with moderate to steep dips by a force directed in general toward the present Cripple Creek district. The folds in the southeastern part of the Pikes Peak quadrangle trend northeast and those in the southwestern part west-northwest. Compression in the southeastern part was the stronger and, as noted by Cross,[12] broke at least one of the folds by an overthrust fault.

The south-central part of the Pikes Peak quadrangle, where the sedimentary cover was probably thickest, became squeezed obliquely between these forces and developed into a complex troughlike or synclinal fold. Its eastern margin may even have been sheared along a transverse or tear fault that marked the western limit of the northwestward thrust. North of this troughlike fold, where the two thrusting forces came close together, the dominant northwestward moving force tended to thrust the eastern ground over the western, and one local thrust fault was noted by Cross[13] at Marigold, north of Helena Canyon, where granite is thrust over limestone along a fault of moderate easterly dip. Farther north along the present valley of Oil Creek the thrust evidently developed a monoclinal fold of westerly dip, which died out near Alnwick and Dome Rock. The valley of Cripple Creek, which joins Oil Creek close by the fault at Marigold (fig. 1), approximately parallels the axes of folds in the eastern ground, and its relation to the warped granite surface suggests that its development began along a local syncline or troughlike fold or along a fracture zone related to such folding.

Deformation was less intense between the monoclinal fold along Oil Creek and the upturned beds of Woodland Park and, so far as can be inferred from available evidence, resulted in a gentle domelike flexure that passed northwestward into a broad, shallow trough or syncline where the present Florissant Valley is situated. This domelike form extended over the entire Cripple Creek district and the Pikes Peak area, to the northeast, although the two areas may have been separated by a minor sag. South of the district the dome passed into

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[12] Cross, Whitman, op. cit. (Pikes Peak folio), p. 4.

[13] Idem, p. 4.

the folded ground in the southeastern part of the Pikes Peak quadrangle.

During this period of compression, in addition to the thrust and tear faults already mentioned, fracture zones developed across the folds and sets of minor fractures developed at 45° or less to the local directions of compression. The Cripple Creek dome was similarly affected. Fracture zones of northwest and east-northeast trends, transverse and oblique to the major axis of the dome, were among the most prominent formed. Zones of north-northeast trend, parallel to the axes of minor folds, and east-southeast zones, normal to those axes, were also formed. This network of fracture zones later on exerted much control over the growth of the Cripple Creek volcano.

Tertiary time

Early erosion cycles

After this period of folding, faulting, and fracturing, prolonged erosion again dominated, although interrupted repeatedly by uplifts and slight tilting or warping of the entire region. The first stage of erosion persisted until the region was again worn down to a low undulating surface or peneplain, of which the summit area of Pikes Peak is the only remnant near the Cripple Creek district.[14] Uplift followed by renewed erosion resulted in a second peneplain represented by the shoulders of Pikes Peak. During these two cycles of erosion the sedimentary rocks were completely removed from large areas to the north, but some sedimentary cover must have persisted over most of the Pikes Peak quadrangle until completion of the third erosion cycle, which developed the gently undulating granite surface much as it appears today. Remnants of sedimentary rock south and southwest of the Cripple Creek district are still sufficient to outline the positions of folds and to show that many of the steeper granite slopes are the limbs of folds modified only slightly by recent erosion.

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[14] Lovering, T. S., and Van Tuyl, F. M., Physiographic development of the Front Range, Colorado: Geol. Soc. America Bull., vol. — (in preparation); abstract in Geol. Soc. America Proc. for 1933, pp. 52-53, 1934.

Early volcanism and sedimentation

After this third great cycle of erosion a period of volcanic activity began, and the earliest volcanic rocks then formed occur extensively west of the Cripple Creek district. During this period a large lake was formed in the broad basinlike area around Florissant, northwest of the Cripple Creek dome, and volcanic ash and carbonaceous clay were deposited in it. These materials, known as the "Florissant lake beds," contain fossil leaves and insects usually regarded as of late Miocene age. Similar fossil leaves were found in 1933 in a thin deposit of dark-gray shale cut by the Cameron shaft, in the northeastern part of the Cripple Creek district. Specimens kindly submitted by Etienne Ritter were examined by R. W. Brown, of the United States Geological Survey, who stated that they were too poorly preserved to be thoroughly identified but closely resembled those of the Florissant lake beds. The shale containing these leaves occurred in horizontally bedded rock derived mainly from pre-Cambrian granite but containing some material derived from the Cripple Creek volcano, which points to a later origin than the Florissant lake beds. Although no final conclusion can be drawn regarding these fossils and the rocks containing them, it is tentatively inferred that the sediments accumulated in a local basin that existed at or soon after the beginning of eruptions from the Cripple Creek volcano. The present structural relations of this local basin are very obscure, as shown on pp. 245-8.

After the deposition of the Florissant lake beds eruptions of rhyolite took place over an extensive area. They covered the Florissant beds and extended as far east as the Cripple Creek district. The remnants of rhyolite nearest to the district are on Grouse Hill and Little Pisgah Peak (fig. 1), where flows rest on pre-Cambrian granite. A mile and a half west of Little Pisgah Peak, on the spur between Cripple Creek and Middle Creek (fig. 1), there is a local vent through which rhyolite and rhyolite breccia were erupted. It was developed at the intersection of faults or fissures of northerly and easterly trend in granite. The rhyolite forms a small plug at the south end of the breccia mass, and dikes that cut the breccia extend along the faults for short distances from the plug. Both rhyolite and granite were silicified and cut by veinlets of quartz along these faults. Certain other faults in the vicinity became mineralized at this time, but nothing of commercial interest has been found along them. (See pp. 424-426.)

An eruption of andesite apparently followed that of rhyolite in the vicinity of Little Pisgah Peak, but its source is outside of the area shown in figure 1. Only two remnants of it have been found within the area, and both are of breccia containing bluish, black, and red fragments of andesite. One of these remnants is at the west base of the phonolite mass that caps Little Pisgah Peak (fig. 1). It is largely concealed by phonolite talus, and its relations to the adjacent rhyolite and conglomerate are not clear, but its position is such that it apparently overlies the rhyolite. It appears to overlie the conglomerate too, but the finding of a few small pebbles of andesite in the conglomerate favors the conclusion that the andesite, like the rhyolite, was subjected to erosion along the old valley in which the conglomerate was deposited and that the present exposure of andesite is along the margin of that valley.

The other exposure is on a ridge to the northwest, across Middle Creek. There the andesite breccia rests on the old granite floor.

After the rhyolite and andesite eruptions, local sedimentation was renewed and gravel and sand, later consolidated into conglomerates and sandstones or "grits," accumulated in valleys or local basins, notably at High Park, 5 miles west of the Cripple Creek district, and in the area that includes Grouse Hill, Straub Mountain, Little Pisgah Peak, and Mitre Peak, south of the district (fig. 1). These two areas may have been continuous at one time and joined in the vicinity of Red Ridge, west of the mouth of Cripple Creek, where Cross found a remnant of the conglomerate and sandstone on rhyolite. The altitude of this remnant accords well with that of the deposits at Grouse Hill, with due allowance for the gentle southwesterly slope of the granite floor and for probable post-volcanic faulting. The remnant of similar material at the reservoir in the town of Cripple Creek was doubtless formed at the same time. If the fossils and volcanic fragments found at Cameron are not too restrictive, it may be that the altered sandstones containing them are also to be correlated with the "grits" south of the district.

These "grits" are mostly red or brownish red and well to poorly stratified. They consist mainly of pebbles and grains derived from granite, with subordinate amounts of quartz and pre-Cambrian quartzite, but locally they contain many pebbles and small boulders of rhyolite and a few small pebbles of andesite. The poorly stratified fine-grained variety, composed chiefly or wholly of consolidated granite debris, is not readily distinguished from the underlying granite. The large masses at Grouse Hill and Straub Mountain are from 200 to 300 feet thick, according to Graton, who mapped them during the first resurvey of the district.[15]

Graton concluded that these deposits of gravel and sand, or grits, were older than the rhyolite, and that the fragments of rhyolite noted in them were incorporated by means of "brecciation at the time of intrusion."[16] The fact that rhyolite appears to overlie the lowest beds of grit on Grouse Hill lends some support to this idea, but a little beyond the area mapped by Graton the presence of large rounded cobbles of rhyolite in the gravel or conglomerate, well removed from any rhyolite flow, and the fact that the greater part of the conglomerate appears to overlie the rhyolite force the conclusion that it is later than the rhyolite, as originally stated by Cross.[17]

Both rocks fill an old shallow granite-floored valley that, as shown by Lindgren and Ransome,[18] extended headward through the present site of Victor into the area now occupied by the Cripple Creek volcano. Lindgren and Ransome regarded these sedimentary beds, which consist mainly of pre-Cambrian granite debris with some of quartzite, as an expression of the earliest eruption of the Cripple Creek volcano,

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[15] Lindgren, Waldemar, and Ransome, F. L., op. cit., p. 22.

[16] Idem, p. 100.

[17] Cross, Whitman, U. S. Geol. Survey, 16th Ann. Rept., pt. 2, p. 53, 1895.

[18] Lindgren, Waldemar, and Ransome, F. L., op. cit., p. 37.

when a great open crater was blown out of the granite and the debris was scattered over and beyond Grouse Hill and Straub Mountain. No other material representing the products of such an eruption has been found, but again the rounded cobbles and pebbles of rhyolite so strongly indicate local derivation by erosion that we favor the interpretation that the conglomerates, sandstones, and grits were derived by erosion of the domelike granite area prior to the eruption of the Cripple Creek volcano and subsequent to the extensive erosion of rhyolite. This interpretation forces the inference that debris blown by the volcano beyond the boundaries of its complex crater have been entirely removed by erosion from the area south of the volcano as well as elsewhere.

Volcanism at Cripple Creek

The development of the Cripple Creek volcano is treated in detail on pp. 261 to 290. It took place in several stages marked by the reopening of fissures formed during the main stage of uplift and compression (p. 235) and ended with the formation of ore deposits. Of the several stages that of the phonolite intrusions was the most widespread, and dikes and large masses of phonolite were intruded in the granite throughout the east-central part of the Pikes Peak quadrangle and in the sedimentary beds and rhyolite south of the district and at High Park.

Subsequent uplifting, faulting, and erosion

The subsequent history of the region was marked by erosion interrupted by broad general uplifts. Faulting, which had doubtless taken place to some degree throughout the volcanic period, accompanied these uplifts, but only one stage of faulting can be closely timed, as is shown below.

The first postvolcanic stage of erosion was apparently local. It was marked by the removal of the easily eroded debris that constituted the Cripple Creek volcanic cone. Erosion of the volcano was apparently retarded when the large, resistant, and once continuous phonolite mass of Grouse Hill, Straub Mountain, and Little Pisgah Peak was exposed, and a broad, gently southward-sloping surface was developed, remnants of which are still represented by Gold Hill, Globe Hill, the northwest base of Ironclad Hill, Raven Hill, and Battle Mountain. Bull Hill and Bull Cliff, which rose above this surface, were protected from erosion by large masses of hard rock.

While a channel was being cut through the large phonolite mass, between Grouse Hill and Little Pisgah Peak, the volcano was dissected into essentially its present form, and the broad granite floor to the south and west was re-exposed. This stage of erosion, if studied in detail, could probably be divided into substages, one or two of which preceded the principal development and one or two of which, most clearly expressed along Pony Gulch southwest of the town of Cripple Creek, followed the principal development. Undulations in the prevolcanic floor, however, may account in part for these apparent substages.

The uplift that followed this stage of erosion was more clearly accompanied by faulting than those that preceded. Faults within the district are concealed beneath soil. Two faults, located underground and known to have formed since ore deposition, are beneath small gulches, but many of the larger gulches are related to intersecting sets of fractures or joints rather than faults. Some of the most clearly defined faults south of the district occur around Mitre Peak, in the extreme southwestern part of the area shown in figure 1. There a network of faults is marked by the dislocation of sandstone, rhyolite, and phonolite. One of these faults follows the steep south bank of Wilson Creek and separates Mitre Peak from a local lowland. Similar displacement of these three rocks has occurred in the eastern part of the High Park area, as noted by Cross,[19] who also showed that rhyolite capped by sandstone on Red Ridge was separated by a fault from the same rocks in the main High Park area to the northwest. So far as the displaced rocks are concerned, the faulting took place after the intrusion of phonolite, but attempts to trace the postphonolite erosion surface on the topographic map of the Pikes Peak quadrangle suggests that this surface

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[19] Cross, Whitman, op. cit. (16th Ann. Rept.), pp. 54-55.

also has been dislocated. The apparent dislocation may be accounted for in part by the monoclinal flexure that parallels Oil Creek (p. 234), but the fact that this flexure is paralleled and crossed by the faults just noted supports the suggestion that the erosion surface also has been dislocated.

The Oil Creek fault, shown in the southwest corner of figure 1, is perhaps a composite fault along which movements have taken place at different times. The overthrust character of its semicircular part, west of Marigold, was noted by Cross and its southern part is closely related to the margin of the Garden Park area, along which some transverse or tear faulting may have taken place during the period of folding; but west of Mitre Peak this fault is so closely related to the neighboring postphonolite faults that some postphonolite movement probably took place along it also. The limestone tableland west of the fault is part of the area that was squeezed and depressed during folding and was probably downfaulted further during the more recent movement.

Erosion since this late period of faulting has developed some lowland areas in the soft sandstones of the Fountain formation south of the area shown in figure 1, but within that area it has been mainly confined to canyon cutting. The rather pronounced faulting and fracturing around Marigold permitted the development of the local lowland, in which the portal sites of the proposed deep drainage tunnel are situated. The low alluvium-covered spurs on the north margins of this lowland show that erosion took place in a succession of stages controlled by conditions farther south. Wilson Creek, aided by the weakness of the shattered granite along the east-northeast fault that it follows and by the branch faults that extend northward, deepened its channel rapidly, undercut the shallow postphonolite valley, and diverted the drainage that formerly passed between Grouse Hill and Little Pisgah Peak. This feature lends further support to the suggestion that the faulting just discussed took place mainly after the development of the main postphonolite surface. Middle Creek, less favored by faults, has worn a much shorter canyon that heads in a small basin whose altitude suggests that it was developed at the same time as the substage represented by the spurs along Pony Gulch (p. 240). The lowest and steepest part of Cripple Creek may have been favored by faults, as it is near and parallel to the north end of the Oil Creek fault. The middle part parallels some of the more prominent fissures or minor faults in the Roosevelt drainage tunnel, which practically underlies it, and also follows a minor trough or synclinal depression suggested in the old granite surface. Its upper part, like the upper part of Wilson Creek, has been developed by the trenching of the postphonolite erosion surface along the principal sets of fractures.

CRIPPLE CREEK VOLCANO

General features

The composite Cripple Creek volcano (fig. 1) occupies a roughly elliptical area of northwesterly trend between the towns of Cripple Creek and Victor. It is about 4 miles long and 2 miles wide. In its central part it encloses an "island" of granite and farther west a smaller "island" of schist. These islands are near peninsulas or prongs of the surrounding formations that project into the crater. Underground work has proved that the schist island is continuous at moderate depth with the schist to the west, and from general evidence it is most probable that the two islands are high places along a continuous mass that divides the crater, as shown by Lindgren and Ransome.[20] In other words, the area north of the islands is a minor crater, which is conveniently referred to as the "Globe Hill crater."

Farther northwest, at Mineral Hill, Copper Mountain, and Rhyolite Mountain, there are small areas that also represent minor craters, although their marginal parts cover the old erosion surface of granite, schist, and gneiss. Beacon Hill, southwest of the main crater, is also a minor eruptive center. The small outliers at the west base of Galena Hill, north of the granite island, and on the summit area of Big Bull Mountain, southeast of the main crater, are merely remnants of volcanic material resting on the granite surface. The major

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[20] Lindgren, Waldemar, and Ransome, F. L., op. cit., p. 30.

and minor craters are filled mainly with consolidated fragmental material (breccia and tuff), into which dikes and irregular masses of alkaline rocks have intruded. The fragmental material is the product of a series of explosive eruptions that took place during the earlier stages of the volcano's activity. These early eruptions, which gave the crater its form, were followed by no less than 10 stages of intrusion, represented in approximate order by two varieties of latite-phonolite, two of syenite, two of phonolite, and at least five of basaltic rock. Minor explosions took place at intervals during or between intrusive stages and locally shattered the intrusive rocks, especially the marginal parts of some of the larger masses, so that their boundaries and stuctural relations are obscure. The latest of the basaltic intrusions was preceded by a pronounced local explosive eruption that formed a local crater of basaltic breccia within the main crater, known as the "Cresson blowout," as most of the ore bodies of the Cresson mine have been found along or within it.

The large masses of these intrusive rocks are shown in figure 1, without any attempt to distinguish between varieties. Several but by no means all of the phonolite and basaltic dikes are shown, but dikes of the other rocks, numerous underground, were not mapped on the surface during the earlier surveys, and no attempt to revise the surface map or to add to its detail has been made by the present writers, except to outline the Cresson blowout.

Rock types

Because of the necessarily frequent use of the rock names mentioned above and the somewhat different meanings attached to them during the earlier and later surveys of the district and by different miners, and also because the rocks are so different from those in most other districts of the State, summary descriptions of the type rocks recognized in this report are presented below. These descriptions are only sufficient to aid in the recognition of the different rocks on the surface and underground. Readers wishing more complete data are referred to chapter 3 (by L. C. Graton) of Professional Paper 54. All the rocks contain considerable quantities of the feldspathoid minerals, especially sodalite, noselite, haüynite, analcite, and nephelite, and of soda-rich pyroxene and amphibole, which are present mainly as inconspicuous or microscopic grains. They are not mentioned in the descriptions below unless they are conspicuous and aid in the ready recognition of the rock.

Breccia and tuff.—The word "breccia" has locally become a general term to designate the fragmental rock that fills the Cripple Creek crater, but most of the rock is sufficiently fine-grained to be more aptly called a "tuff." Nearly all of it is altered to some degree, even in the deepest mine workings. The least altered variety is a soft, rather crumbly reddish, purplish, or bluish-gray rock, in part fine-grained and in part containing distinct small to large rock fragments. The red variety, for example, in the Moose mine has locally been called "andesite," a name that may have persisted since the early days of the district, when the breccia as a whole was called "andesite breccia." Much of the breccia, especially in mine workings, has been bleached by alteration to light yellowish gray and is so compact that its fragmental character is not very evident unless distinct rock fragments are present.

The rock fragments are mainly varieties of latite- phonolite. Near the shattered margins of large masses of latite-phonolite, particularly the mass capping Battle Mountain, there are gradations from rock that has been only slightly dislocated into typical breccia. Near the margins of the crater fragments of granite, gneiss, and schist are prominent, and in places there is a gradation from shattered granite into distinct breccia. In some places large slablike masses of granite approximately parallel to the contact are found a few hundred feet away from it. Small fragments of granite, gneiss, and schist and their constituent minerals are thinly scattered throughout the breccia. Graton[21] states that with one trivial exception not a single mineral or rock particle was seen in the scores of thin sections examined that is not represented in known masses of rock in the district. The breccia is cemented principally by a dolomitic carbonate which, with small

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[21] Graton, L. C., in Lindgren, Waldemar, and Ransome, F. L., op. cit., p. 99 .

crystals of pyrite, has replaced the original dark-colored mineral fragments and considerably impregnated the other mineral grains. Small amounts of secondary quartz, chalcedony, and microscopic opal are present, but silicification has been negligible except close to some of the veins.

Carbonized wood has been found in several parts of the crater—for example, 90 feet below level 2 in the Cameron mine,[22] on the 550-foot level of the Morning Glory mine, the 600-foot or 15th level of the Doctor Jackpot mine, the 600-foot level of the Logan mine, the 800-foot level of the Elkton mine, and at equal or greater depth in the Cresson mine, where a fossil log was found in 1933.[23] These occurrences, as stated by Lindgren and Ransome,[24] show that, at least in certain parts of the complex crater, trees and presumably weathered surface rocks were blown into the air and fell back in a confused mass, filling the great pits that had been formed by the explosions.

Associated sedimentary beds. — Although most of the breccia has no definite structure, it is distinctly bedded in a few places. In some places the bedding is nearly horizontal, and in others it is considerably tilted. The occurrences of bedding noted by Lindgren and Ransome[25] are in parts of the Captain stopes and in the southwestern part of the 220-foot level of the Portland mine, in the Independence mine farther south, in the southeastern drifts of the Isabella mine, in the Lucky Guss No. 2, in the Elkton mine, on the south slope of Bull Cliff, and on the slope south of Cameron. All were nonpersistent and graded into the usual unstratified breccia. The best exposure noted by them was on the Portland 220-foot level, where the beds were 1 foot thick and resembled almost horizontally bedded grits or coarse sandstones. The bedding in the Elkton mine dipped about 40°. The lack of sharpness and persistence and the different attitudes of the bedding

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[22] Written information by Etienne Ritter.

[23] Oral information by Superintendent Al Bebee.

[24] Lindgren, Waldemar, and Ransome, F. L., op. cit., pp. 31-32.

[25] Idem, pp. 30-31.

were regarded as indications that the sorting and arrangement were not effected in a body of water but were caused by the winnowing action of winds on material thrown into the air, to sorting by rolling down slopes, or to alternations in material thrown out by successive eruptive explosions. Some of the bedding, however, is so distinct as to indicate deposition in quiet water.[26]

We have found almost horizontally bedded rock in the School Section (Block 8), Pinnacle, and Cameron mines, in the northeastern part of the breccia area. The continuity of horizontal bedding in the Pinnacle and Cameron mines, whose workings are connected, is in marked contrast to the evidence presented above, and is so persistent that it may well continue to the School Section mine, half a mile to the east. The bedded rock is light to dark red where fresh, but near veins it is bleached to a light gray or yellowish gray, like the typical breccia. It is found by microscopic study to consist largely of quartz and feldspar, derived from the neighboring granite, gneiss, and schist, and to a minor extent of small fragments of trachytic latite-phonolite. The distinct beds are separated by thin layers and partings of greenish-gray shale, and they contain pebbly streaks and lenses and even rather continuous conglomerate beds. It was in this bedded rock that the lens of dark-gray to black shale with fossil leaves like those in the Florissant lake beds (p. 236) was cut by the Cameron shaft 367 feet below its collar.

In the Pinnacle mine the bedded rock, which is most distinct on levels 7 and 8, is underlain by a poorly stratified deposit composed of subangular fragments of granite, gneiss, and schist. The contact between the two is sharp and is cut by a winze about 20 feet below level 8, or about 670 feet below the surface. The winze extends downward about 400 feet, or to a depth of 1,070 feet, and its bottom is still in the coarse fragmental material.

The outcrops of the pre-Cambrian rocks in the vicinity are only about 1,000 feet from the Pinnacle shaft, but their contacts with the breccia as shown in Professional Paper 54

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[26] Graton, L. C., op. cit., p. 98.

and figure 1 are so deeply covered by loose debris and alluvium that their structural relations cannot be studied. It may be inferred that this part of the volcanic crater was developed as a steep-walled bowl with a nearly horizontal floor, either entirely by explosion or by subsidence of the floor after explosion; that a long quiet interval followed during which rock slides from the steep walls together with torrential mud flows from cloudbursts deposited the coarse, poorly stratified debris upon the floor; that the well-bedded material was derived by wash largely from the pre-Cambrian rocks and in part from early eruptions of the volcano; that during the accumulation of the bedded material local shallow basins were developed in which the fossiliferous beds accumulated; and that, still later, explosive eruptions were resumed which destroyed the bedded structure in some places and covered it with typical breccia in others. The exact mode of origin of these well-bedded rocks must remain unexplained until more evidence is available, but the important feature as regards mining geology is that these beds have remained practically undeformed over a considerable area during most of the volcanic period and are therefore outside the limits of the steep-walled root or subcrater in which local explosive and other disturbances took place and in which the deep channels followed by ore-forming solutions were established.

It is interesting to note that with the exception of the tilted beds in the Elkton mine, all the stratified beds noted by Lindgren and Ransome are in the eastern part of the breccia area and either at comparatively shallow depths or at the surface. No record of the mineral composition of these particular beds is at hand. If they consist mainly of volcanic material the origin suggested by Lindgren and Ransome seems the most likely; if they should prove to consist mainly of granitic material their correlation with the strata in the Cameron and adjacent mines would be justified and would favor the suggestion that a basin of obscure origin existed before or soon after the volcanic eruptions began. The fact that these stratified beds have been so little tilted during volcanic activity accords with other evidence pointing to the generally vertical, upward force of the volcanic explosions, whereby large blocks isolated from the main walls of the crater by the blowing out of intervening material remained essentially in their original positions.

Latite-phonolite.—The term "latite-phonolite" was adopted during the first resurvey[27] to designate three or more varieties of porphyritic rocks intermediate in composition between typical latite and phonolite. They include those formerly termed "andesite," "trachytic phonolite," and "syenite porphyry" by Cross.[28] They form dikes and large, irregular sheetlike and knoblike bodies, mainly in the eastern part of the breccia mass, but also in its western part and in the minor masses to the northwest.

The fresh rocks are in part dark gray to nearly black and in part reddish and brownish and consist of dense or felsitic groundmasses with prominent white to light-gray crystals or phenocrysts of feldspar from 1 or 2 millimeters to 2 centimeters in length and a few black crystals of pyroxene. At least one variety contains scattered but prominent smoky-gray 6-sided prismatic crystals of apatite, and some contain small yellow crystals of titanite. The altered rocks are light gray to yellowish gray, and the contrast between their groundmass and the larger crystals is less distinct. It is difficult in some places to distinguish them from altered breccia or phonolite.

The most common variety has a dark-gray to reddish groundmass with short white phenocrysts of soda-lime feldspar (plagioclase) and with or without noticeable black crystals of pyroxene or hornblende. On some company mine maps it has been recorded as "phonolite." Another variety of trachytic character, noted especially in the Eagles, C.O.D., and Gold King mines, has a medium to rather light gray dense to very fine grained groundmass, with conspicuous lath-shaped or tabular crystals of gray to colorless alkalic feldspar (orthoclase), and is characterized in part at least by small vugs or

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[27] Graton, L. C., in Lindgren, Waldemar, and Ransome, F. L., op. cit., pp. 68-77.

[28] Cross, Whitman, op. cit. (16th Ann. Rept.), pp. 41, 46-48.

cavities lined with black scales of specular hematite. The vugs in the C.O.D. and Gold King mines contain some pyrite also. Latite-phonolite in some parts of the School Section mine contains vugs with pyrite but little or no specularite and in other parts vugs lined with small ankerite crystals covered by larger yellow calcite crystals. The restriction of these vugs and minerals to one variety of latite-phonolite favors the conclusion that they were formed by emanations that immediately followed the intrusion of the rock, but they have some resemblance to vugs attributed to the first stage of vein formation. (See p. 293.) Dikes of this variety are cut by dikes of the more common variety. A third variety is commonly light gray or yellowish gray and contains so many phenocrysts that it appears like a granular rock and, if not subjected to microscopic study, would be called "syenite" or "syenite porphyry." It is this variety that contains the most conspicuous crystals of smoky apatite. It is very abundant in dikes and irregular masses in the Vindicator mine, where it has been mapped as light-gray syenite, and it also forms dikes in the Portland, Eagles and other mines. It is cut by the most common variety of latite-phonolite.

Syenite.—The syenite of the district forms one large intrusive mass, or irregular stock, two other smaller masses, shown in figure 1, and a large number of dikes. The large mass is essentially continuous underground from the Vindicator to the Rose Nicol mine, although it is represented on the surface (fig. 1) by two areas separated by breccia. The smaller areas are west of the Logan shaft, south of the granite island, and at the Index mine, on the west boundary of the crater. Syenite is also reported from the Mollie Kathleen mine, in the Globe Hill crater, and has been noted on Copper Mountain. The dikes branch from the large masses or occur independently along master fissure zones in different parts of the district. The type rock is medium to rather dark gray and medium- to fine-grained and consists largely of rather pearly-lustered feldspar with thickly scattered black prismatic crystals of pyoxene. The feldspar is mainly orthoclase, accompanied by a minor amount of plagioclase. Apatite and titanite are less conspicuous than in the syenitic variety of latite-phonolite.

Phonolite.—Phonolite is by far the most widely distributed of the intrusive rocks. It forms large masses and dikes not only in the breccia but over a surrounding area much larger than that shown in figure 1. The fresh rock is commonly medium gray, but that in the mines is mostly a very light gray owing to alteration. A few dark purplish-brown dikes and masses have been noted, and these also are locally altered to a nearly white rock. The texture of both fresh and altered rocks is mainly dense, but a few small crystals of colorless to white feldspar are visible on close inspection. Black grains of pyroxene or hornblende are inconspicuous or microscopic. Some of the large outlying masses, particularly at Grouse Hill, Straub Mountain, and Rhyolite Mountain, contain red crystals of nephelite as much as 2 millimeters long. The phonolite, particularly that of the dikes, has a marked platy structure which is intensified by weathering and causes it to break into thin, flat fragments.

Trachydolerite of Bull Cliff. — The trachydolerite that caps Bull Cliff has not been recognized elsewhere. It consists of a dark gray, nearly black dense groundmass with small phenocrysts of lime-soda feldspar and pyroxene, rarely 0.5 millimeter long, and with elongate grains of black mica 2 to 3 millimeters long. Analcite forms round white spots 1 millimeter in diameter. The rock forms a sill-like mass with rude vertical columnar jointing and develops a peculiar rough fracture on weathering. It is intrusive into latite-phonolite and probably into phonolite, according to Lindgren and Ransome, but is thought to be older than the basaltic dikes described below.

Basaltic or basic dikes.—Four kinds of dikes conveniently classified as basaltic or basic dikes have been recognized. They differ from true basalt in their high contents of alkalic minerals and are more exactly termed "trachydolerite," "vogesite," "monchiquite," and "melilite basalt." The vogesite and monchiquite cut all the other rocks of the volcano except the Cresson blowout and its accompanying dikes, but their relations to each other are not altogether clear. The trachydolerite dike in the School Section mine was believed by Lindgren and Ransome[29] to be later than monchiquite, but Koschmann, in 1930, noted that it was cut not only by monchiquite but probably also by phonolite. The dikes of all four kinds are mostly confined to the main breccia area, but a few cut the adjacent granite in the Granite and Independence mines, to the south, and near the Ophelia tunnel, to the west, and one has been mapped 2 miles north of the breccia contact and a quarter of a mile west of the road to Divide.

The dikes are all very dark gray to black, except where bleached to light gray or greenish gray by alteration, and consist of a dense groundmass with phenocrysts of feldspar, pyroxene, and analcite. Distinction between them, particularly between vogesite and monchiquite, may require microscopic examination. Many of the dikes have a sheeted structure similar to that in phonolite. The vogesite is characterized by small round white grains of analcite and black flakes of mica and is represented by the Anna Lee dike, in the Portland mine; the Moose and Jenny Sample dikes on Raven Hill, and the Pinto dike, in the mines southeast of Bull Hill. The monchiquite is characterized by round white grains or spots of analcite 2 millimeters or less in diameter, black pyroxene, and red olivine. The Gold Sovereign dike, which is fairly continuous southeastward from the vicinity of the Cresson mine to the Portland mine, contains scattered flakes of black mica 1 centimeter or more in diameter. Other representatives of monchiquite are found in the Mollie Kathleen, Index, Cresson ("Sliver dike"), Vindicator, School Section ("little basalt"), Ajax, Granite, Strong, Portland, and Elkton mines and the Ophelia and Raven tunnels. The trachydolerite forms relatively few but commonly thick dikes. Its greater content of dark phenocrysts gives it a granular appearance. Its most conspicuous though small phenocrysts are black augite and gray lime-soda feldspar in crystals 1 millimeter or more long and dull rounded green grains of serpentinized olivine. Its best-known representatives are the Isabella dike, which extends northwestward from the upper part of Bull Hill to the

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[29] Lindgren, Waldemar, and Ransome, F. L., op. cit., p. 97.

School Section mine, where it is called the "Sevey dike" or "big basalt"; dikes in the Portland, Ajax, Dolly Varden, Mary McKinney, and Gold Bond mines; and probably the Funeral dike, in the Cresson mine. Melilite basalt has been recognized in only one dike, on level 11 of the Ajax mine. It is dark green and dense where least altered but for the most part is soft and crumbly.

Basaltic breccia and dikes of the Cresson blowout.—The basaltic breccia of the Cresson blowout is much darker gray than that of the main crater and is more distinctly fragmental, except where it is thoroughly bleached. It contains fragments of breccia and of all the dikes in the surrounding ground, besides many fragments of dark-gray or greenish-gray dense basalt in a dense matrix of basalt and basaltic tuff. The matrix, like that of the surrounding breccia, is considerably impregnated by dolomite and pyrite.

Short basaltic dikes and sill-like masses that cut the blowout and follow its boundaries for short distances so closely resemble the monchiquite and vogesite dikes in the surrounding breccia that they can be distinguished only by their small dimensions and their structural relations.

STRUCTURE

An adequate appreciation of the arrangement and continuity of the veins and ore shoots in the district depends, first, on a comprehensive interpretation of the form and origin of the crater as a whole and the forces that formed the fissures within and around it; second, on the local details that account for the open and tight parts of fissures and therefore the location of ore shoots, as the ore shoots have formed mainly by the filling of openings. As the structure of the large, compound crater is complex and has resulted from both local and regional disturbances, it will be helpful to consider first the structure of the small, relatively simple, and more thoroughly exposed crater at the Cresson mine and to compare its features with those of the main crater.

Cresson blowout.—The Cresson blowout, or minor crater, outlined in figure 2, is an irregular, elliptical, pipelike mass of basaltic breccia whose longer dimension trends east-north-

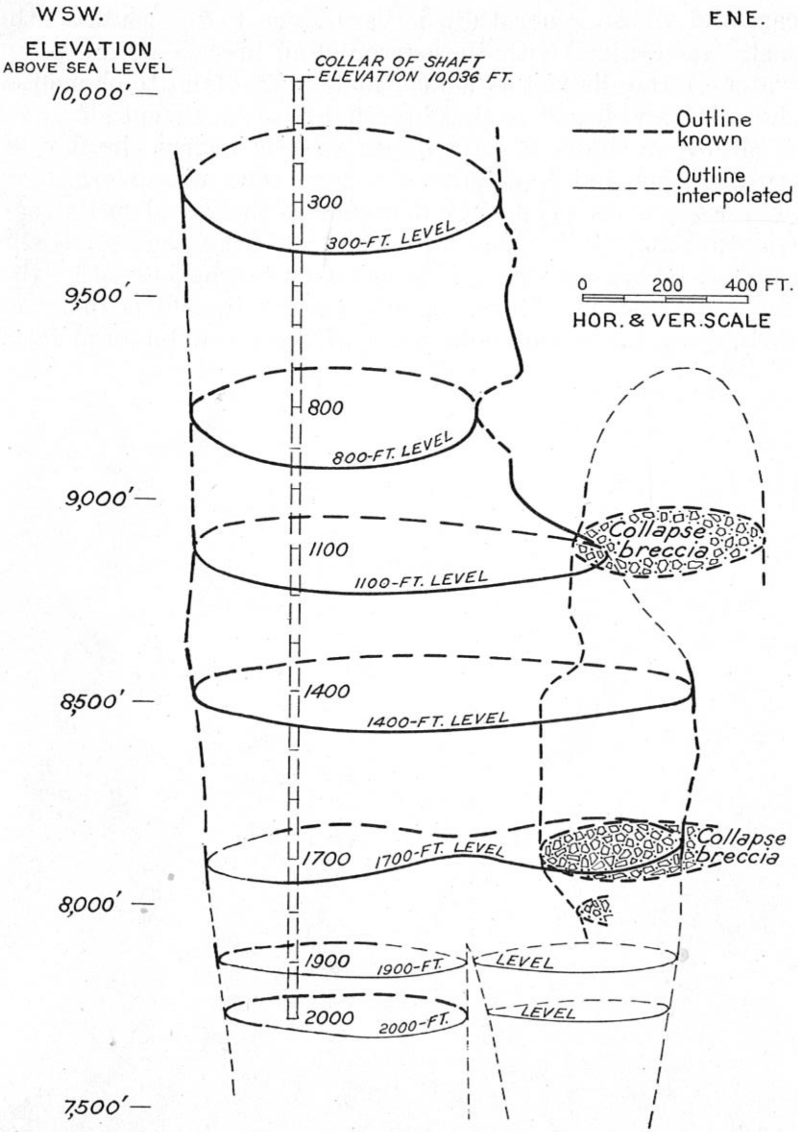

Figure 2.—Generalized outline of Cresson blowout, or minor crater, as revealed by mine workings. It is broken on the east by an irregular cylindrical mass or "pipe" of collapse breccia. (After Am. Inst. Min. Met. Eng. Tech. Paper 13, fig. 3.)