DAMON—JERRY JOHNSON—W. P. H.—FOREST QUEEN—PRIDE OF CRIPPLE CREEK MINES

The Jerry Johnson group, which includes the Damon, Jerry Johnson, W. P. H., Forest Queen, and Pride of Cripple Creek mines, is in the southeast corner of the northern crater along its eastern wall, where the breccia is in contact with schist. The Wild Horse mine within the eastern edge of the granite "island" may also be included. These mines, though small, have a fairly large aggregate production.

The east wall of the Globe Hill crater in this vicinity has an average trend of N. 10° W. (fig. 46), although it is irregu-

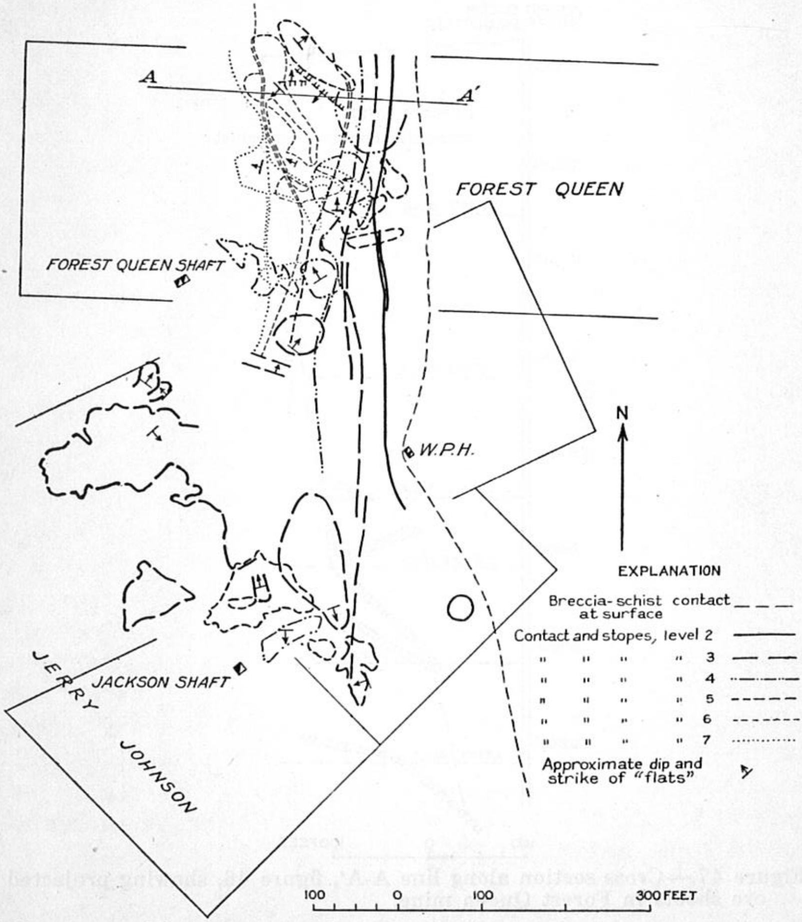

Figure 46.—Plan of Forest Queen and adjacent workings. A-A′, Line of section, figure 47.

lar in detail in the northern part of the Forest Queen and Pride of Cripple Creek mines. Its dip in the Forest Queen mine is about 80° W. with few local exceptions down to level 5, 45° W. between levels 5 and 6, and about 80° W. on level 7. (See fig. 47.) This prevailing steep dip and linear course strongly indicate development along a prevolcanic fissure zone. There are several large inclusions of schist within the breccia in the Pride of Cripple Creek mine, and the contact, though

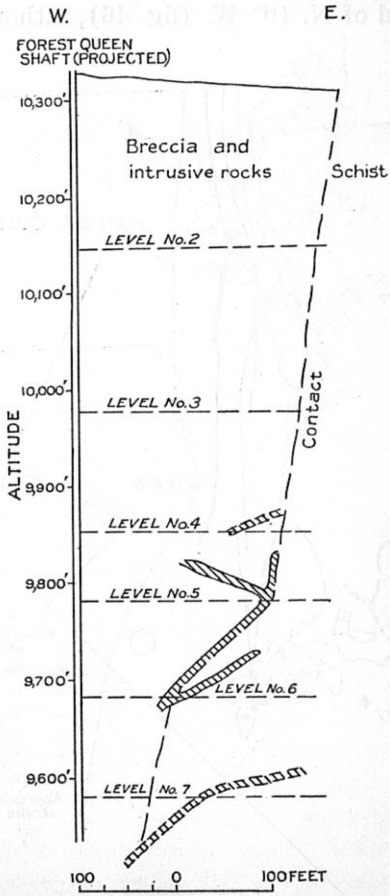

Figure 47.—Cross section along line A-A′, figure 46, showing projected ore shoots in Forest Queen mine.

not exposed, evidently curves locally to the east of its general course. Although no latite-phonolite has been mapped on the debris-covered surface, it is conspicuous underground and in the Forest Queen workings is more abundant than breccia. Dikes and sills of phonolite and basalt are also present. This series of intrusive rocks, here as elsewhere, indicates the presence of a local deep volcanic source nearby, but the accessible workings are not sufficiently extensive to give a clear picture of structural conditions.

The ore bodies thus far developed are mostly along "flats" that dip in different directions (fig. 47), though for the most part toward the contact. A few steeply dipping veins have also been exposed. The most extensively developed of them is the Contact vein, which lies along the breccia-schist contact in the Damon and W. P. H. and much of the Forest Queen ground but departs from the more irregular parts of the contact. The "flat" ore bodies in the Damon, Jerry Johnson, and W. P. H. mines are in breccia, but most of those seen in the Forest Queen mine, whether east or west of the Contact vein, are along foliation planes in schist. The east limit of productive ground is said to be along a nearly vertical phonolite dike.

The positions of the "flat" ore bodies suggest that they were opened by a slight upward thrust on the breccia side of the Contact vein, which itself has not been very productive. The steep westerly dip of the Contact vein, together with the disturbed condition of ground on its west side, also suggests that it may connect downward to the west with a deeper vein that was developed along an extension of the reopened prevolcanic fissure and therefore may be the master vein of the group, even though it may not persist upward as far as the present workings. One "flat" vein, the Caley, which dips 30° SW., extends beyond the westernmost workings of the Forest Queen mine and is so far from the Contact vein that it may connect with a deeper western vein of steep dip. So far as relations to movement along the northeastern part of the main crater are concerned, the north-northwestward trend of the master fissure zone would favor its reopening prior to ore deposition. The general conditions, therefore, seem favorable to downward exploration, and although the contact may shelve considerably to the west below the present workings, exploration by drilling could determine its course and at the same time prospect for additional flat veins.

The ore streaks seen were oxidized and consisted largely of clay with very little fluorspar, and in this respect they resembled the oxidized parts of productive veins of the Pinnacle and Cameron mines. The absence of conspicuous first-stage minerals is a further suggestion that the trunk channels of mineralization have not been reached.

The quantity of water thus far handled on the lowest levels has not been great, and evidently the water can be removed by bailing or intermittent pumping. If deeper exploration should release so much water as to render pumping impracticable, long connections with workings farther south would be necessary for drainage and could incidentally pass beneath the Wild Horse workings. A connection with Logan level 12, about 4,000 feet away, would lower the drainage level only 210 feet; one with Eagles level 21, about 4,300 feet away, would lower it 815 feet; and one with Cresson level 17, about 6,100 feet away, would lower it 1,350 feet.

No information on the Wild Horse mine is available other than that given in Professional Paper 54 (pp. 366-367). The mine is almost entirely in shattered granite along the east edge of the granite "island" and is developed along a curving vein of steep westerly dip, the southern part trending south-southeastward and the northern part north-northwestward, roughly parallel to the Contact vein in the Jerry Johnson group. The principal ore shoot pitched 45° N., and its pitch length was 1,200 feet. The ore became "stringy and thin" between levels 8 and 9 (altitude about 9,700 feet), and on level 10, so far as explored, it consisted of a loose mass of pyrite. The northward pitch is in the general direction of the deep source from which the ore shoots of the Forest Queen and adjoining mines are believed to have been derived, and it therefore seems more consistent to associate the Wild Horse vein with this center than with any other, especially as the vein terminates southward in the direction of the essentially barren area that lies southwest of the granite island. Such a relation suggests that the shallow ground between the Wild Horse and Damon mines may be entitled to more attention than it has received.

FURTHER DEVELOPMENTS

From the foregoing descriptions and their inferred significance in different parts of the district it is concluded that ore-forming solutions rose and spread from relatively few deep sources and that deep developments will converge toward these sources; in other words, although many mines have been very productive at shallow depths, only the relatively few that directly overlie these sources will respond favorably to deep development, and their ore shoots on the whole will become fewer and farther apart with increasing depth. The practical limit of downward development is controlled by structural conditions that have rendered premineral fissures prevailingly tight and nonproductive rather than by the ultimate depth at which physical and chemical conditions permitted the formation of gold tellurides. There is no evidence that this ultimate depth has been closely approached, but further successful developments below the present bottoms of the mines that have reached or passed the Roosevelt drainage tunnel level are dependent on an improvement in local structural conditions as depth increases.

It is to be assumed that, in a district that has been so extensively worked since 1891, the productive ground above drainage level has been rather thoroughly explored and that any new discoveries, whether at the surface or at shallow or moderate depths, are likely to be continuations of known ore zones. Thorough study of structural details throughout a mine or a closely spaced group of mines may indicate unexplored ground whose promising character has been overlooked; but structural conditions differ so from place to place that the character of unexplored ground any considerable distance from mine workings cannot be foretold with much confidence. Among the most likely places for the discovery of new ore shoots are the steplike continuations of productive veins and those parts of intersecting networks of fissures along which second-stage vein minerals are conspicuous. Close studies of the tight and open or productive parts of veins have shown that slight changes in strike or dip have determined the limits of ore shoots, and attention to these details should aid materially in further explorations.

Only incidental mention has been made of large bodies of low-grade ore that cannot be profitably mined by the methods ordinarily employed in the district. These bodies occur in shattered ground full of minute veinlets that intervene between closely spaced, parallel or intersecting veins that may or may not have been workable singly. Some ores of this class have been worked in the upper parts of the Portland and Independence mines, although the mining of them was discontinued in 1929 because of the large amount of waste that was intimately mixed with the ore. Other large bodies have been reported from the Vindicator, Golden Cycle, Mary McKinney, Anaconda, and parts of the Conundrum group, and smaller bodies have been outlined in the Queen and Deerhorn mines. The Cresson mine probably contains considerable quantities. Further practical study of these low-grade ore bodies is an engineering problem, and its successful solution will substantially increase the ore reserves of the district.

Ground Water with Reference to a Proposed Deep Drainage Tunnel

Early drainage

One of the obstacles to mining since the early days of the district has been the abundance of ground water. A few shallow drainage tunnels were driven from time to time in the western part of the district and drained considerable areas. The deepest of them was the El Paso tunnel, with its portal at an altitude of 8,790 feet, which was driven northeastward in 1904, passing beneath the El Paso shaft at the present fourth level and continuing for about 700 feet into the phonolite plug of Beacon Hill. The plug was so thoroughly connected by fissures with the main breccia area that the water level was lowered throughout a large part of that area. The Elkton mine, nearly 5,100 feet east-northeast of the El Paso, was drained by the end of 1908 to level 9 (altitude 8,844 feet), which had been abandoned and flooded in 1901. The impression, therefore, was generally confirmed that the breccia mass as a whole was comparable to a wet sponge in a cup, and that only the puncturing of the granite walls was necessary to drain the entire breccia mass. Owing to the complexity of the composite crater, however, and its probable downward division into subcraters, this comparison becomes less apt with increasing depth. The Gold King mine, for example, in the northwestern part of the district, was evidently not drained to level 9 (altitude 8,965 feet), which was under water in 1904 and is still flooded. This mine has been drained by the Moffat (Ophelia) tunnel to an altitude of about 9,270 feet, but the schist that separates it from the mines to the south evidently became an effective barrier to drainage within the next 300 feet below. It was also evident, from the results of pumping, that shallow barriers separated ground water in the Vindicator-Golden Cycle group and mines farther northeast from that in the greater part of the crater. It may therefore be inferred that with increasing depth the ground water will become more and more separated into minor basins that correspond to the subcraters outlined on pages 255-265. This separation has not been much more in evidence down to the present drainage level but is more likely to be conspicuous at the level of the proposed tunnel.

Drainage by Roosevelt tunnel

The success of the El Paso tunnel led to the driving of the Roosevelt drainage tunnel. This tunnel,[65] financed through the

[65]Sheldon, T. H., Roosevelt drainage tunnel, Cripple Creek, Colo.: Eng. and Min. Jour., vol. 100, pp. 545-549, 1915. Henderson, C. W., Mining in Colorado; a history of discovery, development, and production: U. S. Geol. Prof. Paper 138, pp. 57-59, 1926; also chapters on Colorado in annual volumes of Mineral Resources, U. S., 1909-18. Countryman, T. R., Drainage in Cripple Creek, Colo., gold camp: Min. Sci., vol. 57, pp. 301-302, 322-324, 360-362, 1908. Bagg, R. M., The Roosevelt deep drainage tunnel, Colo.: Eng. and Min. Jour., vol. 88, pp. 1061-1062, November 27, 1909. Warwick, A. W., The Cripple Creek drainage tunnel, Colo.: Min. World, vol. 33, pp. 985-987, November 26, 1910. Arthur, E. P., Jr., Drainage plans for eastern rim of the Cripple Creek contact: Min. Sci., vol. 71, pp. 38-41, May 1915.

cooperation of the principal mining companies, has its portal at Gatch Park, 14,550 feet southwest of the El Paso shaft, at an altitude of 8,020 feet. It was started in 1907 and made slow progress for the first 1,500 feet; but, beginning with January 1, 1908, when the contract was taken over by A. E. Carlton, it was driven 14,167 feet to its original objective at an average cost of $27.27 a foot and was extended 2,712 feet, all in granite, at about the same average cost. An intermediate shaft, 7,975 feet from the portal, was sunk 685 feet to tunnel grade, and the work proceeded from three headings. The tunnel tapped very little water until it reached the El Paso vein system in 1910. The flow then increased to about 1,000 gallons a minute, and when connection was made by a churn-drill hole with the El Paso workings, it increased, according to Sheldon, to more than 10,000 gallons a minute. Until this connection was made, the water level in the El Paso mine had subsided very slowly, if at all; but it was then lowered about 700 feet, to tunnel level, during 1911. The flow by October 1911 had decreased to 5,800 gallons a minute.

The fissure zone that extends north-northeastward from the El Paso mine through the breccia contact to the Mary McKinney mine is not so open or continuous at tunnel level as at considerably higher levels; accordingly, the Mary McKinney mine had been drained only to an altitude of 8,505 feet by the end of 1913, the latest year for which records have been found. Since then this mine has been drained practically to tunnel level, and the Conundrum mine, 4,800 feet farther north a'ong the west rim of the breccia, is dry to its bottom level, at an altitude of 8,445 feet.

Drainage of the principal mines in the central and eastern parts of the district proceeded so slowly, however, that it was decided, late in 1911, to extend the tunnel toward the Elkton shaft. When it had advanced only a few hundred feet, to a point beneath Arequa Gulch and in line with the Gold Dollar vein system, which flanks the Beacon Hill plug on the east, it opened a watercourse that increased the flow to 12,000 gallons a minute, and work was again suspended in March 1912. The flow by July 1, 1914, had decreased to 7,300 gallons a minute, but the unwatering of the mines progressed too slowly to suit the operators. The rate of subsidence is illustrated by records of the Elkton and Portland mines in the following table:

GROUND-WATER LEVEL IN ELKTON AND PORTLAND MINES, 1910-18

Year	Distance of tunnel breast from Elkton shaft (feet)	WATER LEVEL (feet)				Difference in altitude (feet)
		ELKTON		PORTLAND		
		Amount lowered annually	Altitude at end of year	Amount lowered annually	Altitude at end of year	
1908	-----------	(a)	8,844	Pumped 660 g.p.m.	-------	-----
1909	-----------	-----	8,844	Ceased pumping July 1	8,968	124
1910	3,880 west	18	8,826	15	8,953	127
1911	3,680	37	8,789	65	8,888	99
1912	2,665	187	8,602	127	8,761	159
1913	No progress	84	8,495	102	8,659	164
1914	2,395	99	8,396	132	8,527	131
1915	475	150	8,246	154	8,373	127
1916	2,580 east	150	[b]8,096	103	8,270	174
1917	4,325	-----	-------	94	8,176	80
1918	4,735	-----	-------	65	[b]8,111	15

[a]Elkton mine was drained to level 9 (altitude 8,844 feet) in 1908 by the El Paso tunnel, whose altitude is 8,790 feet.
[b]Altitude of Roosevelt drainage tunnel.

The tapping of the "Gold Dollar watercourse" temporarily hastened drainage of the Elkton mine, 2,650 feet to the east, along a network of minor fissures, and of the Portland mine, a mile farther east; but the Elkton fissure system evidently served as a trunk channel through which water flowed from the east, so that subsidence in the Elkton mine in 1913 and 1914 was slower than in the Portland. Extension of the tunnel was resumed in July 1914, and the waste was hoisted through the El Paso shaft. By November 1 the tapping of several fissures, mostly of northerly trend, had increased the flow to 9,861 gallons a minute. Work was interrupted from November 1, 1914, to March 1, 1915, by the burning of the El

Paso plant, and the flow during that time decreased to 8,213 gallons a minute. The breccia-granite contact was crossed about the middle of 1915, and considerable water and loose ground was found on the granite side of it. Several minor watercourses were cut in the breccia, and the approach to the Elkton mine hastened its drainage. The Elkton shaft and fissure zone were reached early in 1916, and drainage of the mine was completed, but the rate of subsidence in the Portland mine decreased, partly because of the lowering of head and partly because the northern part of the Portland fissure system was less continuous as it approached tunnel level. Late in 1916 the tunnel had crossed fissure zones connected with the Cresson, Granite, and adjacent mines and entered the large mass of syenite that is essentially continuous as far east as the Vindicator mine. The northwest fissure zone of the Portland mine was less continuous on the south side of this syenite mass, and its drainage became slower, at least until its north-northeast system was cut where it closely paralleled a local contact between syenite and breccia. The flow in the tunnel diminished in 1917 from 8,500 gallons a minute on January 1 to 4,000 gallons a minute on December 13. Connection with the Portland No. 2 shaft was made on January 1, 1919. The barrier that had been noted west of the Vindicator and Golden Cycle mines at shallower levels was still effective, and these mines were not drained through the tunnel until the west crosscut on level 18 of the Golden Cycle mine was extended and connected with the tunnel 65 feet below it, probably in 1922.

Basins beneath Roosevelt tunnel

The foregoing review of drainage developments through the Roosevelt tunnel shows that the main fissure zones within and adjacent to the breccia mass have been the main reservoirs and have been sufficiently connected through networks of minor intervening fissures to be drained slowly over long distances. The main zones are also connected with large local bodies of very open ground, notably the collapse breccias in the Cresson mine and similar open breccias in the Moose, Rose

Nicol, and northern Ajax (Coriolanus claim), which have added greatly to the supply of water to be drained.

The branches or laterals that connected the Cresson and Portland mines with the drainage tunnel permitted the deepening of these mines by the aid of pumping. According to T. R. Countryman, who made the survey for the Roosevelt tunnel, it was felt that pumping below tunnel level would not be prohibitive and that a central pumping plant could be financed cooperatively,[66] but the three mines, Vindicator, Portland, and Cresson, that were deepened below tunnel level have had to be pumped independently. The isolation of the Vindicator-Golden Cycle mine, which pumped about 500 gallons a minute, has already been noted. The Portland mine, which extended about 1,000 feet below drainage level and pumped from 650 to 1,000 gallons a minute, did not lower the water in the Granite mine, which was only 1,700 feet away but on the opposite side of the eastern granite prong shown in figure 8. The Cresson mine, less than 500 feet below tunnel level, had to pump a maximum of 5,800 gallons a minute and had to curtail development work. It had to pump 3,500 gallons a minute to maintain a constant water level. A pumping capacity of at least 10,000 gallons a minute would seem necessary to unwater the mine and permit still deeper mining.

The Cresson's pumps, in contrast to those of the Portland, drained ground as far south as the Granite mine, 1 mile away, and doubtless drained some water from the drainage tunnel itself. They also drained large amounts of ground in all other directions, owing to the intersection of the Cresson blowout and the associated collapse breccias with several fissure zones of different trends. The vein and fissure systems east and northeast of the Cresson mine are so well connected at moderate depth that it is a reasonable inference that they are fairly well connected down to the level of the proposed tunnel (altitude about 7,000 feet), but the granite prong at the Portland mine and the syenite mass north of the mine evidenly isolate the fissure systems to the southeast. There is an

[66]Countryman, T. R., Drainage in Cripple Creek, Colo., gold camp: Min. Sci., vol. 57, pp. 360-362, 1908.

open connection between the Cresson and the Moose mine, just west of it, at the Cresson level 12 and doubtless much deeper, but how much farther west the open fissures extend is doubtful. The western granite prong, which extends northwestward from the Queen mine, may form a deep barrier between the Cresson and at least the southern part of the Elkton and more western drainage systems. The Cresson mine would evidently be an appropriate place for a central pumping plant, as it is in probably the largest drainage basin in the district and is centrally located; but thorough drainage of the district down to an altitude of 7,000 feet might require some connections through crosscuts to minor basins.

Suggestions regarding drainage by proposed tunnel

As the Cresson and Granite mines, whose prospects for deeper mining are by far the best in the district, are in the same deep drainage basin, the appropriate course for the proposed tunnel appears to be northeastward from its portal at Marigold (fig. 1) at least as far as the Granite mine, where it would be 1,000 feet or more below level 20, and preferably to the Portland No. 2 shaft. An extension from the Granite mine along a continuation of the Montana fissure zone beneath the wedge-shaped embayment of breccia could be driven toward the Cresson mine until adequate drainage is attained.

The extension from the Granite mine to the Portland No. 2 shaft would tap the Portland basin. It has been suggested informally that the Portland shaft could be unwatered and deepened, as much as 250 feet, to the new tunnel's grade, and that a heading could be driven southwestward from it to meet the drive from the portal. This plan would involve the pumping of about 1,000 gallons a minute at first and a gradually increasing amount as the heading advanced down grade beneath and beyond the Granite mine. If, instead, an intermediate shaft should be driven about midway along the tunnel's course it would involve a sinking of about 2,000 feet but probably a smaller rate of pumping, as the chances of cutting a strong watercourse at so great a depth are small along the intermediate part of the tunnel site.

The proposed northeasterly course to the Portland No. 2 shaft would permit a direct extension to the Vindicator shaft whenever it seemed desirable. The Golden Cycle shaft would be somewhat nearer, but its downward extension would probably be in granite and would not afford so prompt a drainage as the tapping of the fissure system at or near the Vindicator shaft; furthermore, the Golden Cycle shaft is said to have caved in beyond repair, and the prospects of finding deep ore are better to the northwest of the Vindicator shaft than to the south.

If deeper development in the Elkton mine should be planned, it might be necessary to drive a west branch or lateral from the tunnel to effect drainage of the Elkton zone. Such a lateral should be well to the north of the Roosevelt drainage tunnel to avoid passing through any more of the western granite prong than is necessary. A further extension might be needed to insure complete and rapid drainage of the El Paso and Mary McKinney zones. This suggested course may seem roundabout, but it would be the most economical way of reaching four of the six large, deep mines, including the two with the largest reserves.

If the tunnel were driven directly toward the Cresson shaft, it would be longer and extend farther in granite, passing obliquely through the western granite prong; furthermore, it might not tap a major watercourse nearly so soon. The driving of a heading southwestward from the Cresson shaft would involve 600 feet or more of sinking and excessive pumping. If the tunnel were driven toward the Elkton shaft it would be somewhat shorter and, if the breccia-granite contact continues to overhang at that depth, would reach breccia in about the shortest possible distance. It would also tap one of the major watercourses, provided the Elkton fissure zone does not tighten downward to too great a degree; but it would be separated from the Cresson basin by the western granite prong, and the driving of an eastern branch through the prong would probably be necessary to effect adequate drainage of that basin alone, and further extensions would be necessary to reach the Portland and Vindicator basins. The extension of the Elkton shaft or of a winze south of it to the new tunnel level would involve 1,000 feet or more of sinking, and unless the winze were placed well away from the Elkton fissure zone and the shattered granite south of it, a high rate of pumping would be necessary. A tunnel direct to the El Paso mine would be by far the shortest and would drain the southwesternmost part of the district, provided the El Paso fissure zone continues to be sufficiently open at so great a depth; but experience with the Roosevelt tunnel proved that a long eastward extension was necessary to drain the central and eastern parts of the district, and a similar extension of the proposed deep tunnel would be all the more necessary. All things considered, therefore, the proposed northeasterly course to the Portland No. 2 shaft and a north-northeastward course from the Granite toward the Cresson mine seems the most practical.

Conditions affecting the selection of a tunnel site

Available topographic maps of the region surrounding the Cripple Creek district show that the only sites worthy of consideration as portals for the proposed drainage tunnel are within the small lowland that surrounds the junctions of Cripple Creek, Middle Creek, Wilson Creek, and Carlin Creek with Oil Creek at Marigold, about 6 miles south of the deep mines of the district. (See fig. 1.) The altitudes of these junctions range from 6,875 to 6,460 feet above sea level. Similar altitudes along Millsap, Eightmile, and Beaver Creeks, south of the district, are from 8 to 11 miles away, and those to the east are no nearer than Manitou, which is 15 miles away in a direct line. A study of possible tunnel sites shows that conditions for tunnel driving are generally favorable, and that the choice of a site will depend largely on an evaluation of areas for the dumping of waste and on the advantage of attaining somewhat greater depth at the expense of a somewhat greater length.

The present topography, as shown on pages 235-241, is the result of a succession of uplifts accompanied by faulting, which involved the dropping of some large blocks within the generally uplifted region. Erosion, following each of the earlier uplifts, reduced the region to comparatively low rolling surfaces, on one of which the volcanic rocks were erupted. Erosion since the last uplift has had time only to develop narrow canyons and gulches, except where faulting and accompanying fracturing have reduced the resistance of the rocks and permitted the formation of relatively broad valleys, such as the local lowland that contains the portal sites.

Faulting and fracturing took place at widely separated intervals, some before the volcanic period and some much later. There are only two areas where any significant amount of faulting that would affect the tunnel problem has occurred. One of these is at and south of the local lowland, and the other is in the immediate vicinity of the Cripple Creek crater.

Faults in the southern area

The southern of these areas is by far the more conspicuous. The longest and best-defined fault in this area may be called the "Oil Creek fault," as it roughly parallels the course of Oil Creek from the vicinity of the mouth of Cripple Creek southward for 5 miles. It forms the east boundary of a depressed block that includes the limestone tableland, and the difference in altitude between the same limestone bed on the two sides of the fault indicates a vertical displacement of about 1,000 feet. Its trend, as shown by Cross in the Pikes Peak folio, is north-northeastward from its southermost exposure to Carlin Gulch, where it turns to a north-northwestward course as far as Steamboat Mesa, just north of Wilson Creek. There it turns west for about a mile and then curves through a north-northwestward to a northeastward course, which is just west of and parallel to the lowest part of Cripple Creek. If the portal of the proposed tunnel should be located at any of the lowest possible sites between Carlin Gulch and Middle Creek, this fault would be crossed by the tunnel. The saddle on the northeast side of Steamboat Mesa shows that the fault zone is decidedly less resistant to erosion than the limestone and granite on each side of it, and the driving of a tunnel through this zone would doubtless meet with considerable loose or "heavy" ground that should be strongly timbered or concreted.

Study of the ground around Mitre Peak, also called "Saddle Mountain," and to the north and northeast of Steamboat Mesa reveals an obscure network of faults east of the north-northwestward-trending part of the Oil Creek fault. Some of these are branches of the Oil Creek fault, and the network as a whole indicates a minor degree of settling, in part at least, coincident with the drop of the main limestone area. The north limit of this network roughly coincides with that of the local lowland.

The faults that can be most clearly followed in this network have been thoroughly healed, either by the intrusion of volcanic material or by the deposition of vein material, and for the most part offer quite as much resistance to erosion as the adjoining granite. Those filled by volcanic material are in the valley of Middle Creek and on the ridge west of it, just north of the Jones ranch. The volcanic rocks form a knob on the crest of the ridge that rises abruptly above the surrounding granite; but recurrent movement along the fault that bounds the rhyolite on the east has produced a narrow, weak zone along which the rocks have been considerably weathered, and this fault accounts for the saddle east of the knob and, in part at least, for the rapid erosion of the slope north of the knob. The volcanic rock along this slope is largely concealed by debris but consists in part of rhyolite dikes that follow old faults and in part of fragmental rhyolite or breccia that disintegrates more rapidly than the dikes or the granite. Small prospect tunnels in this breccia have rather firm walls, but it would be reasonable to expect some heavy ground if a tunnel were driven in it for any considerable distance.

Another fault, north of Wilson Creek and opposite Mitre Peak, has been traced in a bending southeasterly course across the north ends of the low spurs that slope southward to Wilson Creek. This fault has been sealed by the consolidation of gouge within it. It is probably too far east to be cut by any tunnel whose portal would be at a lower altitude than 7,200 feet but is briefly described because similar though smaller faults may lie across the tunnel course to be selected. It is characterized by a dark greenish-gray filling that resembles certain dikes of volcanic rock and contains small, more or less rounded granite fragments and mineral grains and microscopic aggregates of dickite, a mineral of the kaolinite group but not one likely to slake when exposed to air. The greenish matrix also contains considerable submicroscopic material, which because of its hardness is evidently some form of silica. A small amount of sericite is present, especially in the dickite. Although it would not be surprising to find in such a mineralized fault local streaks or bunches of soft clay minerals that would slake on exposure to air, it is improbable that a sealed fault like this one will cause any appreciable trouble if cut by a tunnel. The facts that this fault trends across the upper ends of the low spurs and that no small local gullies have been formed along it lend support to this conclusion. Its position at the northern limit of the low spurs implies that the ground between it and the steep south slope of the Wilson Creek Valley has been thoroughly fractured and perhaps dislocated along short unmineralized faults that are concealed beneath gulch bottoms. Examination of exposed rock along the low spurs, however, warrants the conclusion that, although the granite is so thoroughly fractured that it is broken up by frost action with relative rapidity, the fractures have not produced loose ground that would cause any serious trouble in tunneling. Here and there fractures may intersect in such a way that blocks in the tunnel roof would have to be supported, at least until work in the tunnel was completed, but such places are likely to be found in any tunnel.

Similar faults with solidified gouge have been located on the low spur at the northwest end of the phonolite mass on Mitre Peak and also on the southeast end of the peak. Slight mineralization is also shown by the rhyolite dike in Middle Creek, which contains a little fluorspar, and sericitized streaks with fluorspar are found in several scattered places, best exposed near the lower end of the ridge between Wilson and Middle Creeks. The fluorspar suggests a close relationship to the veins of the Cripple Creek district, but neither this showing nor any other in the vicinity would encourage a hope of discovering productive veins.

The positions of unmineralized faults within the network are in part conjectural, for they are likely to be concealed beneath alluvium or rock debris, and the uniform appearance of the granite on opposite sides of them affords no clue to their existence. The most apparent and continuous of these faults nearly coincides with the westerly course of Wilson Creek and is entirely south of any tunnel site except one whose portal would be in Carlin Gulch. It apparently joins the Oil Creek faults just east of Steamboat Mesa, and its position is expressed by the marked contrast between the steeply truncated spurs south of the creek and the low, gently sloping spurs north of it. The only exposure of this fault is at the small saddle on the 7,650-foot contour about three-quarters of a mile northeast of Mitre Peak. A little farther east the fault apparently branches. Its northeastern branches are in steplike arrangement and have been traced along the valley of Wilson Creek to a point nearly due east of Little Pisgah Peak. A spring in the patch of alluvium just north of Wilson Creek and due south of Little Pisgah Peak is depositing considerable calcium carbonate and brown iron oxide, which have locally cemented the alluvium. This material is similar to that being deposited along the walls and floor of the Roosevelt drainage tunnel. Considerabe seepage is also taking place from the vertical north bank of the creek along bedding planes in the alluvium. Veins of iron oxide and travertine are found along known faults in Wilson Creek and it is therefore likely that the spring is the surface indication of a fault concealed beneath the alluvium.

Other faults that are exposed are shown in figure 1 by solid lines, and concealed and suspected faults are shown by dashed lines. None of them are continuous or likely to cause appreciably more trouble in tunneling than the average fractured rock that underlies the low spurs.

Faults in and near the Cripple Creek crater

Of the faults and fissures in and near the Cripple Creek crater only those that have been opened or reopened since vein deposition need to be considered here. No faults unoccupied by dikes or veins have been definitely traced on this surface, but a few have been cut in mine workings. The most conspicuous of these are the Thompson fault, or "dead vein," in the Elkton mine, and the Ajax fault, in the Granite (Ajax) mine. Others might be found along any of the deep tunnel sites, but there is no reason to suspect that they would cause any more trouble than these two faults, which are described below.

Thompson fault.—The Thompson fault (fig. 44) almost coincides with the steeply overhanging breccia-granite contact at the south end of the Elkton mine. Linngren and Ransome[67] estimated that its south wall may have dropped as much as 100 feet. Its projected position on the surface roughly parallels the broad ravine that slopes westward into Arequa Gulch. It has not been seen below level 7 of the Elkton mine (altitude 9,045 feet), although it may have been exposed in the southernmost parts of levels 11 and 17. On levels 6 and 7 the ground along the fault is much caved, largely because of extensive stoping. The fault may be tighter at the depth of the proposed tunnel, 2,000 feet below level 7, but its intersection with fissures of the Elkton vein system may locally cause loose ground, even at that depth, though nothing more than the mining companies of the district are accustomed to handle.

The Thompson fault is the easternmost of a group of faults and fissures along which nearly all the loose ground penetrated by the Roosevelt drainage tunnel between Beacon Hill and the Elkton mine was found. This ground, which also contained some of the principal watercourses, caused considerable delay and even suspension of tunnel driving for a time, and the tunnel was eventually protected with concrete arches where the ground was lowest. These arches are in good condition today, and the rock above them may have wedged itself into a firm mass, as there is considerable empty space over the ends of the arches.

[67]Lindgren, Waldemar, and Ransome, F. L., op. cit., pp. 166, 334.

The only surface expression of this group of faults and fissures is the broad alluvium-filled basinlike depression in which the former town of Arequa was situated. It serves to cast suspicion on similar depressions that lie along the proposed tunnel sites.

Ajax fault.—The Ajax fault (figs. 33-36) is exposed on the lower levels of the Granite mine. It is essentially vertical and cuts the Newmarket vein at a very low angle. Koschmann estimates that its east wall has dropped about 120 feet. The width of the shattered zone reaches a maximum of 60 feet on Ajax level 16, but in most places it is only 15 to 25 feet wide. This ground has been closely timbered but has caused no unusual difficulties. It is possible that the fault may assume an easterly dip and that the shattered zone may narrow with increasing depth, but some concreting of a tunnel even 1,000 feet lower would probably be necessary. This fault would be crossed by any of the proposed tunnels driven to the Portland shaft.

The position of the Ajax fault projected to the surface is along the steep east slope of Squaw Mountain and is approximately in line with the ravine that extends south-southeastward through the south-central part of Victor. The few outcrops of granite on the east slope of this ravine are thoroughly fractured and partly bleached. The relation of the Ajax fault to the surface and its influence on erosion also raise the suspicion that the broader and more continuous ravines and gulches throughout the granite area may also be underlain by faults or by thoroughly fractured and therefore loose ground.

Other fissures in the Granite and Portland mines.—Some caving has also taken place along the more eastern vein fissures in the lower levels of the Granite mine, largely because mining and exploration along them had been finished or suspended and there was no further need of keeping the workings open. These veins could be kept open by local timbering, or concreting, if not by guniting.

Some movement since ore deposition has taken place along the main or contact vein zone in the Portland mine and has caused loose ground in places at least as far down as level 30 (altitude 7,250 feet), which is only a few hundred feet above the lowest possible level of the proposed tunnel. The loose ground has not interfered seriously with mining and is in part a result of mining; but if the tunnel should be extended northeastward to the Vindicator mine a little concreting might be necessary where it crosses this fissure zone.

Area between the southwest lowland and the Cripple Creek district

The area between the two groups of faults described above consists largely of high ground that is cut by gulches and ravines similar to those at Arequa and Victor, but faulting could not be proved along any of them. The steepness of the slopes around Little Pisgah Peak is an indication of firm ground; moreover, examination of the slopes and ravines shows that erosion has been caused by frost action along intersecting fractures, and the rock beneath even the largest of the ravines should be firm. This statement even applies with a little qualification to the canyons of Wilson, Middle, and Cripple Creeks above their entrance into the lowland.

The longer gulches that enter Cripple Creek from the southwest and northwest slopes of Grouse Mountain are approximately in line with minor faults or fissures in the Roosevelt drainage tunnel that have promoted a little alteration and sloughing of granite and enclosed masses of schist, to depths of at least 800 feet; but after 25 years of exposure in the tunnel none of these fissures require timbering, and the amount of fallen debris along them does not seriously obstruct drainage. These fissures are still less likely to give trouble at an additional depth of 1,000 feet—the approximate level of the proposed tunnel.

The form of the basin floored with alluvium at the head of Middle Creek and southwest of Grouse Mountain suggests erosion along intersecting fissure zones. The basin is slightly northwest of any of the proposed tunnel sites, but if the fissure zones maintain the prevailing steep southerly and westerly dips of the region their intersection may extend downward across the course of a tunnel from Cripple Creek, which would cut the intersection at a depth of about 1,800 feet and might encounter some loose ground and considerable seepage. Serious difficulty, however, is hardly to be expected.

The southward-trending gulch that enters Wilson Creek east of Grouse Mountain has developed along a steplike series of fracture zones of northerly trend, and the mouths of its tributaries have developed along fracture zones of westerly trend. No appreciable chemical alteration has been noted along these fractures, and there is no doubt that firm rock would be found a short distance beneath the alluvial floor of the gulch. The disintegrated granite along the low spurs above the gulch is a superficial feature and is attributed to the prolonged weathering of an old land surface. The smaller gulches farther east show similar development, though less clearly. At a few junctions of these gulches with their tributaries—for example, just east of the cemetery near Victor — small basinlike depressions have formed and suggest that a small amount of wet, loose ground may be found at considerable depth, but it would be too small to affect the cost of tunneling appreciably. In short, a study of conditions on the surface justifies the conclusion that no very serious conditions would be met in the driving of the proposed tunnel.

Character of different kinds of rock along the tunnel sites

Any of the tunnel sites that may be selected will be almost entirely in granite that encloses scattered masses of schist. A few dikes of diabase, rhyolite, and related breccia that cut the granite and schist may be found in the lowland near the portal sites, and dikes of phonolite and perhaps of rhyolite may be found beneath and northeast of Little Pisgah Peak. Close to the Cripple Creek crater, beneath the town of Victor, a few basaltic dikes are likely to be found in rather close association with the veins of the Granite mine. Extensions of the tunnel into the crater will be in breccia, which is cut by dikes of latite-phonolite, syenite, phonolite, and basalt. None of the trouble encountered in mining and tunneling can be attributed directly to any of these rocks except the basaltic dikes, which tend to slake on exposure to the air. This tendency can be overcome by guniting.

Loose or heavy ground has been found at one place or another in all these rocks but is due to fissuring and shattering, much of which has been accompanied by the alteration and softening of the rock along veins and faults. The granite is the hardest of the rocks to drill and break. The schist is softer and because of its foliation is more likely to be softened by alteration along faults and veins, although along some fissures granite appears more altered than the adjoining schist. The different kinds of dike rock are not so hard as the granite, and they are likely to be more thoroughly cut by internal fractures than the granite. The breccias are softer than the granite and dike rocks but will stand well in a tunnel except where thoroughly altered along fissures.

Portal sites

The principal requirements for a drainage tunnel site are that it shall afford the greatest possible depth for drainage and at the same time adequate space for dumping and that its length and position shall involve the least expense in driving. As the deepest mine workings in the district, on level 31 of the Portland mine, have an altitude of about 7,115 feet, the tunnel should be still lower, if possible. Even an altitude of 7,115 feet would lower water in the other deep mines from 500 to 1,000 feet below their deepest workings. The junctions of Cripple, Middle, and Wilson Creeks with Oil Creek have altitudes of 6,875, 6,770, and 6,670 feet, respectively, but the slope of the ground near them is too gentle to afford good dumping ground. The space required for dumping depends upon the proportion of waste that will be trammed through the portal and the amounts that will be hoisted through shafts. The distances from these junctions to the Portland shaft, which, as stated in the section on ground water, is regarded as the most practical objective for the tunnel, are 6.15, 6.39, and 6.57 miles, respectively. As a length of 1 mile and a cross section of 88 square feet (equal to that of the Roosevelt tunnel) would produce about 25,000 cubic yards of loose rock, 45 percent being allowed for voids, the total amount of waste would range from 153,750 to 164,250 cubic yards. If all this waste were to be removed through the portal, and the portal were 100 feet above the creek bed and on a ground slope of 27°, the top of the dump would attain an area of about 6,600 square yards. If the top extended 100 yards parallel to the contour of the slope and only 66 yards out from the slope, its base at the foot of a 40° dump slope would be about 100 yards away from the portal. These dimensions would conform to the topography at several places near the creek junctions and suggest that a portal site 100 feet above the creek bed would be practical, even if all the waste were to be removed through the portal.

If a second heading were to be driven southwestward from the Portland No. 2 shaft, after unwatering and deepening to the required level, the work would be expedited and the size of the dump at the portal would be considerably reduced. If headings were also to be driven from an intermediate shaft, sunk near the bed of Wilson Creek and east or northeast of Little Pisgah Peak, the size of the dump at the portal would be still further reduced, perhaps to one-third of the volume stated above, and the altitude of the portal could be correspondingly less than 100 feet above the creek bed. Whether an intermediate shaft, which would have to be from 1,810 to 2,205 feet deep and would require an extra pumping plant, is worth while would depend in part on the flow of water below the Granite mine property in a heading from the Portland shaft. Pending its solution, the lowest altitude that would be satisfactory for the portal is assumed to be 100 feet above creek bed.

Tunnel sites

With the foregoing discussion in mind, comparative data on the different tunnel sites are summarized in the following table:

DATA ON TUNNEL SITES
SOUTHWEST OF THE CRIPPLE CREEK DISTRICT

Portal sites[a]	Altitude of portal (feet)	Distance to Portland No. 2 shaft (feet)	Altitude at Portland No. 2 shaft[b] (feet)	Intermediate shaft	
				Altitude of collar (feet)	Approximate depth (feet)
A. Cripple Creek	7,000	31,300	7,078	9,250	2,205
B. Oil Creek	6,875	32,700	6,957	9,100	2,175
C. Wilson Creek	7,000	30,500	7,076	8,850	1,810
D. Oil Creek	6,800	34,200	6,886	8,950	2,100
E. Carlin Gulch	6,625	36,600	6,717	8,550	1,830

[a]The positions A to E are shown in figure 1.
[b]Based on an assumed grade of 0.25 per cent, or 13.2 feet to the mile.

There is little choice between sites A, B, and C. At each site it may be advisable to start the tunnel at an angle to its principal course, in order to take advantage of the lowest site with adequate dumping space and at the same time to get beneath high, firm ground in the shortest distance possible. Site B affords the deepest drainage level by 125 feet, but an intermediate shaft connected with site C would afford the shallowest depth of shaft by 395 feet compared with site A and 365 feet compared with site B. Site C also affords the shortest tunnel of all.

As the proposed tunnel would undoubtedly be the final drainage tunnel of the Cripple Creek district, the greater depth seems preferable, so long as its excess in cost is not so great that it could not be offset by the saving in pumping costs; but the cost and questionable need of pumping to a height of 100 feet, in view of the uncertainty of finding and developing promising ore shoots below the level afforded by site C, may be insufficient to offset other advantages, such as rights of way.

Sites A, B, and C are geologically almost identical. They all pass through the fractured granite of the lowland for about equal distances, and each may cross faults at the margin of the lowland, as shown in figure 48. They may also pass for short distances through rhyolite and breccia that have been intruded along some of these marginal fault zones. Neither these rocks nor the faults are likely to give appreciable trouble, but evidence of slight recent movement along the faults suggests that a little wet and soft or "heavy" ground may be found along them. No further trouble along either tunnel is expected other than a few local spots of wet and loose, fractured ground beneath junctions of fissure zones, as suggested on page 417. All three sites, as well as site D, in Oil Creek, on the southwest side of Steamboat Peak Mesa, are so close together beneath the Granite mine that there is no choice among them there. All are likely to cut the wedge-shaped embayment of breccia that plunges southward beneath the overhanging granite contact between the Ajax and Portland shafts, and all are likely to furnish direct connection with the largest reservoir of ground water in the district.

Site D would afford about 75 feet greater depth than site B and 200 feet greater than site C; but a tunnel to site D would be 1,540 and 3,660 feet longer, respectively, than to sites B and C. With the portal at site D, the tunnel would probably penetrate some limestone and would cross the Oil Creek fault a short distance from the portal. Northeast of the Oil Creek fault the tunnel on site D would extend beneath the high spur that extends into the lowland between Middle and Wilson Creeks and would probably meet with less loose ground than on the other sites. Northeast of the lowland it would be likely to find conditions similar to those along the sites shown in figure 48.

The Carlin Gulch site has received only cursory attention. According to rough measurements, it would afford a further increase of about 170 feet in depth but would call for an intermediate shaft about 20 feet deeper than that called for by site C. The tunnel would be 6,100 feet and 2,440 feet longer, respectively, than tunnels on sites C and D, and the extra

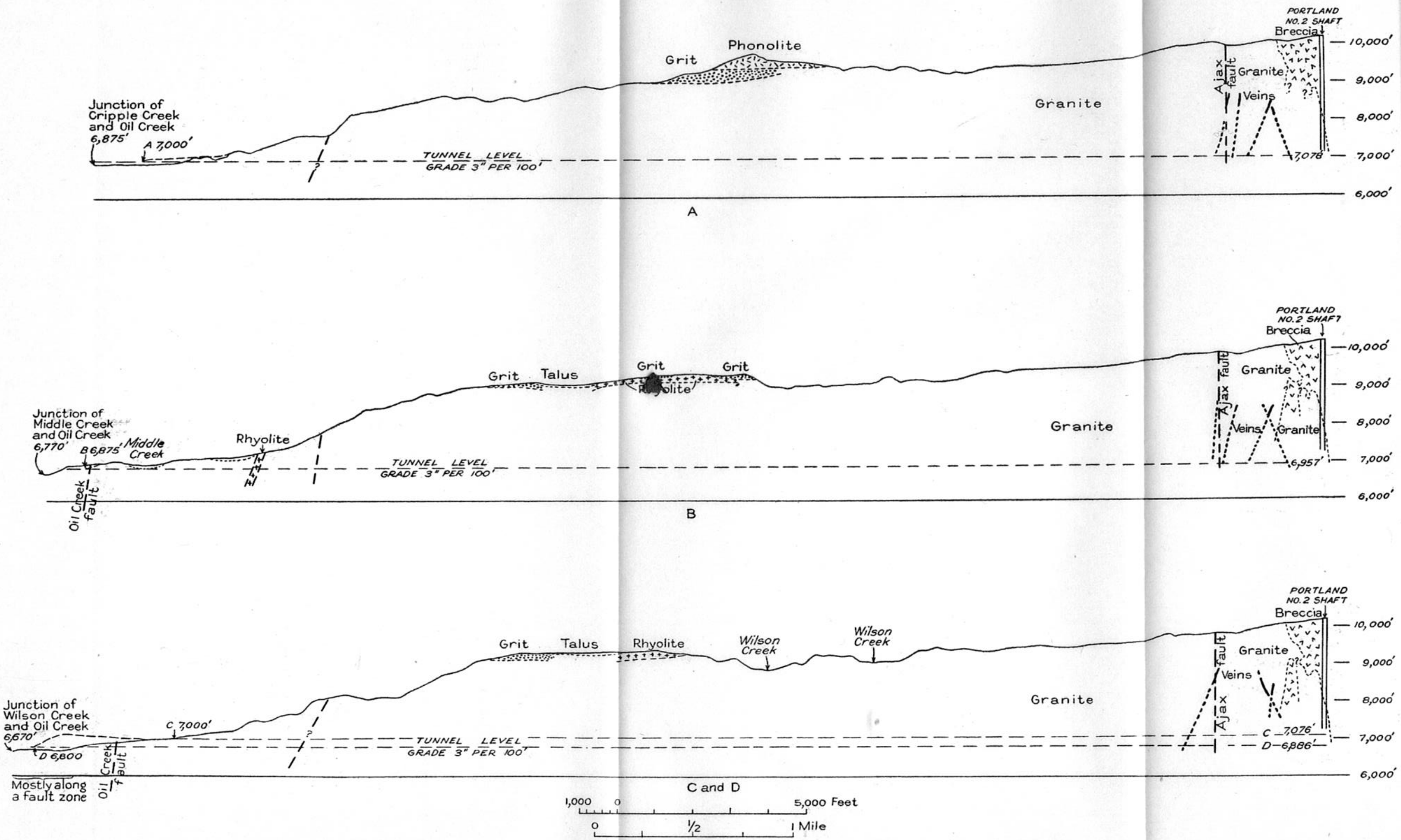

Figure 48.—Longitudinal sections along proposed deep drainage tunnel sites.

length would lie through an area that is cut by faults of large displacement and doubtless bordered by broad zones of shattered ground. This ground would increase the cost of tunneling appreciably and would seem to offset the advantages.

So far as natural features are concerned, sites B, C, and D appear the most favorable on the whole. Other questions, such as rights of way or purchase of dumping ground, may affect the final choice and are beyond the scope of this report.

APPENDIX

[Copy from Report on Proposed Deep Drainage Tunnel for the Cripple Creek District, Colo., to the Public Works Administration, by G. F. Loughlin and A. H. Koschmann, May 5, 1934.]

Estimated output below present (Roosevelt) tunnel.

Eight mines have been worked down to ore below the present drainage level, and are all located in the southern part of the complex crater and in the adjacent part of the surrounding granite. By far the largest part of the district's output of gold has come from this restricted part. The more productive mines in other parts of the district are still so far above the present drainage level that they must undergo considerable further development before their need of any deeper drainage can be demonstrated.

Detailed study of the 8 deep mines, with due regard for the uncertainties involved in the downward projection of geologic structures, leads to widely different estimates of ore reserves below present drainage level; a minimum of only 105,200 ounces of gold, based on the assumption that the unfavorable conditions exposed in the present lower workings persist to the proposed deep-tunnel level; a maximum of 372,000 ounces based on the assumption that favorable conditions will offset unfavorable conditions below present drainage level as they have above, though to a smaller degree. The corresponding minimum and maximum gross values, with gold at $35 per ounce, would be $3,682,000[68] and $13,020,000.[68]

[68]Gross value should be figured at $32.76 per ounce, the value upon which settlements for ore are made. Figures of gross should be: 105,200 ounces at $32.76= $3,446,352; 372,000 ounces at $32.76=$12,186,720. [C.W.H.]