would be locally influenced by the uniform or diversified character of the rocks and the distribution of preexisting fissures. Simple compression of homogeneous material would produce a simple system of conjugate fractures; compression with rotation would produce a less distinct conjugate system together with tension fractures; compression of a mass containing a cylindrical hole or core of less resistant material would produce, according to Nadai,[39] four fracture or shear zones that radiate from the core. These processes all appear to have been active to some degree in the Cripple Creek district. The origin of the major fissure zones in granite is attributable to Nadai's principle, and their subsequent modification, as well as the arrangement of productive fissures throughout the district, appears to be the result of two shearing or rotational couples that caused a tendency of the eastern and western parts of the district to move northward with respect to a relatively rigid middle zone that contains the granite "island" and the granite prongs south of it.

The ideal arrangement of fissures formed by simple compression of homogeneous brittle material is illustrated in figure 12 and that of fissures formed by a combination of compression and shearing, or a rotational stress, in figure 13. In either case two sets of conjugate fractures are developed, although under rotational stress only one set is likely to be prominent. The fissure system of the Eagles mine (fig. 42) resembles figure 12, although its complete history is more complex, and systems in parts of the Portland, Elkton, and other mines (figs. 27 and 44) are attributed to the rotational stress illustrated by figure 13.

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[39] Nádai, A., Plasticity: Eng. Soc. Mon., pp. 96-97, McGraw-Hill Book Co., 1931.

Besides these two main directions of conjugate fracturing, local cleavage fractures may develop in material that has been subjected to pronounced shearing within a shear zone. The positions of the cleavage fractures indicate the direction of shearing, as shown in figure 14, which diagrammatically illustrates conditions in the Eagles mine.

Whatever the exact direction of compression, any preexisting fractures, if not well healed, are likely to determine the direction of at least one of the sets of fractures and, if they lie at a small angle to the direction of application, are likely to become the direction of shearing. The related tension fractures are likely to form steplike or en echelon groups, no member of which is very continuous either horizontally or downward. Where the shearing component weakens, the fissure along which it takes place may pass into a steplike zone of tension cracks, and if the shearing force is weak throughout a considerable area, the actual shearing movement may be taken up by a slight warping of the material and only the steplike zones of tension cracks be in evidence. This steplike arrangement, in part independent of and in part clearly associated with shear zones, is a common feature throughout the district. Where the ground is broken into a group of blocks

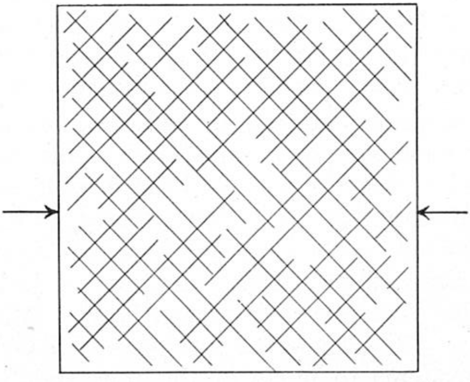

Figure 12.—Ideal relation of fractures to simple compression in homogeneous material. The fractures form two sets of a conjugate system, at 90° or less to each other and 45° or less to the direction of compression. The more brittle the material and the weaker the force the smaller the angles.

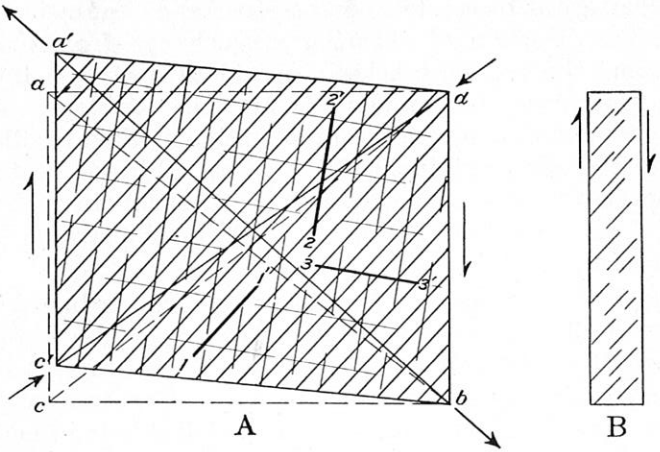

Figure 13.—Relations of fractures to rotational stress or shear. In A the diagonal **a′b** is longer than **ab** of the original square and marks the direction of tension. Tension fractures (1-1′) form normal to **a′b.** Compression fractures (2-2′ and 3-3′), less common than tension fractures, may form at about 45° to the direction of compression, and one set (2-2′) will nearly coincide with the actual direction of shear. If this set develops, continuation of movement is likely to occur as slipping along it, and the resulting structure will consist principally of a few master shear fractures or faults and intervening oblique tension fractures. B represents tension fractures in a narrow elongate block between two shear zones.

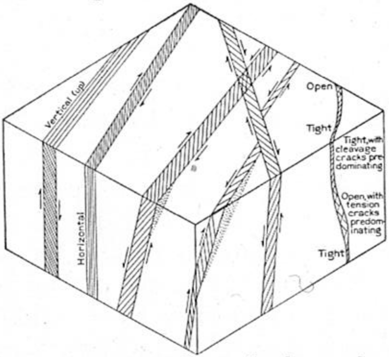

Figure 14.—Cleavage fractures formed along shear zones. Arrows show directions of horizontal and vertical components of movement. Planes outlined by oblique cleavage fractures and connecting dash lines are about normal to inclined directions of movement. In the zone on the extreme right both cleavage and tension fractures are present along the tight and open parts of an undulating fissure. Drawn from exposures in the Eagles mine.

that are forced to rotate and therefore slide against one another, the direction of shearing may change from block to block, and the tension cracks in one block may pass into the shear zone along the boundary of an adjacent block. Where the force acts in one general direction but is thus modified or deflected locally, certain blocks may be subjected to torsion and develop local sets of fractures at about 90° to each other and 45° to the axis of torsion, a condition illustrated in the Queen mine.

Regional compressive and shearing stresses in the Cripple Creek district were evidently affected by the difference between the relatively weak breccia in the crater and the stronger granite that surrounds it. The effect was evidently similar to that produced around a cylindrical hole in material under compression, though to a less degree and in a much less regular manner owing to the irregular form of the crater. As shown by Nadai,[40] "Stresses in elastic bodies are increased or concentrated at concave boundary surfaces in a member subjected to pure tension, compression, or shear. At a sharp reentrant edge stresses are theoretically infinite. Even if the stresses in the neighborhood of a reentrant edge have only small values, nevertheless these may be sufficient to produce plastic deformation or even fracture at the corners. In compressed test pieces of brittle material * * * which contain small notches, failure by fracture begins at these notches."

The results of experiments illustrating this principle are shown in figure 15.

If the Cripple Creek crater were a simple cylindrical or slightly tapering conical form, four broad shear zones converging and narrowing toward the crater, as in figure 15, might have been formed; but as the crater is very irregular in form and evidently is underlain by elongate subcraters controlled by prevolcanic fissure zones (figs. 8 and 10), no such symmetrical arrangement is to be expected. A simple tendency of the walls of the elongate subcraters to close in might start the development of shear zones near the ends of their long sides, and some of the fissure zones in granite conform

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[40] Nádai, A., Plasticity: Eng. Soc. Mon., pp. 96-97, McGraw-Hill Book Co., 1931.

fairly well to such a development—for example, the El Paso zone, in line with the southwest corner of the McKinney-Elkton subcrater; the zone marked on the topographic map of the district by a large number of shallow shafts south of the Elkton mine; and the fissures filled by dikes and veins near the Index and Conundrum subcraters. The broad fissure zones of northerly trend in the Granite and Independence groups of mines are in appropriate positions with respect to the Queen-Ajax and Portland subcraters, but no complementary zones of easterly trend can be definitely recognized. It is more likely that the McKinney-Elkton, Queen-Ajax, and Portland subcraters are separated at so great a depth that, so far as fissure zones at the present granite surface are concerned, they have acted as an irregular unit, and the El Paso fissure zone on the west and the Granite and Independence zones on the east have formed as complementary master shear zones. (See fig. 10.) The minor zone south of the Elkton mine may mark a minor shear induced by the east end of the overhanging wall of the crater.

Although the stresses at sharp reentrant edges are theoretically infinite, according to Nadai, it is a question whether

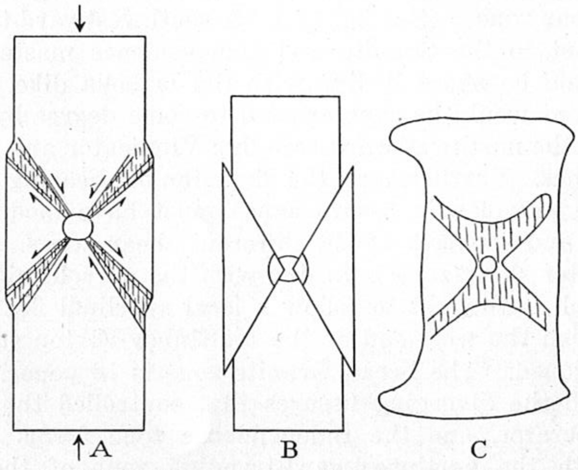

Figure 15.—A, B, Slip lines on the sides of a paraffin prism having a hole and stressed in compression; C, flow figure on compression test piece of steel having a hole. (After Nádai, A., op. cit., figs. 72 and 74, p. 97; fig. 93, p. 105.)

the stresses developed by the tendency of the granite walls to close in against the breccia in the subcraters were sufficient to account for such long shear zones as the El Paso, Granite, and Independence zones; but a mild regional compression from the south or south-southwest could readily account for it. The details of fissuring throughout the mines studied by us, and considered in the different mine descriptions point to a compression from a general southerly source, and the positions of these major shear zones in granite, therefore, seem consistently explained.

The absence of corresponding shear zones on the north side of the crater may be attributed to the comparative shallowness of the northern subcraters and the probable moderate slope of the northern walls of the deep, southern subcraters. A northern, southeastward trending complement of the El Paso master shear zone would lie approximately beneath the Conundrum subcrater, and its development would be counteracted to a considerable extent by the local fissure zones of northeast and east-northeast trend west of the Conundrum and Index subcraters; but the tendency of ground in and adjacent to the western part of this subcrater to expand along intersecting fissures accords with what would be expected west of the shear zone. (See fig. 15.) A southwestward-trending complement to the Granite and Independence master shear zones would be about in line with the Isabella dike, and its development would be counteracted to some degree by shearing along the northwestward-trending Vindicator and Isabella fissure zones. Furthermore, the diversion of shearing stresses along the prevolcanic fissure zones must have modified the direction and strength of the different shear zones. The El Paso master shear zone is in line with the prevolcanic fissure zone which is thought to follow a local synclinal flexure and along which the west end of the McKinney-Elkton subcrater was developed. The broad Granite zone is in general alinement with the diverging fissures that controlled the Queen-Ajax subcrater, and the Independence zone forms a small angle with the northwestward-trending zone of the lower Portland levels. (See fig. 10.)

As the compression from the south tended to thrust the ground between the El Paso and Independence zones into the crater, it would compress the more eastward-trending boundaries, develop shearing along the northwestward and northward-trending fissure zones of the subcraters, and produce tension fissures of northeasterly trend adjacent to them. The slight northerly bulge of the granite contact at the Elkton mine favored the production of a local conjugate fissure zone with shearing along fissures of north-northwest trend and tension along fissures of north-northeast trend. (See fig. 44.)

Adjustment west and east of the deep part of the crater that lay between the converging master shear zones was also doubtless controlled by those prevolcanic fissures whose east and northwest trends conformed to those of any new fissures that would have been formed. Even the details of movement along some of them, especially in the Vindicator zone, accord with the adjustment that would be expected.

This compressive movement acted intermittently, reaching a maximum before the phonolite stage of intrusion and subsiding until after the final stage of ore deposition. During its subsiding stages temporary relaxation doubtless took place, producing local tension effects where compression effects had predominated. After the compression had completely subsided, further relaxation together with regional vertical uplift produced postmineral faults, only two of which of any considerable size—the Thompson fault, in the Elkton mine, and the Ajax fault, in the Granite (Ajax) mine—have been recognized within the district.

The local concentration of force along the shear zones must have subsided after the breccia had become well compacted, and thereafter the regional compressive movement was more evenly distributed; but the large mass represented by the granite and schist "islands" and the narrowing of the deep part of the crater between the granite island and the granite prongs to the south offered more resistance to compression than the breccia to the east and west and induced rotational or shearing stresses whereby both the west and east walls of the main complex crater tended to move northward. This tendency was favored by the positions of some of the more continuous fissures, particularly those in the Vindicator and Isabella zones, which trended northwest and could be reopened as tension fissures in the eastern part of the district. Fissures of similar trend in the western part, however, would have been about normal to the local direction of compression, corresponding to set 3-3′ in figure 13, and only fissures of northeast and east-northeast trends were likely to be formed or reopened as tension fissures. The basaltic dikes (fig. 1) and the veins represented in plate 3 of Professional Paper 54 conform generally in direction to the tension fissures that could have been formed by these rotational stresses, although there are some exceptions. (See page 286.)

All the movements described in the foregoing paragraphs—contraction, upthrust, and expansion within the crater and regional compression modified by shearing and torsion both within and around the crater—are illustrated in the mines of the Cripple Creek district. Some fissures point to only one kind of movement, but many suggest several successive movements of similar or different kinds. On the whole, however, compression modified by shearing and less commonly by torsion has been the most effective, especially in the stages just prior to ore deposition. With these general conclusions in mind the different stages of igneous intrusion and mineral deposition will be considered in historical order.

Intrusive processes

The geologic map (fig. 1) emphasizes the dominance of intrusive masses in the east-central part of the main crater and strengthens the impression that this, the deepest part of the crater, was the most active. The large, irregular masses of latite-phonolite and phonolite shown on the map, however, are somewhat misleading, as they are all of sill-like or knoblike form, and those whose roots have not been destroyed by relatively late explosions taper downward into dikes at shallow depths. Dikes of latite-phonolite are numerous in certain other places—for example, in the mine workings of the McKinney-Elkton, Conundrum, Gold King, and Forest Queen subcraters and in the School Section mine, which is on a fissure zone extending northeastward from the Isabella subcrater. Failure to show these dikes in figure 1, therefore, gives the impression that the latite-phonolite is more restricted than it really is. These dikes, however, are almost entirely confined to the main crater and the minor craters of Globe Hill and Mineral Hill, and the fissuring that preceded their intrusion was evidently due mainly to local disturbances within and beneath the craters. One dikelike mass, shown in figure 1, projects northwestward from the breccia of Mineral Hill into the granite and evidently fills a reopened prevolcanic fissure. A small dike of north-northeast trend was noted in 1933 in the north end of level 7 in the El Paso (Nichols) mine and suggests either a reopening of the local prevolcanic fissure zone or an early development of the El Paso master shear zone.

A few of the latite-phonolite dikes follow or closely parallel the straighter contacts of the crater—for example, in the Portland mine and in the Roosevelt drainage tunnel west of the Elkton mine—but most of them fill fissures in the breccia. In some mines, notably the Cresson (fig. 3) and Eagles, they follow a conjugate system of intersecting fissures, one set of which is roughly parallel to the fissure zones along which the crater was locally developed. These conjugate systems imply a mild renewal of movement that reopened the prevolcanic fissures and extended them upward into the breccia, at the same time developing an associated set of tension fissures. Some upward thrust, due either to renewed explosive activity or to the latite-phonolite magma itself, doubtless took place, but the steep dips of the fissure sets indicate a force with a considerable horizontal component, such as could result from a beginning of the compressive movement from the south. The magma, rising from beneath the crater along reopened prevolcanic fissures, continued upward along the newly formed conjugate fissures in breccia. On reaching the higher parts of the crater it was able to lift or thrust aside large masses of breccia and to expand into knoblike masses or spread along "flats" and form sill-like masses.

The large syenite mass also tapers downward but is still of considerable size in the lowest mine workings. Although its longest dimension lies in an east-northeast direction, it sends branches or dikes mainly along fissures of northwest trend (fig. 40, p. 373), and also along a marked zone of north-northeast trend, coincident with the "east" vein system of the Portland mine. Its outline strongly indicates that it forced its way upward along a zone of east-northeast trend, thrusting the walls apart and sending dikelike branches along the northwest fissures that were opened or reopened by tensional forces normal to the outward thrust of the intruding syenite. The process conformed to that shown diagrammatically in figure 11. This movement, developed entirely beneath and within the crater, implies a suspension of lateral compression from the outside.

Smaller bodies of syenite isolated from the main mass include a dike in the Eagles mine, which trends east-northeast and is in general alinement with the small mass mapped west of the Logan shaft; a dike near the west-northwestward-trending breccia-granite contact in the Roosevelt drainage tunnel; and the small mass along the west-northwestward-trending contact near the Ophelia (Moffat) tunnel and Index mine. The last two occurrences indicate a reopening of fissures along which the crater was developed, and the first suggests the reopening of a prevolcanic fissure parallel to that along which the large syenite mass was intruded.

The dikes and masses of phonolite, as shown in figure 1, are much more widely distributed than any of the other intrusive volcanic rocks of the district. Their entire extent, shown in the Pikes Peak folio, is embraced in an elliptical area that centers in the Cripple Creek district. The dikes, however, do not show a marked radial arrangement either within or around the main crater and are not to be explained entirely by a vertical upthrust of the rising phonolite magma, although such an upthrust was doubtless a partial cause of the fissuring. Certain of the dike-filled fissures along or near the southern edge of the crater—for example, the N. 65° W. dikes cut by the Roosevelt drainage tunnel between the Elkton mine and Beacon Hill and the Hamlin dike, which strikes east and dips 45° N. in the Granite (Ajax) mine—may have been formed or reopened by such an upward thrust rather than by regional compression from the south; but most of those mapped south of the crater have trends that conform to the shear and tension fissures that would result from such a compression. It may be significant that these dikes are largely concentrated in an area that broadens southward between the El Paso and Independence master shear zones, where deformation was intensified. Some of these dikes may fill prevolcanic fissures that were favorably situated for reopening, and others may fill fissures that originated during the culmination of the compressive period, which evidently preceded the phonolite stage of intrusion and made the relatively wide distribution of dikes possible.

No attention has been given by us to the phonolite dikes north, west, and east of the crater, but their positions, shown in figure 1, suggests a similar explanation. The dikes within the breccia mass in part fill upward extensions of reopened prevolcanic fissures and in part fill shear zones and tension fissures that were newly formed during the culmination of regional compression. Those in the eastern part of the mass fill fissures of northwest trend, which are the master fissures in the eastern subcraters, and also the large fissures of north-northeast trend that branch from them. Those in the western part follow the main fissures of north-northeast trend and their branches. Those mapped in the Raven Hill area have north-northwest trends intermediate between the converging directions of master fissures.

The large masses of phonolite, in contrast to those of latite-phonolite, are almost all outside of the main area of breccia. It may be that the masses of latite-phonolite so greatly increased the rigidity of the volcanic rock as a whole that subsequent fissuring was more continuous and favored the formation of simple dikes rather than large sill-like masses. Some of the phonolite dikes that cut the latite-phonolite masses may have passed upward into sill-like masses that have been completely eroded. The relations of the masses at and east of Bull Cliff suggest such an origin. The masses at Grassy Creek, Big Bull Mountain, Straub Mountain, and Grouse Hill rest in part on thin layers of breccia or sedimentary rock and in part on the granite floors below them. Their origin is most clearly illustrated at Grouse Hill, where the phonolite rose along well-defined fissures in granite to the base of the overlying rocks and spread in the form of a thick sheet or laccolith, lifting them in part and also gradually working its way obliquely across the bedding as its intrusive force became weaker.

The basaltic dikes were intruded after a weak renewal of compression that further deformed the breccia and older intrusive rocks and the phonolite dikes also. Outside of the main crater basaltic dikes are very scarce. A few are found in the surrounding granite along the Ajax and Independence shear zones and near the Index mine. The direction of newly formed tention fissures was at a slight angle to that of the phonolite dikes, as illustrated diagrammatically in figure 16. In some places the angle was so small that a new fissure, as well as the basalt intruded into it, on reaching a phonolite dike was likely to follow the phonolite dike for a short distance before resuming its regular course. A most striking example of this slight change in direction is afforded in the Los Angeles mine, where dikes of latite-phonolite, phonolite, and basalt converge, follow the same course for a short distance, and then diverge, as shown in figure 17. A similar relation is poorly shown between two basaltic dikes, the Funeral and Sliver dikes, in the Cresson mine, and between the "big basalt" or Sevey dike and the "little basalt dike" in the School Section mine. The eruption of the Cresson blowout, which followed the intrusion of the basaltic dikes, marks a local interruption in the period of shearing, when a late accumulation of volcanic gas beneath the main crater caused an explosion along the intersection of a prevolcanic fissure with these dike-filled fissures.

Fissuring subsequent to intrusion.—Further renewals of shearing in the same general directions took place during mineral deposition, which occurred in three principal stages, separated and followed by slight shearing movements. The first of these stages may even have preceded the eruption of the Cresson blowout, as the relations between the earliest barren veins and the blowout have not been satisfactorily determined. The productive veins, or ore shoots, were formed during the second stage, and where fissures formed at this time intersected the earliest veins or any of the dikes at low angles, or even followed them for short to considerable distances (fig. 17), ore shoots were likely to form along the veins or dikes. Experience in some small part of the district may have given operators the impression that one particular kind of dike was most favorable for the deposition of ore, and accordingly some may ascribe it to basalt, other to phonolite, and still others to latite-phonolite or syenite. However, it is not the kind of dike but the reopening of any dike-filled fissure during the second stage of mineral deposition that accounts for the ore shoots. Other fissures formed or reopened at the same time and independent of any dikes were filled with ore if situated where the ore-forming solutions could reach them. The master shear zones, however, which represent persistent directions of weakness, opened repeatedly and accom-

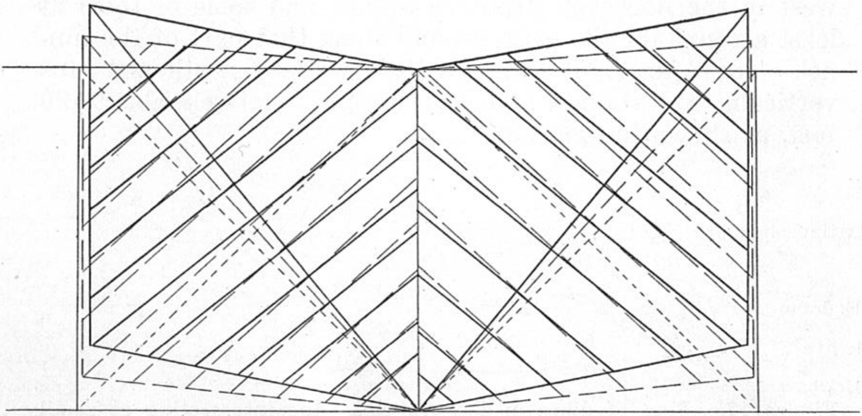

Figure 16.—Positions of tension fissures formed during two successive stages of shearing in the same general direction. The principal compression fissures formed during the two stages would be nearly parallel to the vertical sides of the diagram. (See fig. 13.)

panied by nearly or quite all the different kinds of dikes and veins, are likely to contain the most continuous ore shoots and to be productive to greatest depths. Most of them are the upward extensions of prevolcanic fissures. Even along these zones, however, there are low-grade or barren intervals, commonly attributable to steplike interruptions, tight places along shear fractures, or tight places between intersections with other steeply dipping fissures or "flats."

That some mild shearing took place after ore deposition is proved by the fact that a few productive veins have undergone a little crushing and have even been offset horizontally for a few inches by postmineral fractures; but these slight offsets may be related to a prevailing vertical uplift that produced faults of considerable size in the surrounding region. The only postmineral faults of considerable size thus far recognized in the district are the Thompson fault, in the Elkton mine, and the Ajax fault, in the Granite (Ajax) mine. The Thompson fault trends west and dips steeply to the south just inside the crater wall. Lindgren and Ransome[41] regarded it as a normal fault with a throw of about 100 feet, implying that the granite had dropped relative to the breccia. Postmineral faults of similar strike and dip are exposed to the west in the Roosevelt drainage tunnel, and some of them at least account for the loose ground along that part of the tunnel. The Ajax fault trends a little west of north and dips vertically, and its east wall has dropped relatively about 120 feet, as shown in figure 36.

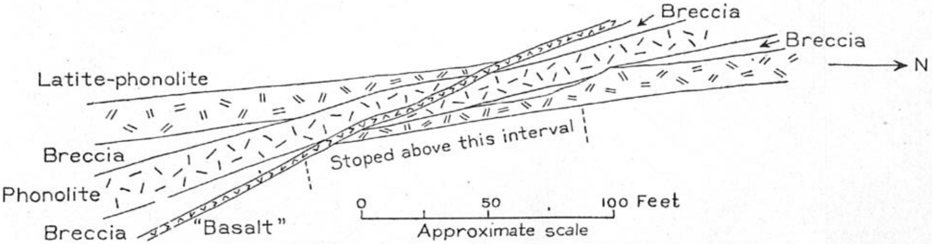

Figure 17.—Plan of dikes in Los Angeles mine intersecting at small angles and following a common course for a short distance on the 1000-foot level. An ore shoot was mined along the common course at a higher level.

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[41] Lingdren, Waldemar, and Ransome, F. L., op. cit., pp. 26, 333-334.

Minor craters

Little attention has been given by us to the minor craters of the district. The Globe Hill crater, north of the granite and schist "islands," has had its southwestern and southeastern walls exposed to depths of about 800 feet. The southwestern wall, exposed in the Gold King and C. O. D. mines, is steep and irregular and has a sharp overhanging embayment, as shown in figure 8. This embayment lies along a fissure zone of northeast trend, which is followed by dikes and masses of latite-phonolite, phonolite, and basalt and which represents a prevolcanic fissure zone that was repeatedly reopened. The southeastern wall, exposed in the Jerry Johnson and Forest Queen group of mines, is similarly developed along a fissure zone of north-northwest trend that is accompanied by latite-phonolite and phonolite. The northeastern wall, along Tenderfoot Hill, which follows a shattered zone in granite, is also steep, as it is not reached by the Hoosier shaft. These three places, however, are too widely separated to give a satisfactory impression of the shape of the crater, which may be single and developed mainly along a fissure zone of northwest trend, or composite with roots developed in the southwestern and southeastern parts, as suggested by the number and variety of intrusive bodies in mine workings and perhaps elsewhere. The northeast embayment of this crater at Galena Hill and the small outlier close by are so related to the topography that they appear to be merely veneers over a hilly granite surface, but the northeast trend of the embayment also suggests that it may have been developed along a fissure zone parallel to that in the Gold King-C. O. D. area.

No additional data regarding the forms of the minor craters at Mineral Hill, Copper Mountain, and Rhyolite Mountain were obtained in the present investigation. The fact that the breccias of the Mineral Hill and Copper Mountain areas rest in part on sedimentary rock shows that they extend beyond the limits of the local craters, but their clearly defined, steeply dipping contacts in certain other places are evidently along crater walls. The mass of latite-phonolite that intrudes into the breccia of Mineral Hill and tapers northwestward into a dikelike mass that cuts granite is also doubtless over the crater itself and suggests that this minor crater also was developed in part along a fissure zone of northwest trend. The syenite exposed in a small open cut on the south slope of Copper Mountain points to another local eruptive center. The roots of both craters, however, are evidently small and may taper to mere fissures at rather shallow depths.

Beacon Hill affords an interesting example of the root of a minor crater. Although it consists mainly of a knoblike plug of phonolite that tapers irregularly downward into a dike on the Roosevelt tunnel level, the plug was found by Lindgren and Ransome[42] to enclose some phonolitic breccia. Ransome therefore concluded that a shallow, minor explosive crater was formed at first and filled with breccia, which was later largely crowded out, at least above the present surface, by the intruding phonolite. The phonolite dike, 100 feet thick, now fills the fissurelike root of the crater (fig. 18) and bulges upward, sending out sill-like branches along fissures of low-angle dip that were evidently formed by the outward push of the bulging phonolite. This crater root represents a more extreme development than the small rhyolite mass near Marigold (p. 237), where a greater proportion of breccia remains. It also represents what may be expected on a larger scale below the present workings of the Portland mine, where the increasing amount of syenite shows that it is likely to become the dominant rock and fill the root of the Portland subcrater.

Origin of the volcano

In the outline of regional geology attention was called to the local northeast trend of the pre-Cambrian gneissic structure and to the northeast and northwest trends of pre-Cambrian dikes; also to the doming of the Cripple Creek area, during the Laramide revolution, by compression, dominantly in east-west and northwest-southeast directions, and the accompanying development of fissure systems with northwest, east-northeast, and other trends, including the "flats," or fis-

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[42] Lindgren, Waldemar, and Ransome, F. L., op. cit., p. 359.