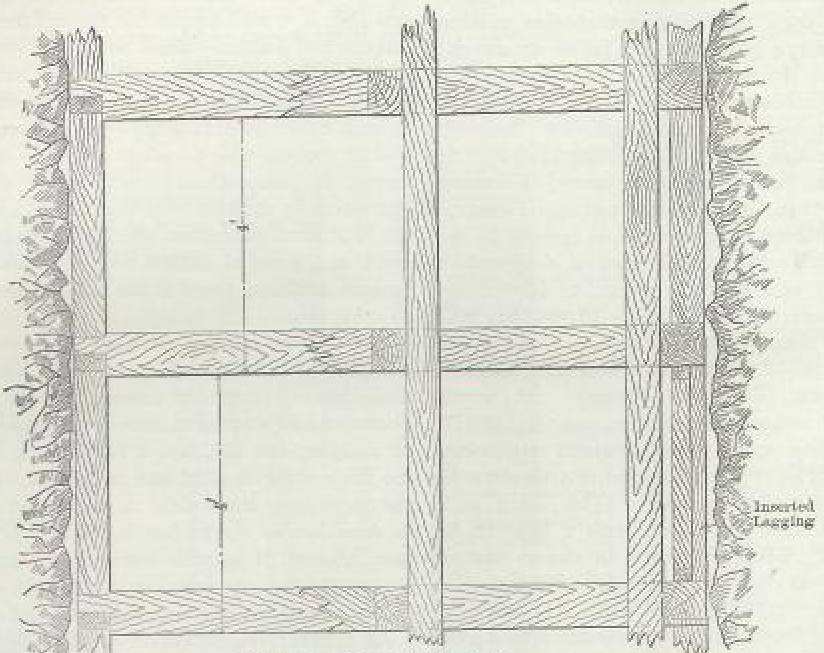
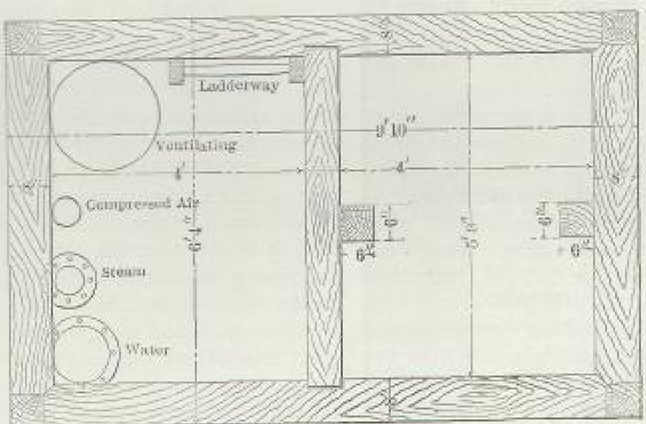
Drainage of the Cripple Creek District.*

BY D. W. BRUNTON.†

A study of existing conditions, of records, and of reports made from time to time, shows that the water in this district is "ground water"; *i. e.*, water that is stored in the rock, replenished from the surface and not by springs from beneath.



VERTICAL PARTIAL SECTION



PLAN

When the natural water level is lowered (either by pumping or tunnel drainage) the flow toward the pumps or tunnel takes place through every available opening, and even through the rocks themselves. When the depth of drainage below the natural water-level is increased, the available drainage area is proportionately enlarged; the velocity of the flow is also increased in direct proportion to the head; in other words, the greater the pressure the greater the flow.

The annual precipitation (as shown by records kept by Mr. Victor G. Hills) is from 15 to 18 in., but there is nothing to indicate what percentage of this finds its way into the rocks and what is "run-off."

A recent heavy shower nearly buried the end of the Cripple Creek drainage tunnel with an immense mass of gravel and boulders, and in locating a tunnel in either of these cañons particular pains should be taken to keep the portal and tunnel buildings at a sufficient height above the stream to prevent any possible damage or interruption from floods.

Water now Pumped from the District.—This is shown as follows:

Gold Coin	500	gal per min.
Strong	250	" " "
Vindicator	153	" " "
Golden Cycle	275	" " "
Total	1,178	" " "
Flow from Cripple Creek Drainage Tunnel	4,115	" " "
Grand total	5,293	" " "

Quantity pumped, Jan. 17, 1903 (report of V. G. Hills): Isabella Lee, 50 gal.; Vindicator, 480 gal.; Gold King, 140 gal.; El Paso, 600 gal.; Strong, 200 gal.; Stratton's Independence, 300 gal.; Gold Coin, 750 gal.; Saint Patrick, 30 gal.; total, 2,250 gallons per minute.

At that date the water level on the western portion of the district was about 9,028 ft. elevation; this was maintained until the Cripple Creek drainage tunnel cut the water courses on Nov. 22, 1903, since which time the water level has gradually fallen off 137 feet.

Permeability of the Rocks.—The productive area is roughly coincident with the core of eruptive rocks occupying the vent of the old crater and the distance to which the fissuring extends into the surrounding granite. The eruptive rocks (excepting some phonolite and basalt) are extremely porous. There are also open fissures along dikes, in veins, and often directly through the country rock; these fissures are known among miners as "water courses." They have, in common with the vein system, a general north and south direction, but vary somewhat, so that the drainage of any one section will affect the entire area.

At present, the group of mines on the eastern and southern sides of the district (including the Vindicator, Golden Cycle, Gold Coin, Strong and Stratton's Independence) are but little affected by the drainage which has been going on in the central and western portion since the water-bearing fissures were cut by the Cripple Creek drainage tunnel. The fact that they do not connect at the present water level is no certain indication that they would not at greater depth, as the plug of eruptive rocks filling the crater of the volcano probably narrows as depth is gained. A drainage tunnel, passing through the granite rim into the most highly fissured eruptives, in time would probably drain the entire district.

This opinion is shared by Messrs. Mudd and Lindgren in their respective reports.

It is generally conceded that the granite rim surrounding the volcanic area carries little water, and that the water which is being handled by the pumps and by the Cripple Creek drainage tunnel is drawn almost entirely from the eruptive rocks. Some idea of the immense amount of water carried in these rocks may be gathered from the fact that the removal of 4,115 gal. per minute is lowering the water level in the central and western portion of this underground basin at the rate of only 4 ft. per month.

Amount of Water Removed to Lower Water Level One Foot.—Since the completion of the Cripple Creek drainage tunnel, A. C. Jaquith has kept a record not only of the amount of water flowing from the tunnel, but also of the rate of recession of the water in the principal shafts. In the latter part of 1903 the amount of water necessary to lower the water level one vertical foot was 25,204,000 gal. This amount raised steadily as the drainage area increased, until Sept., 1904, when it reached 58,109,000 gal. for one vertical foot drained; since then the relation of discharge to drainage has remained practically constant.

Comparative Costs of Pumping and Tunneling Schemes.—Any attempt to drain the entire district even by the most modern centralized pumping station,

*A report prepared for a committee appointed by Cripple Creek mine owners.

†Mining engineer, Denver, Colo.

would prove a complete failure, as the expense entailed would be prohibitive.

Mr. Jaquith has calculated that to drain the district to a depth of 730 ft. below the Cripple Creek drainage tunnel by pumping would cost 6.6 times as much as by tunneling. Even if the cost of the two systems were the same, the tunnel would be preferable as it would take care of itself without any expense.

Most Desirable Course for Tunnel.—The most effective way to tap the greatest number of fissures in the least distance would be to run a tunnel in an east and west direction; to afford the *earliest* relief to all portions of the district, it should run through the center, which practically means that it should cross the eruptive area from the El Paso to the Vindicator. I believe that it would not be necessary to crosscut the entire district in order to drain it; although the combined advantages of drainage, ventilation and prospecting would justify such an expenditure. Another advantage of tunneling over pumping, even where both can be effected at equal costs, is the freedom from breakdowns and stoppages, either by accident or design as often happens during strikes.

History of Tunnels in the District.—Four tunnels have already been driven: the Blue Belle, Ophelia, Standard and El Paso. These tunnels were run in the order named, each, respectively, at a considerable distance below the preceding. As each successive tunnel struck the water bearing fissures it immediately drained the tunnel above it; at present, only the El Paso is discharging water. The elevation of tunnel portals and the amount of water cut by each are shown herewith.

	Elevation.	Flow. Gal. per Min.
Blue Belle	9,342	200-300
Ophelia	9,275	1,000-3,000
Standard	9,034	1,000-12,000
El Paso	8,790	1,800-6,800

Efficiency of Tunnel Drainage.—The effect on the water levels (described in the report of Mr. Mudd, and in the report of Victor G. Hills to the Portland Mining Company, Jan. 19, 1903) was almost immediately felt in the mine workings over an immense area; it seems probable that the mines on the extreme south and east, whose water level was apparently unaffected, must have derived considerable benefit by the lowering of the water level to the north and west of them; each of these mines is now pumping much less water than before the Cripple Creek drainage tunnel tapped the district; in some instances, as at the Portland and Independence, the pumps have been entirely stopped.

Difference of Cost of Mining in Wet and Dry Ground.—The expense of pumping is by no means the only measure of the increased cost of mining in wet ground. When drifts, winzes and raises are driven where the miners can work in comfort, wearing ordinary clothing, they can do at least 33% more work than when weighed down with rubber coats and boots. In addition to this, with Cripple Creek ores, the loss in "fines" is certainly much less in dry than in wet mining. Deep-level drainage would show a difference of at least 20% in favor of dry against wet mining.

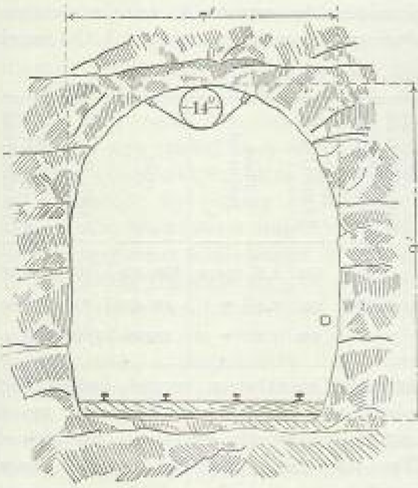
Depth at which Drainage Tunnel should be Driven.—Four drainage tunnels have already been driven, each in a measure parallel with the other, but ideas change with conditions. Thus the El Paso tunnel was driven 244 ft. below the Standard, but it did not reach its maximum flow until May 1, 1904; yet another tunnel is already required. Commercial considerations demand that the proposed tunnel shall be run at sufficient depth to obviate absolutely the necessity of ever having to drive another.

On the other hand, it is well known that all rocks (especially volcanic ones) usually soften somewhat in depth; and that under the ever-increasing pressure of superincumbent rocks, as depth is gained, there is also a tendency for the fissures to narrow. Considering the thickness of the mineralization zone, and the comparative shallowness of the present workings (granting a steady decrease of fissuring and mineralization with depth), complete extinction is further off than the pessimists would have us believe; the commercial limit is apt to be reached before the geological limit.

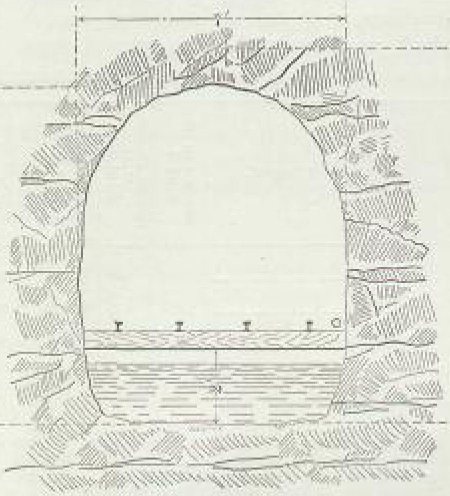
Within reasonable limits, the greater the depth at which the water-bearing rocks can be tapped, the more rapidly and thoroughly will the eruptives be drained to the outer edge of the rim. No harm would be done if the district should be drained below some of the smaller veins, as it seems probable that some of the more highly mineralized fissures will continue beyond a depth at which it will be commercially profitable to drive a tunnel.

Comparison of Tunnel Sites.—The different ravines to the south and west of the district afford excellent tunnel sites. At its junction with Four Mile, Wilson creek is lower than Cripple creek; but at the level at which it would be desirable to run a drainage tunnel, the shortest routes to the productive area from any given elevation are found in Cripple creek cañon. Messrs. Davis and Byler made a survey down Wilson creek to an excellent site at an elevation of 8,100 ft.; the length of a tunnel by the route from the portal to the Gold Coin shaft would be 17,900 ft.; and to the igneous rock, where it would begin drainage, 20,500 ft. The same result can be accomplished in Cripple creek with a tunnel 5,000 ft. shorter. Moreover, any tunnel from Wilson creek would have the disadvantage of passing under Straub mountain at 1,200 to 1,500 ft. below the surface, thereby prohibiting the use of intermediate shafts and necessitating driving from the portal only. The length of time required would effectually prohibit the Wilson creek route.

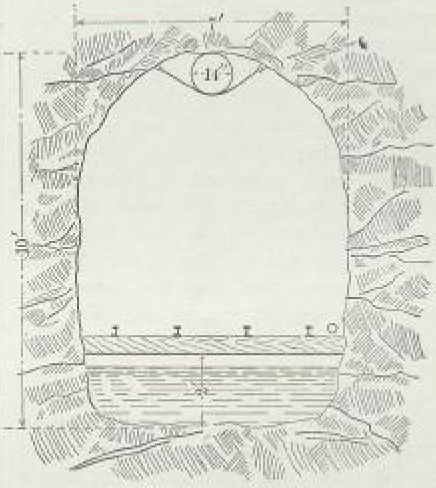
Excellent tunnel locations are found in Cripple creek cañon; just below Cape Horn, at Gatch Park, and below Window Rock, the conditions afford good places for operations. In comparison with the magnitude of the work, the cost of grading near the mouth of the tunnel scarcely needs to be taken into consideration; the necessary buildings can be erected on



TUNNEL WEST OF SHAFT
During Construction



TUNNEL WEST OF SHAFT
After Completion



TUNNEL EAST OF SHAFT

posts, and the ground filled up with waste to the tunnel level in a short time.

Only a few small springs show in Cripple Creek cañon; this indicates that no water of any consequence need be expected in driving the proposed tunnel. This conclusion is also confirmed by the Big Twenty tunnel, which has been driven into the mountain below Sentinel Rock for a distance of 1,300 ft. without finding any water.

From each of the above-mentioned sites the tunnel would pass through coarse-grained granite for the entire distance to the Black Belle water courses; no better material for driving in than this could be selected. The Cripple Creek drainage tunnel is now flooded nearly to the roof by an accumulation of débris near its mouth; careful inspection of the Big Twenty tunnel (in identical rock) showed few drill holes and "guns," yet the rock stood the entire 1,300 ft. without a single stick of timber.

The grade of Cripple creek increases considerably as it descends toward Oil creek; consequently deep-level tunnels will gain more depth per ft. of length than shallow ones. Again, as the new tunnel will be driven under the old one for over a mile, in which distance no additional drainage depth is gained, it follows that this mile of practically dead work forms a smaller proportion of the total length in the long deep-tunnels than in the shorter, shallower ones; and that the deeper we drive the proposed tunnel, the less will be the cost per vertical foot of ground drained.

A comparison of the three sites selected, the cost of driving, and the length of time required to complete the tunnel to the eruptive rocks, are given herewith; also a synopsis of the principal figures.

Estimated Cost of Driving Tunnel from Below Cape Horn, Elevation 8,160 ft., to Main Water-Course.—Distances: Portal to El Paso shaft, 12,840 ft.; portal to Black Belle water-course, 13,840 ft.; portal to tunnel shaft, 8,840 ft.; depth below portal of Cripple Creek drainage tunnel, 630 ft.; depth of tunnel shaft, 650 feet.

Costs:

Shaft, sump and station.	$30,000
Portal to shaft workings, 5,500 ft. at $20 per ft.	110,000
Shaft workings, 6,680 ft. at $25 per ft.	167,000
Shaft workings to Black Belle, 1,660 ft. at $22.50	37,350
Road, buildings and depreciation of machinery	35,650
Total	$380,000

Time required: Shaft, sump and station, 216 days; tunnel workings from shaft, 334 days; tunnel workings to Black Belle, 166 days; total 1.97 years, or 716 days.

The depth gained under Cripple Creek drainage tunnel is 605 ft.; the cost per vertical ft. of depth drained is $628.

Time Required to Drive Tunnel from Gatch Park, Elevation 8,020 ft., to Main Water-Course.—Distances: Tunnel portal to El Paso shaft, 14,550 ft.; El Paso shaft to main water-course, 1,000 ft.; portal to tunnel shaft, 10,570 ft.; depth of tunnel shaft, 800 ft.; elevation of portal, 8,020 ft., or 753 ft. below portal of Cripple Creek drainage tunnel. Time required to sink tunnel shaft with sump and station (allowing a daily rate in shaft of 3½ ft.), 261 days.

While this was being done, the heading from the portal would have been in operation 261 days, and (at an average rate of 10 ft. per day) would have been driven 2,610 ft. This would leave a gap between the portal heading and the bottom of the shaft of 7,960 ft., which (by combined attack from the tunnel shaft and the portal heading) could be driven through in 398 days. During this 398 days, the heading from the tunnel shaft to the eastward would have advanced 3,980 ft., thus reaching a point 1,000 ft. from main water-course, when connection is made between the portal and shaft workings. This 1,000 ft. would be driven in 100 days, making the time required for effective drainage to begin, as follows: Sinking tunnel shaft, sump and cutting station, 261 days; making connection between shaft and portal headings, 398 days; connecting tunnel-shaft workings with main water-course,

Time Required.—Tunnel shaft, sump and station, 367 days; connection between portal heading and shaft workings, 451 days; tunnel shaft workings to main water-course, 100 days; total, 918 days, or 2.5 years. The depth gained by Cripple Creek drainage tunnel, 1,090 ft. Cost per foot of depth drained, $468.

Rate of Driving.—In the preceding estimates, it has been assumed that the tunnel shaft could be sunk at a rate of 3½ ft. per day, and that an average daily rate of progress of 10 ft. could be maintained in the headings by employing skilled tunnel men and 3½ to 4-inch air drills. This is better than was made in the Cripple Creek drainage tunnel, but that was a small tunnel, driven by miners using 3¼-in. air drills. In Europe, in the Arlberg and the Simplon tunnels, 15 or 18 ft. per day has been maintained over a period of years. Even in this country, drifts have often been driven in granite at a rate of 360 ft. per month. In two long tunnels recently completed in California, rates considerably over 10 ft. were maintained during the entire progress of the work.

DETAILS OF PROPOSED TUNNELS.

Location of Portal.	Elevation of Portal.	Depth Below C. C. D. Tunnel.	Distance to El Paso Shaft.	Distance to Main Water Channel.	Distance from Portal to Tunnel Shaft.	Depth of Tunnel Shaft.	Time Required.	Cost.	Depth Gained.	Cost per Vertical Ft. of Depth Drained.
Cape Horn	8,160	630	12 840	13,840	8,840	650	1.97 years	$380,000	605	$628.00
Gatch Park	8,020	770	14,550	15,550	10,570	880	2.1 "	430,000	740	581.00
Window Rock	7,060	1 130	17,200	18,200	12,690	1,140	2.5 "	510,000	1,090	468.00

100 days; total time, 759 days, or 2.1 years.

Cost of work:

Sinking shaft and sump, 820 ft. at $40 per ft.	$32,800
Cutting station	3,200
Driving tunnel heading 6,590 ft. at $20	131,800
Driving tunnel from bottom tunnel shaft, 7,960 ft. at $25	199,000
Driving tunnel heading 1,000 ft. at $22.50	22,500
Buildings, road and depreciation of machinery	40,700
Total	$430,000

The depth gained would be 740 ft.; the cost per vertical ft. drained, $581.

Should it be necesary (in order to obtain drainage of the eastern part of the district) to drive across to the Vindicator shaft (11,640 ft.), this could be done in 1,164 days (3.2 years) at $25 per ft., or $291,000. This should not be all charged to drainage, as the crosscut would be of value both for prospecting and ventilation.

Cost of Driving Tunnel from below Window Rock (Elevation 7,660 Ft.) to Black Belle Water-Course.—Distances—Portal to El Paso shaft, 17,200 ft.; portal to Black Belle, 18,200 ft.; portal to tunnel shaft, 12,960 ft.; depth below portal of Cripple Creek drainage tunnel, 1,130 ft.; depth of tunnel shaft, 1,140 feet.

Tunnel shaft, sump and station	$50,000
Tunnel from portal to shaft workings, 8,180 ft. at $20 per ft.	163,600
Tunnel, shaft portion, 9,020 ft. at $25 per ft.	225,500
Tunnel shaft workings to Black Belle, 1,000 ft. at $22.50 per ft.	22,500
Road, buildings and depreciation of machinery	48,400
Total	$510,000

In the Cowenhoven tunnel (when rock conditions were favorable) from 300 to 427 ft. per month was easily maintained. To do this, however, special pains must be taken with ventilation, transportation and drainage — three all-important branches.

Expediting the Work.—The early completion of the new drainage tunnel is urgent. In the portal and shaft heading toward the west (where no water is expected until after connection shall have been made) mucking from the face will be easier and quicker if the ties are laid in the bottom of the tunnel (instead of above the water grade, where they will have to be placed before the water fissures are opened up). After connection is made between the portal heading and shaft workings, the plant at the tunnel shaft will provide ventilation for the heading to the east, and thus permit the pipe between the shaft and portal to be removed and used again elsewhere. If this pipe is removed before the track is raised it is evident that this portion of the tunnel need not be over 9 ft. in height, instead of 10 ft., as will be necessary where the ventilating pipe must be used after the ties have been placed above the water level.

No great speed in tunneling can be obtained without the active co-operation of the workmen; to this end (as men cannot be expected to perform extra labor without extra compensation) some means of interesting them in rapid driving must be adopted. The most successful plan yet adopted for this purpose is what is known as "the bonus system," in which all grades of employees are paid the standard wages of the district, plus a certain amount for each foot above two hundred driven during the month. If this figure is placed at $6 per ft., and if 10 men are employed on each shift in each heading, the bonus paid each man over and above his daily wage, if 300 ft. were made per month, would be $20; and $40 if 400 ft. were driven during the month. This system has given excellent satisfaction to both employers and employees where it has been adopted; at the same time the speed rate is raised from 33 to 50%, without increasing the cost per running foot driven.

Size of Tunnel.—On coarse blocky granite, such as the tunnel will encounter, the maximum rate of speed cannot be reached in an opening less than 7 ft. in diameter; this establishes the width once and for all. But drainage below the tracks, and room for ventilating pipe, workmen and tunnel cars above it, will increase the tunnel height to 10 ft. While it is possible, by putting in sidings, to remove the waste on a single track, it is more expeditious and cheaper in the end to use double track throughout.

Considering the hardness of the rock and the purpose for which the tunnel is being driven, a section like that shown (Fig. 2) would probably be cheapest and best.

The Tunnel Shaft.—It is not expected that much water will be encountered in the tunnel shaft and the headings driven from it, but it would be unwise to sink a shaft 1,140 ft. deep without making provision for pumping. The headings will be driven in both directions from the bottom of the shaft; at the most rapid rate, the waste hoisted would not exceed 200 tons in 24 hours. This could readily be hoisted in a single compartment and leave abundant time for handling men and materials. The pumping compartment should be 4 by 5 ft. to give sufficient room for steam, water, compressed air and ventilating pipes, and for a ladder way. Timbers need not be over 8 ft. by 8 in., and should be placed 4 ft. apart, center to center; lagging will not be necessary, except in a few places; it will be better to have the timbers blocked securely against the walls and the lagging placed between the timbers as shown in Fig. 1.

Grade.—At times the tunnel will carry from 10,000 to 15,000 gal. per min.; it is evident that the water-way must not only have a large cross-section, but considerable grade. A grade of 1 foot in 300 is recommended.

Haulage.—Four methods of tramming are in common use underground, viz.: By men, mules, electric and air locomotives. For distances over 1,000 ft., man power is too expensive. For temporary work (such as drainage tunnel driving) mules are usually employed. In the present instance, the section adopted renders their use impossible without planking the entire width of the tunnel, both between and outside the tracks.

Electric motors furnish the cheapest and most efficent method of underground haulage; but where transportation is to be discontinued immediately after the tunnel is completed, it scarcely seems worth while to go to the expense of bonding the rails and putting in an underground trolley wire; moreover the water, at and near the contact, would render insulation difficult.

On the other hand air locomotives would furnish excellent haulage, the only objection being the cost of the locomotives and the high-pressure air-compressors necessary to charge them.

On the whole, it would probably be cheaper to plank the tunnel and use mules, which in spite of their many disadvantages, possess one point of undoubted superiority over locomotives, viz.: they can step across the tracks at the headings, thereby avoiding the necessity of maintaining switches near the face.

Power Plant.—The water flowing from the Cripple Creek drainage tunnel could easily be utilized to operate an electric power plant; for this purpose the El Paso Company has already surveyed a ditch and taken out water rights at a point below the proposed Gatch Park tunnel. If one of the other sites mentioned should be selected, suitable locations for a ditch and pipe line could be obtained. By locating the inlet to the ditch below the point selected for the new tunnel, the water now flowing from the Cripple Creek drainage tunnel could be deflected into it. After the completion of the drainage tunnel, the power would undoubtedly find a ready sale in the district.

Ventilation.—This problem, one of the most important adjuncts to rapid tunnel work, has long since been completely solved. No difficulty need be expected from failure to clear the tunnel of smoke within a few minutes after each round of shots is fired. Small single openings (like mine drifts and drainage tunnels, which, from the nature of the case, necessitate the use of small ventilating pipes either as an inlet or outlet) cannot be successfully ventilated with a fan blower, as the friction-head increases, and the volume of air delivered diminishes, with the length of pipe. Workings of this kind should always be ventilated by a force blower, in which case the volume of air delivered or removed remains the same no matter what the increase in the length of the ventilating pipe may be; the only difference being that the power required to operate the blower increases with the distance. As power forms but a small item in the cost of ventilating, this increase is immaterial, while the results gained by this system are everything that can be desired. In the Cowenhoven tunnel, two miles from the face, by this system the air was kept almost as pure as at the surface.

In removing foul air from a tunnel with a ventilating pipe, it is evident that either the pipe or the tunnel may be used as the inlet. Where speed is the first consideration, the use of the tunnel for the outlet, driving fresh air through the pipe over the drill men, is the most efficient. Where heavy charges of powder are used, and much poisonous gas is imprisoned in the muck and released as it is shoveled into the cars, a stream of fresh air blowing into the heading protects the workmen from its bad effects; but where this system is used there is always a heavy bank of smoke moving slowly out of the tunnel for some hours after the shots have been fired, through which the trammers must pass.

Conclusions.—Assuming the cost per vertical foot of ground drained as the same for each of the tunnels heretofore considered, if a balance is struck between the desirability of a deep-level tunnel (with its long life and certainty of drainage for all portions of the district) and the necessities of many of the mines now working at or near the water level, it would result in the choice of the tunnel from Gatch Park (elevation, 8,020 ft.). However, when we consider that the tunnel from Window Rock would give an additional 350 ft. greater depth at an additional cost of $80,000 (or only $228 per additional vertical foot of ground drained), it will be seen that this is an advantage too great to be foregone, and should lead unhesitatingly to the selection of the deep-level tunnel.

If the funds of the association, and the urgency of some of the mines, will not permit the selection of a tunnel site at elevation 7,660 ft., then a choice must be made which will meet the conditions imposed; in which case, either the tunnel from elevation 8,020 ft., or that from elevation 8,160 ft., will fulfil all requirements for many years to come. In making the selection, it must not be forgotten that provision must be made for the future as well as for the present; the deeper the tunnel is driven, the less will be the cost per vertical foot of ground drained throughout the entire district.

In respect to tonnage, Parral is one of the largest ore producing districts of Mexico, if not the largest. Three of its important mining companies are controlled in New York and Philadelphia. The United States Mining Co. is a Philadelphia concern, while the Parral Corporation and the Quebredillas Mining Co. have their offices in New York.