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CHARLES D. WALCOTT, DIRECTOR

GEOLOGY AND GOLD DEPOSITS

OF THE

CRIPPLE CREEK DISTRICT, COLORADO

BY

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AND

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SYNOPSIS OF PART I.

CHAPTER I.—INTRODUCTION.

The Cripple Creek gold deposits, discovered in 1891, were investigated by Messrs. Cross and Penrose, of the United States Geological Survey, in 1894. The present reexamination was requested by citizens of Colorado, and has been carried out under the financial cooperation of the State with the Federal Survey. It has involved complete revision of the topographic map of the district used as a base by Cross and Penrose, the running of a line of accurate levels from Colorado Springs to Cripple Creek, remapping of the geology, and a thorough study of the extensive mine workings opened during the past ten years. Due acknowledgment is made of the cordial assistance rendered by mining men, and a list is given of the important publications concerning the geology or mines of the district.

CHAPTER II.—GENERAL GEOLOGY.

Results of first geological survey of the district.—The Cripple Creek hills lie near the eastern border of a much dissected plateau which slopes gently westward for 40 miles from the southern end of the Colorado Range, dominated by Pikes Peak, to the relatively low hills connecting the Mosquito and Sangre de Cristo ranges. The prevailing rocks of this plateau are granites, gneisses, and schists. The granites inclose masses of Algonkian quartzite and are therefore post-Archean; but they are older than the only Cambrian sediments known in Colorado. During Tertiary time volcanic eruptions broke through these ancient rocks at several points and piled tuffs, breccias, and lavas upon the uneven surface of the plateau. The eruptive rocks of the Cripple Creek district are the products of one of the smaller isolated volcanic centers of this period, a center characterized by the eruption of phonolite, which does not occur elsewhere in this general region.

The most voluminous products of the Cripple Creek volcano now preserved are tuffs and breccias. They occupy a rudely elliptical area in the center of the district, about 5 miles long in a northwest-southeast direction and about 3 miles wide. According to Cross, these breccias and tuffs rest in part upon an earlier flow of andesite, but mainly upon an unevenly eroded surface of the granites and schists. The breccia is much indurated and altered, but was thought by him to consist mainly of andesitic fragments. The most characteristic massive rock of the Cripple Creek volcano is phonolite. It occurs as dikes and masses in the breccia and in the surrounding granitic rocks.

The general succession of igneous rocks, according to Cross, is as follows: The earliest rocks were andesites containing some orthoclase. Then came a series of allied phonolitic rocks, rich in alkalies and moderately rich in silica, together with

some andesites. Among them are trachytic phonolite, nepheline syenite, syenite porphyry, phonolite, mica andesite, and pyroxene andesite. Phonolite was erupted at several periods. The nepheline syenite he considered as probably younger than the trachytic phonolite. At the close were intruded a small number of narrow dikes of basic rocks, the so-called basalts, which contrast very markedly with the phonolite.

Modification of earlier results.—The present investigation indicates some necessary modifications of the earlier report in the way of stronger emphasis on the intimate genetic relationship of the rocks. The "phonolite," "nepheline syenite," "trachytic phonolite," "syenite porphyry," and "andesites" of Cross are all very closely related and have been found to be in most cases so closely connected by intermediate types as to be practically inseparable. None of the massive rocks can properly be called andesite, and although it can not be affirmed that andesitic fragments are entirely absent from the usually much-altered volcanic breccia, the term "andesitic breccia" does not seem applicable to this formation as a whole, which is composed chiefly of fragments of phonolitic rocks accompanied locally by much granite, gneiss, or schist detritus.

None of the massive rocks erupted from the Cripple Creek volcanic center and now preserved in the district show any evidence of having been surface flows. They are for the most part intrusive porphyries, ranging in texture, however, from the granular so-called nepheline syenite near the town of Independence to the nearly aphanitic phonolite of the smaller dikes and sheets. Most of them come under the designations phonolite, latite-phonolite, trachydolerite, and syenite.

While the breccia may in a few places rest upon an uneven surface of erosion, it occupies in the main a steep-walled chasm extending to unknown depth and constitutes a typical volcanic neck.

The rhyolite of Grouse Hill and Straub Mountain is intrusive into the associated grits of this part of the district. The grits can not, therefore, be correlated with the Miocene High Park lake beds, and this modifies somewhat the argument from which Cross deduced the probable Miocene age of the Cripple Creek volcano.

Structure of the district.—The pre-Cambrian crystalline complex which forms the general plateau of the region was perforated by a volcanic explosion. The deep pit thus formed was filled with a breccia composed of fragments of phonolite and allied rocks and of granite, gneiss, and schist. The walls of the pit are steep and rather irregular. They exhibit local bench-like flattening and in some places overhang the breccia. The breccia occasionally shows an indistinct and nonpersistent bedding or banding and its constituent particles vary widely in size.

The breccia is cut by intrusive bodies of syenite and trachyphonolite, these two rocks showing frequent gradations from one to the other. The intruded bodies are usually of very irregular shape and have been peripherally shattered to such a degree that their contacts with the breccia are very obscure. These rocks generally form stock-like masses or thick, irregular sheets. The breccia is also cut by numerous dikes of phonolite, and this rock forms intrusive sheets and masses of considerable size in the prevolcanic crystalline rocks. Beacon Hill is a conspicuous example of a plug of phonolite in granite.

CHAPTER III.—DESCRIPTION AND PETROLOGY OF THE METAMORPHIC AND IGNEOUS ROCKS.

The rocks of the district are chiefly of metamorphic and igneous origin. Two broad divisions may readily be made: (1) The pre-Cambrian metamorphic and igneous basement complex and (2) the products of the Tertiary Cripple Creek volcano.

The metamorphic rocks comprise a much foliated quartz-muscovite-fibrolite schist, which was probably derived from sedimentary rocks, and a biotite gneiss derived from a granitic rock. Of the ancient igneous rocks two groups may be distinguished. The first group comprises three varieties of granite, which are closely related in composition and have been named, in order of probable age, the Pikes Peak type, a coarse-grained quartz-microcline-biotite granite, the most abundant rock of the whole region; the Cripple Creek type, a finer-grained rock of similar composition, and the Spring Creek type, of medium grain, composed mainly of quartz and orthoclase, with a little muscovite. An interesting feature of these granites is the presence of fluorite, which is probably original. The second group includes the products of differentiation from an olivine-syenite magma. The predominant rock is composed of microperthite, diallage, and olivine, with accessory quartz. The other rocks are an olivine gabbro, with a doleritic contact phase which establishes a close relation to the olivine-bearing diabase dikes which cut the granite in many parts of the area.

Tertiary volcanic rocks afford a striking example of the chemically related products of a single center of eruption. The most abundant and characteristic of these rocks is phonolite. Next in importance is latite-phonolite, which consists essentially of soda-orthoclase, sodic plagioclase, sodalite, nosean, analcite, ægirine-augite, and augite. A syenite rich in alkalies and containing orthoclase, augite, and hornblende as essential constituents is the third member. A trachydolerite composed of plagioclase, orthoclase, analcite, augite, and biotite is the least abundant of the rocks occurring in irregular intrusive masses. Three varieties of rocks occur as dark basic dikes. These are (1) trachydolerite, (2) vogesite, and (3) monchiquite.

These Tertiary rocks are mentioned above in the order of decreasing silica. In spite of wide variations in texture, mineralogical character, and chemical composition an intimate connection or consanguinity exists between all these rocks, of which some of the manifestations are the almost invariable appearance of orthoclase and analcite as the final products of crystallization and the remarkably constant ratio of silica to alumina. All these volcanic rocks have unquestionably been derived from the same magma and constitute an excellent example of magmatic differentiation within a confined petrographic province.

Owing to simple structural relations the composition of the average rock of the Cripple Creek volcano can be computed and is found to be close to that of phonolite.

CHAPTER IV.—GENERAL MINERALOGY OF THE DISTRICT.

A list of well-established vein minerals includes the following species:

Calaverite.	Tetrahedrite.	Rhodochrosite.
Sylvanite.	Hübnerite.	Barite.
Krennerite.	Quartz.	Celestite.
Pyrite.	Chalcedony.	Wavellite.
Molybdenite.	Opal.	Adularia.
Sphalerite.	Fluorite.	Sericite.
Galena.	Calcite.	Roscoelite.
Stibnite.	Dolomite.	

Among the more important secondary minerals due to oxidation are:

Gold.	Psilomelane.	Gypsum.
Emmonsite.	Molybdite.	Chalcanthite.
Limonite.	Alunite.	Epsomite.

CHAPTER V.—HISTORY AND TECHNOLOGY OF THE GOLD DEPOSITS.

Earlier work.—The excellent work of R. A. F. Penrose, jr., was done at a time when there were no deep workings in the district. That his results should require some slight modification in the light of present facilities for investigation was to be expected.

History of mining development.—Ore found by Robert Womack in Poverty Gulch drew E. M. De la Vergne and T. F. Frisbee to the district in December, 1890. They returned in February, 1891, and recorded the first mining location. On July 4 of the same year W. S. Stratton located the Washington and Independence claims, and in the rapid development of the district that followed the Independence mine soon attained great prominence. It was rivaled, however, by the Portland, now the largest mine in the district. Two railroads were completed into the district in 1893, and a third in 1901. There have been two periods of depression due to labor strikes, one in 1894 and another in 1903–4. The most important recent event in the history of the district was the opening of the El Paso tunnel in 1903, enabling several of the mines to extract ore previously below the water level.

Production.—The district has produced, to the end of 1905, $124,415,022 in gold and 646,193 fine ounces of silver, the maximum production having been reached in 1900.

Mining.—The ore is broken by overhand stoping and is usually hoisted by steam through vertical shafts. It is generally screened, the screenings as a rule constituting the richest part. The coarse ore is washed and hand sorted. The total cost of mining, including development and sorting, is probably nowhere less than $8 per ton.

Sampling.—The district is well provided with sampling works, and through these nearly all the ore passes in its course from mine to reduction works. The sampling charges, exclusive of freight, range from 60 cents to $1 per ton.

Processes of reduction.—Probably about one-sixth of the tonnage of ore mined at Cripple Creek goes to the smelters at Pueblo and Denver. This is the richest ore. The balance of the product is treated in chlorination and cyanide mills at

Florence, Colorado City, and elsewhere. In 1904 the charges for treatment at the mills ranged in the lowest schedule issued from $5.50 per ton for half-ounce ore to $9 per ton for 3 to 5 ounce ore. This included freight from mine to mill.

Labor conditions.—The minimum wages for ordinary miners are $3 for an eight-hour day. Conditions of work and living are good, but the district has suffered from two serious conflicts between mine owners and miners.

Financial conditions.—While there are several large companies operating in the district, many small mines are under individual ownership, and there is much leasing, with royalties ranging from 15 to 35 per cent of the net returns. A tendency exists to organize companies at capitalizations greatly in excess of the probable value of the prospects which it is proposed to develop. Very few companies have been organized with less than $1,000,000 capital, and very few mines have yielded the amount of their capitalization in dividends. The fascination of a mining venture tempts investors to accept a rate of interest on their capital which is lower than it should be when the uncertainties of ore bodies and the usual limited life of a mine are taken into consideration. The costs of mining and treatment at Cripple Creek are high and do not always compare favorably with those prevailing in other districts that labor under no greater disadvantages.

Extent of productive territory.—There is nothing in the history of the district since 1894 warranting any extension of the bounds of the productive territory as then known. All the important mines lie within a circle of 6 to 7 miles in diameter.

CHAPTER VI.—PRELIMINARY REVIEW OF THE MINING INDUSTRY.

Distribution.—In Poverty Gulch, near Cripple Creek, are the Abe Lincoln, Gold King, and C. O. D. mines. On Globe Hill, east of the town, are numerous properties belonging to the Stratton estate. Gold Hill, southeast of Cripple Creek, contains the Anchoria-Leland, Moon-Anchor, Half Moon, Midget, Conundrum, and other mines. Near the town of Anaconda are the Anaconda, Doctor-Jackpot, Morning Glory, and Mary McKinney mines. Around the phonolite plug of Beacon Hill are the El Paso, C. K. & N., Gold Dollar, Prince Albert, and many smaller mines. On the south slope of Raven Hill are the Elkton and Moose mines.

On the east and southeast side of Blue Hill a very important belt of mines, extending from Altman through Independence to Goldfield, includes the Isabella, Victor, Pharmacist, Zenobia, Findley, Hull City, Vindicator, Lillie, Golden Cycle, Logan, Orpha May, Blue Bird, Last Dollar, and other well-known properties.

On the south slope of Battle Mountain and extending into Victor is the great group of mines embracing the Portland, Stratton's Independence, Strong, Ajax, Granite, Dead Pine, Gold Coin, and others.

Extent of underground development.—The productive part of the district contains over 20 shafts more than 1,000 feet in depth and is intersected by very numerous and extensive drifts and crosscuts.

Placers.—These were never very extensive, although they produced a fair amount of gold in early days. There is probably still ground on the southwest slope of Mineral Hill which would pay were water available for washing.

CHAPTER VII.—STRUCTURE OF THE GOLD DEPOSITS.

Principal types of deposit.—The ore bodies are in almost all instances causally related to fissures. They comprise (1) lodes or veins and (2) irregular replacement bodies, usually in granite. These two types are not sharply distinct. All of the ore deposits are characterized by the narrowness of the fissures which gave passage to the ore-bearing solutions and by the comparatively small volume of material deposited in these fissures.

Lode fissures.—These occur mainly within and near the volcanic neck, and have a rough radial plan. They are usually nearly vertical, although there are some notable examples of productive "flat veins." Individual fissures rarely exceed half a mile in length, but some well-defined zones of fissuring are traceable for twice that distance. Some of the most productive fissures are less than 300 feet in length. The persistence of a fissure down the dip is roughly proportional to the length of the same fissure. In general the fissures seem to be smaller and less abundant in depth than near the surface.

Productive lodes occur in all the rocks of the district, with the possible exception of the schist. They are most abundant in breccia and in granite. Many lodes follow phonolitic or basic dikes.

The structure most characteristic of the Cripple Creek lodes is the sheeted zone, which occurs in various degrees of regularity and in widths ranging from a few inches to over 100 feet. The fissures of the zone are usually very narrow, although there are a few notable exceptions to this rule. Evidence of tangential movement or faulting along the fissures is rare.

Intersections of one fissure zone by another are common and usually show no visible displacement. In general the fissures are not fault planes, although there are some exceptions to this statement.

The fissures were probably formed about the same time as the intrusion of the basic dikes and represent a late phase of volcanic activity. They were probably opened under relatively light load by local compressive stresses due to a slight subsidence of the solidified breccia and associated intrusive rocks forming the volcanic neck.

CHAPTER VIII.—THE ORES.

The characteristic feature is the occurrence of the gold in combination with tellurium and chiefly as calaverite. Native gold is present in the unoxidized ores only as a rarity. Pyrite is widely distributed in the country rock and also occurs in the veins, with tellurides. Galena, sphalerite, tetrahedrite, stibnite, and molybdenite are sparingly present. Among the gangue minerals quartz, fluorite, and dolomite prevail; celestite is also often present, but is frequently changed into quartz. The ore occurs chiefly as filling of narrow fissures, and consequently the ores as mined have the approximate composition of the country rock. The average tenor of gold in the ores is about $30, or 1.5 ounces per ton, and at various mines ranges from 1 ounce up to 3 or 4 ounces. Ore with less than $12 per ton is rarely mined. Small amounts of ore with up to 2,500 ounces of gold per ton have been mined. The pyrite is rarely auriferous except when admixed with tellurides.

The ores contain on an average only about 1 ounce of silver to 10 ounces of gold. In some mines the proportion is very much less. Small shipments have been made of tetrahedrite ore rich in silver.

The tenor of the ore as mined has decreased somewhat in the last ten years, but this is probably mostly due to lowered operating and reduction expenses.

CHAPTER IX.—PROCESSES OF ALTERATION.

Metasomatism in connection with vein formation.—During the vein-forming processes the rocks adjacent to veins have undergone a certain amount of alteration, and in case of the porous breccia this alteration has spread over large areas. The alteration is, on the whole, slight and involves a transformation of the dark silicates to carbonates, pyrite, and fluorite and a change of the feldspars and feldspathoid minerals into sericite and adularia. The latter mineral is characteristic of all the altered rocks, but especially of the so-called "granitic ore" of the Elkton, Ajax, Stratton's Independence, and other mines. Calaverite develops in places by metasomatic processes in breccia, gneiss, phonolite, and basic dikes, but its appearance in this form is rare, compared to its universal occurrence as fissure filling. Galena, zinc blende, and other sulphides sometimes appear as metasomatic products, but are not common. Chemically the process, when carried to completion, involves an almost entire loss of soda and a corresponding gain of potash. Small amounts of sulphur, carbon dioxide, and fluorine are introduced. The percentage of silica is slightly reduced, and lime and magnesia have often been partially removed. The course of the alteration, which is shown to have been produced by hot alkaline waters, is illustrated by several analyses.

Oxidation.—The oxidation away from the vicinity of veins has not penetrated to great depths. Globe Hill is an exception, for here complete oxidation has affected the breccia to a depth of at least 800 feet below the surface. Along the veins oxidation extends far deeper, in some cases down to 1,200 feet below the surface. The water level originally stood at an elevation of about 9,500 feet, rising to 9,600 or 9,700 feet under Bull Hill. In a general way the depth of oxidation along veins coincides with the depth of the water level. There are many exceptions; in the western part of the district unaltered tellurides may be found close to the surface, while in other cases complete oxidation extends for 200 or 300 feet below the water level.

Oxidation tends to destroy the original structure of the vein and changes the ore to a brown, soft, and homogeneous mass. Oxidation tends also to transform tellurides into brown, spongy gold and tellurites, while sulphides are altered to various oxy-salts. The silicates are changed to kaolin, quartz, manganese dioxide, and limonite. The agent producing oxidation is atmospheric water percolating downward along the vein and the process continues until this water has lost its oxygen. The waters are acid, due to the sulphuric acid derived from pyrite. The results of oxidation are illustrated by several analyses. No evidence favoring the deposition of secondary sulphides has been found. The tetrahedrite supposed by some to be of such origin is a primary vein mineral.

CHAPTER X.—THE ORE SHOOTS.

As a rule the ore in the veins occurs as well-defined shoots similar to those of other gold veins; their limit in depth is ordinarily as well marked as their extent in a horizontal direction. In discussing the shoots the terms pitch length, stope length, breadth, and width or thickness are adopted and defined.

The shoots are generally tabular, elongated bodies dipping at steep angles from the horizontal on the plane of the vein. The width varies from a few inches to 50 feet, 4 to 5 feet being a common size. The stope length in an ordinary shoot varies from 50 to 300 feet, and in rare cases attains 2,000 feet. The pitch is steep, ranging from 45° to 90° and is generally northward. An average of the pitch length in the large shoots would probably be 500 feet, but in a few shoots this dimension attains 1,500 feet, and in others the total length of the shoot has not yet been ascertained. While the outline is sometimes equidimensional, or again wholly irregular, elongated forms with ratio between pitch length and breadth of from $1\frac{1}{2}:1$ to $5:1$ prevail. When one shoot ceases in depth, another may be found below it upon the same or adjoining fissure.

Absolute and truncated pitch lengths are distinguished. In the latter case the upper part of the shoot has been removed by erosion.

The influence of country rock is very slight, as excellent shoots occur in granite, gneiss, breccia, latite-phonolite, phonolite, syenite, and basic dikes. Breccia is, on the whole, the most favorable rock on account of its porosity. The smaller ore shoots are very commonly found at intersections of fissures or fissure systems, but this factor is by no means the only one nor the most important one. The largest shoots are entirely independent of intersections.

There is no decrease in the value of the ore per ton in depth, but the quantity of ore available is distinctly less below the 1,000-foot level, irrespective of the elevation of the surface. Difficulties of exploration and development may to some extent account for this, but another influencing factor is that in many cases the fissure system is less well developed in depth. In addition to this explanation it is likely that for reasons related to temperature and solubility precipitation of ore took place more abundantly nearer to the surface.

CHAPTER XI.—GENESIS OF THE DEPOSITS AND PRACTICAL CONCLUSIONS.

Origin of the ores.—The waters which deposited the Cripple Creek veins were hot alkaline solutions which contained the following compounds and ions either free or in various combinations: SiO_2, CO_2, H_2S, CO_3, SO_4, S, Cl, F, Fe, Sb, Mo, V, W, Te, Au, Ag, Cu, Zn, Pb, Ba, Sr, Ca, Mg, Na, K. We believe that at least some of the SiO_2, SO_4, Cl, Fe, Ba, Sr, Ca, Mg, Na, and K are derived from the volcanic rocks by leaching of waters, while the remaining metals, as well as CO_2, H_2S, S, and some SiO_2 and Cl, were more probably separated from intrusive cooling magmas at considerable depth and brought up as solutions in magmatic water given off in the same manner.

It is concluded that the formation of the veins took place shortly after the intrusion of the last basic dike. The temperature at the time of deposition was high, but the critical temperature of water was probably not exceeded. It is shown that the igneous rocks contain primary water and the conclusion is drawn that the magna

was correspondingly rich in water. The question of the derivation of the vein minerals is discussed; derivation by leaching from the granitic or the volcanic rocks by cold or hot atmospheric waters is shown to be improbable. The view that most of the water and most of the substances contained in the veins were given off by intrusive bodies slowly cooling at considerable depth and were forced up through the upper part of the volcanic mountain as soon as the formation of fissures allowed them to rise is considered more plausible. The waters ascended in the deeper part of the volcano with comparatively great velocity on the fewer fissures here available. Nearing the surface they spread through a larger space in a more complicated fissure system. The speed became checked and conditions for precipitation improved. Deposition and the chemical action of the country rock changed the composition of the solutions and a mingling with fresh ascending waters, possibly also with atmospheric waters, induced further precipitation. In this manner are explained the smaller amount of ore deposited in depth and the richness and abundance of ore nearer to the old surface. The portion of the volcano removed by erosion may have contained still richer deposits.

Future of the district.—It is probable that the production of the district, while exhibiting fluctuations, will on the whole slowly decline. New ore bodies will undoubtedly be discovered from time to time, and individual mines may be as profitable in the future as they have been in the past, or even more so. An increased output may be expected to follow each successful step in deep drainage. But existing conditions indicate that if the maximum production of $18,000,000 in 1900 is to be surpassed the increase will be due to the ore bodies encountered in a zone within 1,000 feet of the present general surface.

CHAPTER XII.—UNDERGROUND WATER.

Although the annual precipitation at Cripple Creek is not heavy and the conditions for rapid run-off are unusually favorable, standing water was originally encountered in the mines at moderate depths. At the beginning of mining operations the underground water surface stood at an elevation of about 9,500 feet in the western part of the district and, on an average, fully 100 feet higher in the eastern part. Several mines began pumping about the year 1895, but it was soon found that this mode of lowering the water was slow and costly. Attention was directed to tunneling, and the Ophelia tunnel was driven into Gold Hill at an elevation of 9,268 feet. This tunnel drained the western part of the district until 1898, when the Standard tunnel, over 200 feet lower, tapped the phonolite of Beacon Hill and became the chief effluent. Finally the El Paso tunnel, with its portal at an elevation of 8,783 feet, was driven under Beacon Hill in 1903 and has since been the main drainage outlet of the district. Prior to January 1, 1905, this tunnel is estimated to have discharged about 3,550,000,000 gallons or nearly 15,000,000 tons of water.

The records of the pumping operations and tunnel projects show that the underground water is for the most part held within open fissures and cavities in the rocks of the volcanic neck. It is stored water, inclosed by the relatively impervious rim of granitic and schistose rocks that form the general Cripple Creek plateau, and has been supplied by the rain and snow that fell upon the surface of the district.

Drainage and pumping have both shown that the underground water does not flow freely through the rocks in all directions. Neighboring mines in some cases show marked differences in water level, and the drainage tunnels on the west side of the district have but slightly benefited the mines on the east side. The behavior of the water shows that the unfissured breccia is practically almost impervious and that artificial drainage affects only those parts of the district that are connected by fissures with the tunnel or shaft whence the water is drawn off.

A movement is now in progress to begin a new drainage tunnel several hundred feet below the El Paso tunnel. Knowledge of the number of gallons of water corresponding to a fall of 1 foot in the general reservoir would be of use in planning future operations. Mr. S. W. Mudd estimated that a discharge of 66,684,683 gallons corresponded to a general lowering of the water 1 foot. Mr. A. C. Jaquith estimated that in April, 1904, the discharge from the El Paso tunnel, corresponded to a lowering of the water 1 foot in the Elkton mine, was 34,839,775 gallons. The data on which Mr. Mudd's estimate was based, however, are necessarily very incomplete and it is difficult to deduce, from the record of the Elkton, figures applicable to the entire area drained. The quantity of water drained for each foot of fall is likely to diminish with increase of depth, although it is probable that at a depth of 1,000 or 1,500 feet below the El Paso tunnel open fissures and shattered zones in the breccia will still be sufficiently abundant to contain in the aggregate a large body of water.

CHAPTER XIII.—UNDERGROUND GASES AND TEMPERATURE.

Gases.—During the earlier years no unusual amounts of mine gases were noted, but as the workings deepened several properties began to be seriously inconvenienced by a heavy gas which issued from the porous breccia or fine fissures. The principal sufferers have been the mines west of Battle Mountain and Bull Mountain. The gas has no smell or taste, but its presence is soon indicated by the fact that the candles refuse to burn and by several forms of physical distress among those who are obliged to work near the point where it issues. A number of fatal cases of suffocation have occurred. The gas consists of a mixture of prevailing nitrogen with 8 to 15 per cent of carbon dioxide and 5 to 10 per cent of oxygen.

The gases carry much moisture and are warmer than the normal temperatures of the mines. The emanations are generally most copious when the barometric pressure is low, but they also exhibit fluctuations that are apparently independent of the state of the barometer. The gases are believed to be the last exhalations of the extinct Cripple Creek volcano. Probably the only effective way of combating the evil is by working under an air pressure slightly above the normal.

Underground temperature.—Numerous observations in the mines lead to the conclusion that the average increment of underground temperature in the Cripple Creek district is about 1° F. for each 60 feet of depth. There is thus no special source of local heat that is likely to interfere with mining. As already mentioned, the mine gases have a temperature above that normal to the mines in which they occur.

GEOLOGY AND GOLD DEPOSITS OF THE CRIPPLE CREEK DISTRICT, COLORADO.

By Waldemar Lindgren and Frederick Leslie Ransome.

PART I.—GENERAL DESCRIPTIONS, DISCUSSION, AND CONCLUSIONS.

CHAPTER I.—INTRODUCTION.

FIELD WORK AND ACKNOWLEDGMENTS.

The Cripple Creek gold deposits were discovered in 1891. Shortly afterwards, in 1894, an examination of the new district was undertaken by the United States Geological Survey, Mr. Whitman Cross having charge of geology and petrography and Mr. R. A. F. Penrose, jr., undertaking the examination of the mines. Their report, accompanied by a geological map, was published in the Sixteenth Annual Report of the Geological Survey, part 2, pages 1–207, and has for the last ten years served as a useful and accurate geological guide to mining operations.

With the astonishingly rapid development of the Cripple Creek mines the opportunities for geological study multiplied. Great complexity of vein phenomena was thereby revealed and a desire arose for further investigation, particularly with reference to the question of the persistence of the veins in depth. This desire found expression in a request by citizens of Colorado for a reexamination of the district by the United States Geological Survey and in an offer of cooperation, whereby the cost would be equally divided between the State of Colorado and the national Survey. The total cost of the geological work was estimated at $7,000, and one-half of this amount, having been subscribed in Cripple Creek, Colorado Springs, and Denver, was put in the hands of Mr. John Wellington Finch, State geologist of Colorado, and by him disbursed as the State contribution. The cordial thanks of the geologists in charge of the work are due to Mr. Finch for his hearty and efficient cooperation. Of the State money, $780.22 was lost in a bank failure, but of this amount $300 was refunded by the Mine Owners' Association. It proved necessary to make an additional allotment of $962.50 from the funds of the Geological Survey, so that the total expense for field work from June 20, 1903, to May 1, 1904, amounted to $7,482.28, of which $3,019.78 was contributed by the State and $4,462.50 by the Geological Survey. The expenses of final office work, publication, and all topographic work excepting the level line from Colorado Springs to Cripple Creek have been borne by the Geological Survey.

The reexamination began with a thorough revision of the topographic map of Cripple Creek by Mr. R. T. Evans, Mr. E. M. Douglas in charge. This involved a great deal of painstaking work, nearly every prospect hole being located, as well as all shafts and tunnels. The new map is on the scale of 1:25,000, or about 2½ inches to the mile, and includes practically the same area as the old map, a small strip only

being added on the western side, so that the total area mapped is about 40 square miles. The small developments outside of this area did not seem to justify further extension of the boundaries. Contours are 50 feet apart, and a numbered list of 324 mines is given on the margin of the sheet. A line of accurate levels was run to Cripple Creek from Colorado Springs, thus settling the conflicting data of the different railroads. A bench mark was established at the National Hotel at Cripple Creek, in the south wall of which an aluminum tablet is set. The height of this is derived from a point established by the Colorado Springs and Cripple Creek District Railroad, the top of a nail in a cross-tie in front of the station, the elevation of which,

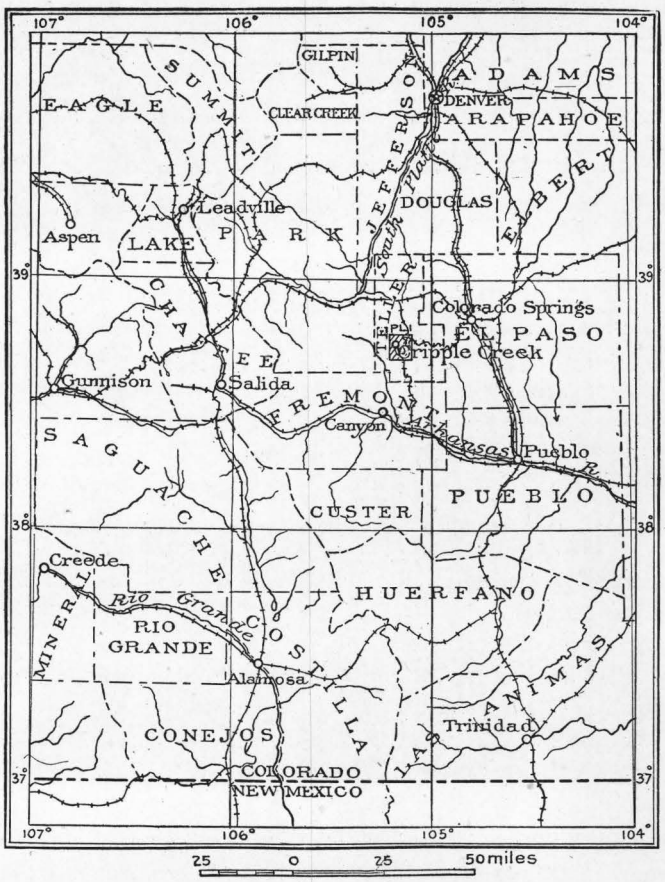


FIG. 1.—Index map showing situation of Cripple Creek district.

as corrected in accordance with the adjustment of 1903 by the United States Coast and Geodetic Survey at Colorado Springs, is accepted as 9,492.08 feet above mean sea level. Dependent on this the elevation of the datum tablet is accepted as 9,495.136 feet above mean sea level. All permanent bench marks dependent on this datum are marked with the letters "C C" in addition to the figures of elevation. The datum plane commonly accepted before this accurate work was done, and used by Mr. V. G. Hills in his reports on the water conditions in the district, is 7 feet lower, so that to obtain the correct elevation 7 feet should be subtracted from his data.

List of points in the Cripple Creek district determined by accurate levels.

[N. S. Bright, levelman, under the direction of E. M. Douglas, geographer.]

CIRCUITS IN CRIPPLE CREEK.

	Feet.
Cripple Creek, opposite Midland Terminal station; top of rail	9,519.8
Cripple Creek, on southwest corner of City Hall; city bench mark	9,495.551
Cripple Creek, National Hotel, 3 feet west of south entrance, stone foundation; aluminum tablet, marked "9495 C C"	9,495.136
Cripple Creek, Teller County jail, in east end of stone doorsill, north entrance; aluminum tablet marked "9510 C C "	9,509.546

CRIPPLE CREEK NORTHWEST AND NORTH, VIA RED MOUNTAIN UP SPRING CREEK, TO PIPE LINE; THENCE SOUTH, VIA HOOSIER PASS, VISTA GRANDE, WINDY POINT, ELKTON, AND ANACONDA, TO CRIPPLE CREEK.

	Feet.
Cripple Creek, northwest corner of West Carr and C streets, 3 feet west of telegraph pole, on sandrock outcrop; paint point	9,553.81
Cripple Creek, 1.5 miles northwest of, on saddle, northeast foot of Mount Pisgah, 40 feet north of road forks, near line of telegraph poles, in granite outcrop; aluminum tablet marked "9455 C C"	9,455.440
Grand Review mine, 800 feet west of, 25 feet south of road, and 275 feet west of road forks; paint point on stone	9,213.606
Standard tunnel, 0.25 mile south of, 10 feet north of road, 50 feet north of Spring Creek, in rock outcrop; aluminum tablet marked "9328 C C"	9,327.928
Standard tunnel, mouth of; top of east rail	9,524.9
Midway dairy, 120 feet north of road, in rock outcrop; aluminum tablet marked "9817 C C"	9,816.810
Midway dairy, 1 mile east of, 1 mile south of Lincoln mine, 50 feet east of pipe line, in triangle of roads; iron post marked "10088 C C"	10,087.711
Tenderfoot Consol, southeast corner of gallows frame; nail in top of mudsill	10,420.67
The Friday, northeast corner of gallows frame; spike in collar	10,401.25
Hoosier, northeast corner of gallows frame; nail	10,378.98
Hoosier Pass, between main line Colorado Springs and Cripple Creek District Railway and switch, 12 feet west of public road, between two posts supporting Hoosier Pass signboard; iron post marked "10315 C C"	10,314.743
Iron Clad, southeast corner of engineer room; nail in top of timber	10,401.36
Vista Grande, or Midway station, 13 feet west of Florence and Cripple Creek Railroad track, 1 foot south of signpost "Vista Grande;" iron post marked "10487 C C"	10,486.749
Windy Point, upper road crossing; top of south rail	10,444.6
War Eagle mine, southwest corner of gallows frame; nail	10,355.91
Bull Hill, west mudsill gallows frame; nail	10,029.98
Elkton, Elkton Consolidated Mining and Milling Company, in stone foundation, south corner of south stack; aluminum tablet marked "9734 C C"	9,733.753
Anaconda, 400 feet south of Midland Terminal Railroad depot, 6 feet east of track, in wall of rock cut; aluminum tablet marked "9525 C C"	9,524.816
Anaconda, 1 mile northwest of, 450 feet north of Worlds Fair, 8 feet west of Midland Terminal Railroad track, in granite outcrop; aluminum tablet marked "9534 C C"	9,534.034

HEAD OF SPRING CREEK, VIA GILLETT, VICTOR PASS, AND GOLDFIELD, TO ELKTON.

Midway dairy, 1 mile east of, west side of divide and Cripple Creek road, on northeast side of curbing to Cripple Creek pipe line; nail in top	10,084.685
Gillett, 1.25 miles east of, 100 feet south of road forks, claim 14888; nail in top of post 3	10,049.66
Lincoln, east side of gallows frame; nail	10,068.81
Gillett, 1.25 miles west of, 600 feet south of Lincoln mine, 20 feet west of road forks, in phonolite-rock outcrop; aluminum tablet marked "10021 C C"	10,021.130
Gillett, in stone foundation of unfinished electric-light plant, in west wall 1 foot north of southwest corner; aluminum tablet marked "9940 C C"	9,939 742

	Feet.
Gillett, in front of Midland Terminal Railroad station; top of rail	9,934.3
Gillett, 1.5 miles south of, 60 feet east of track; chiseled cross	9,877.40
Gillett, 2.5 miles south of, 1,000 feet south of milepost 17, in granite wall 8 feet west of Midland Terminal Railroad track; aluminum tablet marked "9841 C C"	9,840.752
Milepost 18, 750 feet west of, at road crossing, 10 feet north of track; railroad spike in signpost (north side)	9,878.06
Cripple Creek sampler, 0.5 mile north of, 20 feet west of road; cross cut in flat rock	10,123.26
Cripple Creek Sampler and Ore Company, 425 feet east of, in Victor Pass, 12 feet south of Midland Terminal Railroad track, 1 foot east of telephone pole; iron post marked "10202 C C"	10,201.976
Goldfield, north side of Ninth street, between Main and Portland, entrance to Red Mens Hall, in west end of stone doorsill; aluminum tablet marked "9903 C C"	9,903.197
Goldfield, in front of Florence and Cripple Creek Railroad station (line continued along railroad)	9,882.8
Stratton Junction; top of railroad frog	9,809.1
Victor, in front of Colorado Springs and Cripple Creek District Railway station; top of rail	9,707.7
Victor, Colorado Trading and Trust Company Building, northeast corner Diamond avenue and Third street, in north end stone doorsill; bronze tablet marked "9718 C C"	9,717.748
Victor, in front of Florence and Cripple Creek Railroad station; top of rail	9,729.4
Victor, in front of Midland Terminal Railroad station; top of rail	9,771.8
Victor, 0.9 mile northwest of, 100 feet north of switch back, east side of track; spike in telegraph pole	9,842.61

ANACONDA, WORLD'S FAIR MINE NO. 50, SOUTHWEST DOWN CRIPPLE CREEK ALONG THIRD-CLASS ROAD; THENCE WEST TO PONY GULCH; THENCE NORTH-NORTHEAST TO CRIPPLE CREEK.

	Feet.
Ophelia tunnel, west entrance; top of north rail	9,268.9
Mound, 0.5 mile southwest of, west side of Cripple Creek, 200 feet south of road, in granite outcrop; aluminum tablet marked "9232 C C"	9,231.837
Field's ranch, 0.75 mile southwest of, 200 feet east of road forks, on saddle, south side of Deadox Gulch, in granite outcrop; aluminum tablet marked "9133 C C"	9,132.604
G. P. Taft's cabin, 100 feet west of; nail in top of 20-inch pine stump	9,074.88
Arlington dairy, 2,000 feet north of, west side of Pony Gulch, east side of road, in granite outcrop; aluminum tablet marked "9113 C C"	9,112.852
Cripple Creek, 1.25 miles south of, 700 feet north of powder magazines, in road forks, set in granite outcrop; bronze tablet marked "9393 C C"	9,392.874

The geological and mining work was undertaken jointly by the authors of this report. Mr. L. C. Graton served as assistant throughout, participating most efficiently in all branches of the work. Messrs. A. M. Rock and J. Bruce also rendered excellent aid as draftsmen. Mr. Lindgren undertook the preliminary examination from June 24 to July 12, 1903, and finished the mining work during the three months from February 1 to May 1, 1904. Mr. Ransome took the field from July 4 to August 4 and from August 19 to October 10, 1903; also from January 7 to February 2, 1904. In a general way the mines of the southwestern part of the area shown in the detailed map have been examined and described by Mr. Ransome and those of the northeastern part by Mr. Lindgren, but each of the authors has visited all the important mines in the district. A number of smaller mines have been described by Mr. Graton. The work of areal mapping was undertaken by Mr. Ransome, with the aid of Mr. Graton.

To all the mine owners, managers, engineers, and other gentlemen interested in the mining industry our sincere thanks are due for their cordial cooperation. They have aided us by their experience and allowed us without reserve to inspect their mines, to examine their maps, and to ascertain their output, and this friendly

attitude has more than anything else assisted our work. Particularly do we desire to express our appreciation of the many courtesies extended to us by the mining engineers of the district, including Messrs. Countryman & Jaquith, Hills & Willis, Haff & Colwell, Charles J. Moore, and James Smith, of Cripple Creek; and Messrs. Davis & Byler and Bodfish & Atherton, of Victor. To the excellent professional work of all these and to their hearty personal cooperation we are deeply indebted. The chemical division of the Geological Survey has aided us by many detailed and careful analyses, made by Messrs. W. F. Hillebrand, George Steiger, and W. T. Schaller.

LITERATURE.

The following list is intended to include the important publications on the Cripple Creek district, particularly those having some geological or historical significance. Articles of less value are scattered through mining journals, and considerable information is sometimes obtainable from special mining editions of the local newspapers and from the published annual reports of a few of the larger companies, such as the Portland and Stratton's Independence.

LIST OF PUBLICATIONS ON THE CRIPPLE CREEK DISTRICT.

BANCROFT, GEORGE J. Secondary enrichment at Cripple Creek. Engineering and Mining Journal, vol. 74, 1902, pp. 752–753.

Suggests that below the zone now worked in the Cripple Creek district there may be a zone of secondarily enriched ores. It is thought that the occurrence of tetrahedrite in the lower levels of some of the mines is indicative of such deep enrichment. This article was followed by a discussion in succeeding numbers of the journal.

BANCROFT, GEORGE J. The bottom levels at Cripple Creek, Colorado. Engineering and Mining Journal, vol. 76, 1903, pp. 86–88.

A review of conditions at the bottoms of some of the deeper mines, with particular reference to drainage and to enrichment or impoverishment of the ore.

BLAKE, WILLIAM P. The gold of Cripple Creek. Engineering and Mining Journal, vol. 57, 1894, p. 30.

Suggests that the "sylvanite" is probably for the most part calaverite or krennerite.

CROSS, WHITMAN. Geology of the Cripple Creek gold mining district, Colorado. Colorado Scientific Society, Proceedings, vol. 5, 1894–1896, pp. 24–49.

A preliminary outline, based on field work in 1893 on the Pikes Peak quadrangle.

CROSS, W., and PENROSE, R. A. F., JR. The Pikes Peak folio. Geologic Atlas of the United States, folio 7, U. S. Geol. Survey, 1894.

Contains a detailed geological map of the Cripple Creek district and brief descriptions of the geology and ore deposits.

CROSS, W., and PENROSE, R. A. F., JR. The geology and mining industries of the Cripple Creek district, Colorado. Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 1–209.

The best and most complete account of the geology and ore deposits of Cripple Creek.

CURLE, J. H. The gold mines of the world. Second edition, London, 1902, pp. 271–284.

Particularly valuable as a shrewd and unprejudiced review of the mines from the financial standpoint.

FINCH, JOHN W. The circulation of underground aqueous solutions and the deposition of lode ores. Colorado Scientific Society, Proceedings, vol. 7, 1904, pp. 193–252.

A paper treating of ore deposition in general, but with special application to Cripple Creek, whence most of the illustrations are drawn.

HILLEBRAND, W. F. Calaverite from Cripple Creek, Colorado. American Journal of Science, 3d ser., vol. 50, 1895, pp. 128–131.

Shows by chemical analyses that specimens from the Prince Albert, Raven, and C. O. D. mines have the composition of calaverite. Crystallographic study by Penfield indicates that the crystals are probably triclinic, but are near sylvanite in angles and axial ratios.

HILLS, FRED. The official manual of the Cripple Creek district, vol. 1. Colorado Springs, 1900.

A useful compilation giving the organization, holdings, and equipment of each mining company in the district.

HILLS, VICTOR G. Water record of mines at Cripple Creek, Colorado. Engineering and Mining Journal, vol. 76, 1903, p. 117.

A record of 39 mines in tabular form.

HILLS, VICTOR G. Water in the mines of Cripple Creek. Engineering and Mining Journal, vol. 76, 1903, pp. 195–197.

Concludes from the study of carefully collected data that, from a practical standpoint, the mines do not have a common water level, and that pumping in one mine does not necessarily lower the water in a neighboring mine.

KNIGHT, F. C. A suspected new mineral from Cripple Creek. Colorado Scientific Society, Proceedings, vol. 5, 1894–1896, pp. 66–71.

Concludes from chemical studies that in the oxidation of calaverite a part of the tellurium may combine with iron to form a tellurite.

LIEBENAM, W. A. Der Cripple Creek Golddistrikt, seine Entdeckung, Entwicklung, Geologie und Zukunft. Berg- und hüttenmännische Zeitung, vol. 63, 1904, pp. 2–5, 29–32, 57–60, 89–92, 117–121, 161–164.

An extended account of the district, for the most part a compilation, with rather slight acknowledgment, from writings of Cross, Penrose, and Rickard.

LINDGREN, W. Metasomatic processes in fissure veins. Transactions American Institute of Mining Engineers, vol. 30, 1901, pp. 612, 630–631, 654–657.

The first recognition of adularia (valencianite) as a vein mineral at Cripple Creek.

LINDGREN, W., and RANSOME, F. L. Report of progress in the geological resurvey of the Cripple Creek district, Colorado. Bull. U. S. Geol. Survey No. 254, 1904.

A brief preliminary statement of results.

MATHEWS, E. B. The granites of Pikes Peak, Colorado. Geological Society of America Bulletin, vol. 6, 1895, pp. 471–473.

A petrographical study of the granitic rocks of the Cripple Creek region.

MATHEWS, E. B. The granitic rocks of the Pikes Peak quadrangle. Journal of Geology, vol. 8, 1900, pp. 214–240.

A detailed petrological study of the granites of the Cripple Creek region. Four types are distinguished, three of which are recognized as occurring in the Cripple Creek district.

MYERS, W. S. Quoted in "On krennerite from Cripple Creek, Colorado," by Albert H. Chester. American Journal of Science, 4th ser., vol. 5, 1898, pp. 375–377.

A chemical analysis of material from the Independence mine.

PALACHE, CHARLES. Notes on tellurides from Colorado. American Journal of Science, 4th ser., vol. 10, 1900, pp. 419–427. Also a German translation in Zeitschrift für Krystallographie und Mineralogie, vol. 34, 1901.

Chemical and crystallographic study of crystals from two localities in the Cripple Creek district proves them to be sylvanite. It is shown that the supposed new mineral goldschmidtite is really sylvanite.

PEARCE, RICHARD. The mode of occurrence of gold in the ores of the Cripple Creek district. Colorado Scientific Society, Proceedings, vol. 5, 1894–1896, pp. 5–10.

Shows that the gold, prior to oxidation, occurs as a telluride, probably as sylvanite. Tests of various samples of oxidized ore indicate that oxidation, while setting free the gold, increases the ratio of tellurium to gold in the ore.

PEARCE, RICHARD. The occurrence of gold in the ores of the Cripple Creek district. Engineering and Mining Journal, vol. 57, 1894, p. 271. (Abstract of a paper read before the Colorado Scientific Society.)

Shows that the usual ratio of gold to silver in the Cripple Creek ores corresponds to the composition of sylvanite rather than to that of krennerite or calaverite.

PEARCE, RICHARD. Further notes on Cripple Creek ores. Colorado Scientific Society, Proceedings, vol. 5, 1894–1896, pp. 11–16.

Points out that tellurium, in oxidized form, is always present with gold in the oxidized ore, and usually in much greater proportion than in the unoxidized ore. It is concluded that part of the gold and most of the silver originally present in the sylvanite is removed in solution during oxidation.

PENFIELD, S. L. Quoted in "On krennerite from Cripple Creek, Colorado," by Albert H. Chester. American Journal of Science, 4th ser., vol. 5, 1898, pp. 375–377.

A crystallographic study of a specimen from the Independence mine.

PENFIELD, S. L., and FORD, W. E. On calaverite. American Journal of Science, 4th ser., vol. 12, 1901, pp. 225–246. Also a German translation in Zeitschrift für Krystallographie und Mineralogie, vol. 35, 1902, pp. 430–451.

The authors conclude that the apparent monoclinic symmetry is the true symmetry of the mineral, notwithstanding the extraordinarily complex crystallographic symbols which that supposition demands.

PENROSE, R. A. F., jr. The ore deposits of Cripple Creek, Colorado. Colorado Scientific Society, Proceedings, vol. 5, 1894–1896, pp. 50–53.

A preliminary outline, written before detailed examination of the district had begun.

PENROSE, R. A. F., jr. [*See also under* Cross and Penrose.]

RICKARD, T. A. The Cripple Creek gold field. Institution of Mining and Metallurgy (London), Transactions, vol. 8, 1899–1900, p. 49–111.

Contains an interesting account of the early history of the district, an outline of the general geology, a description of the ore deposits, statistics of production, and notes on the mines.

RICKARD, T. A. The telluride ores of Cripple Creek and Kalgoorlie. Engineering and Mining Journal, vol. 70, 1900, p. 611.

Gives an interesting account of the Cripple Creek ores from mineralogical, chemical, and metallurgical standpoints.

RICKARD, T. A. The Cripple Creek volcano. Transactions American Institute of Mining Engineers, vol. 30, 1901, pp. 367–403.

A semipopular summary of the geological history of the district.

RICKARD, T. A. The lodes of Cripple Creek. Transactions American Institute of Mining Engineers, vol. 33, 1903, pp. 578–618.

Describes in considerable detail, with numerous illustrations, the structural characteristics of the lodes.

SCHWARZ, T. E. The Independence mine, Cripple Creek, Colorado. Colorado Scientific Society, Proceedings, vol. 4, 1893, p. 422.

Describes the essential geological features of the Independence vein as exposed at that time.

SKEWES, E. The ore shoots of Cripple Creek. Transactions American Institute of Mining Engineers, vol. 26, 1896, pp. 553–579.

Records some facts of interest relative to the upper portions of the ore bodies of the Elkton, Raven, and Doctor mines.

SMITH, G. F. HERBERT, and PRIOR, G. T. On the remarkable problem presented by the crystalline development of calaverite. Mineralogical Magazine, vol. 13, 1901–1903, pp. 122–150.

The authors conclude that the mineral is either monoclinic with remarkably complex symbols, or triclinic with extraordinary complicated twinning.

STEVENS, E. A. An occurrence of limburgite in the Cripple Creek district. Transactions American Institute of Mining Engineers, vol. 30, 1901, pp. 759–764.

Describes the occurrence of a dike at the western edge of the town of Victor.

STEVENS, E. A. Basaltic zones as guides to ore deposits in the Cripple Creek district, Colorado. Transactions American Institute of Mining Engineers, vol. 33, 1903, pp. 686–698.

Maintains that there is a genetic relation between the basaltic dikes and ore deposition and that the type of rock is more important than the structure in determining the occurrence of ore.

STONE, G. H. The granitic breccia of the Cripple Creek region. American Journal of Science, 4th ser., vol. 5, 1898, pp. 21–32.

An attempt to explain several deposits of diverse origin as breccias produced by the shattering of the older rocks by igneous intrusions.

VAN HISE, C. R. A treatise on metamorphism. Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 1120–1125, and elsewhere.

Discusses Cripple Creek deposits in connection with a general treatment of the problems of ore genesis. The rich telluride ores are regarded as secondary concentrations due to descending waters.

CHAPTER II.—GENERAL GEOLOGY.

INTRODUCTORY STATEMENT.

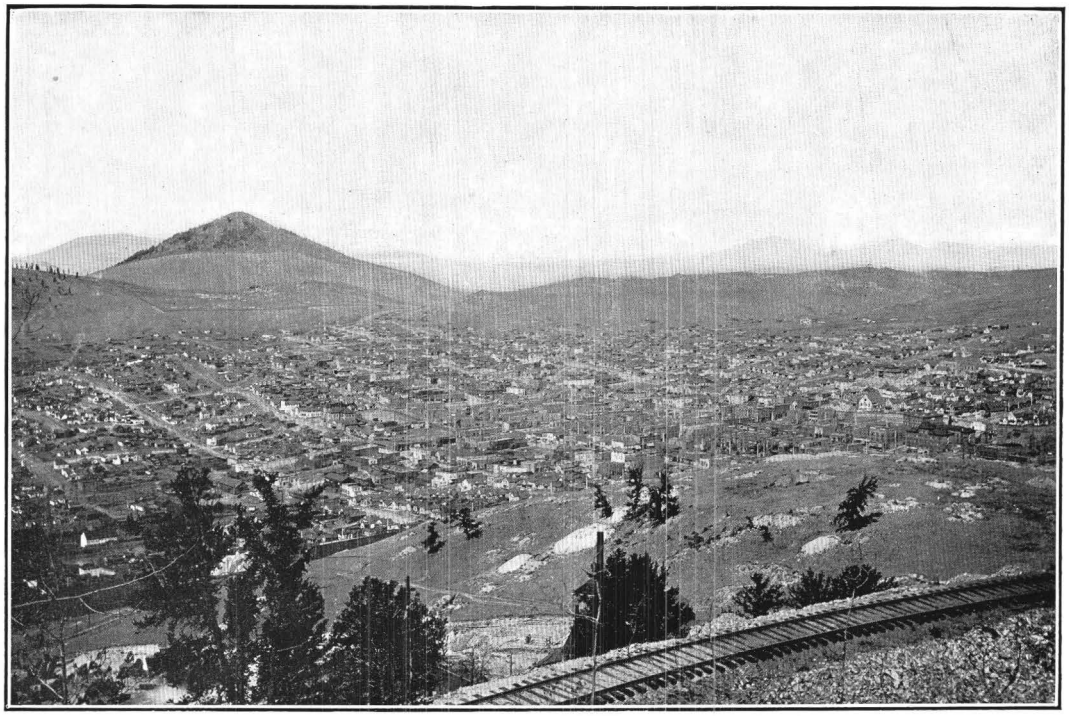
In view of the well-known work of Mr. Cross, it is not necessary, as in the earlier report, to present a detailed account of the geology of the district. The general relations of the rocks and the main facts of the volcanic history are now familiar to those interested in the region, and the first official report is still a valuable source of detailed and accurate descriptions of particular localities. The plan adopted in the present work, therefore, does not contemplate so exhaustive a description of the district as would be appropriate in a new geological field. It is proposed to recount briefly the essential results obtained by Mr. Cross and to indicate in a few words the general character of the modification of these results required by later study. Mr. Graton's report on the petrography of the Cripple Creek rocks, presenting further details of the changes involved, forms a separate chapter and is followed by a sketch of the geological structure of the district with such additional matter as is necessary to supply a satisfactory geological basis for the discussion of the ore deposits.

The new geological map of the district forms Pl. II and is accompanied by five sections, on which full black lines indicate that the contact lines are actually known from mining developments.

FIRST GEOLOGICAL SURVEY OF THE DISTRICT.

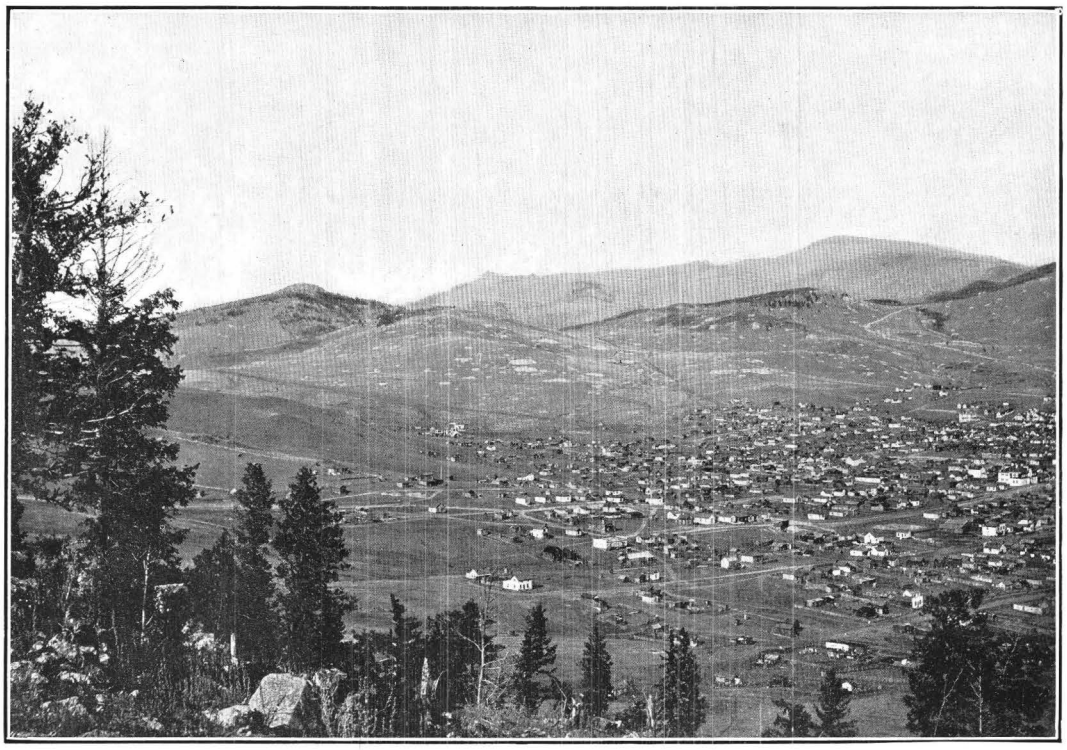
When Mr. Cross made his careful study of the geology of the Cripple Creek district ten years ago, mining had barely begun and the various hills were not, as now, perforated by deep underground workings. That his work has in general stood the test of subsequent mining exploration and continues to be highly regarded in the district is convincing testimony to its excellence. Later workers, however they may amplify or modify his results, should fairly acknowledge their debt to the pioneer who first unraveled the structure and deciphered the history of the Cripple Creek volcanic complex. The account of the district as given by Cross may be very briefly summarized as follows:

The Cripple Creek hills lie near the eastern border of a lofty and deeply dissected plateau which slopes gently westward for 40 miles, from the southern end of the Colorado Range, dominated by Pikes Peak, to the relatively low hills connecting the Mosquito and Sangre de Cristo ranges. The prevailing rocks of this plateau are granites, gneisses, and schists. The granites inclose masses of Algonkian quartzite and are therefore post-Archean, but they are older than the only Cambrian sediments known in Colorado. During Tertiary time volcanic eruptions broke through these ancient rocks at several points and piled tuffs, breccias, and lavas



A. CRIPPLE CREEK. LOOKING WEST FROM GOLD HILL.

The Midget and Conundrum mines are in the foreground and Mount Pisgah is in the background.



B. CRIPPLE CREEK. LOOKING NORTHEAST.

The partly wooded knob on the left is Rhyolite Mountain. Just beyond the town are Mineral and Carbonate hills, and in the background is Pikes Peak.

upon the uneven surface of the plateau. The eruptive rocks of the Cripple Creek district are the products of one of the smaller isolated volcanic centers of this period, a center characterized by the eruption of phonolite, which does not occur elsewhere in this general region. The most voluminous products of the Cripple Creek volcano now preserved are tuffs and breccias. They occupy a rudely elliptical area in the center of the district about 5 miles long in a northwest-southeast direction and about 3 miles wide. According to Cross, these breccias and tuffs rest in part upon an earlier flow of andesite,[a] but mainly upon an unevenly eroded surface of the granites and schists, although along the southwest edge of the area the contact was found to be so steep as "to support the idea that the central vent or vents of the volcano were adjacent to this line." The breccia is much indurated and altered, but was thought to consist mainly of andesitic fragments, although it was recognized that fragments of phonolite are locally abundant. The most characteristic massive rock emanating from the Cripple Creek volcano is phonolite, which was erupted at several periods and more abundantly than any other type. It occurs as dikes and masses, not only in the breccia, but in the surrounding granitic rocks. Among the massive rocks distinctly younger than most of the breccia Cross distinguished trachytic phonolite, nepheline syenite, syenite porphyry, mica andesite, pyroxene andesite, and basaltic rocks of various types. The nepheline syenite he considered as probably younger than the trachytic phonolite, while the basaltic dikes represent the last eruptions in the district.

MODIFICATION OF EARLIER RESULTS.

In the course of the present investigation the geology of the district has been entirely remapped upon the carefully revised topographic base. A comparison of the new map with the old will reveal a number of changes in the boundaries of igneous masses, the division of the granitic terrane into several distinct formations, the recognition of a number of eruptive masses not shown on the older map, and considerable change in the nomenclature of the igneous rocks. There is also recorded an important revision of conclusions as to the age and the relation to the rhyolite of the sedimentary rocks of Grouse Hill and Straub Mountain.

BASEMENT ROCKS.

The most ancient rocks in the district are fibrolitic muscovite schists and fine-grained granitic gneisses. The gneisses are typically exposed in the streets of Cripple Creek and at the terminal station of the Colorado Springs and Cripple Creek District Railway. The schists may be well seen in Poverty Gulch between the Abe Lincoln mine and the railway trestle bridge and near the station of the Florence and Cripple Creek Railroad in Cripple Creek. This gneiss was not separately shown on the older map, being included partly with the granites, which were mapped as a unit, and partly with the schist.

Cross and Mathews recognized three types of granite in the Cripple Creek region, which they designated the Pikes Peak, Cripple Creek, and Spring Creek types. They did not, however, distinguish these types upon the map. This has

[a] At the time Cross wrote, the term "andesite" embraced rocks, such as latite, which have since been given separate names.

now been done. The Pikes Peak granite prevails over a large area in the district and is the common rock in the vicinity of Squaw Mountain and Victor. It is younger than the gneiss and schist. The Cripple Creek granite also occupies a considerable area extending westward from Anaconda beyond the bounds of the area studied and is well exposed along Cripple Creek in the vicinity of Mound. It cuts the schist and gneiss and is intrusive into the Pikes Peak granite. The Spring Creek granitic mass is of comparatively small superficial extent, and its age with reference to the other granites is unknown.

In the northwestern part of the district there has been found and mapped an area of a rock which is mainly an olivine syenite, though the mass exhibits remarkable range and variability in mineralogical composition. The olivine syenite is younger than the Pikes Peak granite, but is pre-Tertiary, for numerous diabase dikes genetically related to the syenite are covered or intruded by Tertiary eruptive rocks. A dike of anorthosite cuts the olivine syenite and is genetically related to it in a manner similar to pegmatite dikes in granite.

It will be seen on looking at the map that the schist, gneiss, Spring Creek granite, Cripple Creek granite, and olivine syenite together constitute a wedge-shaped area projecting into the Pikes Peak granite from the west. The center of volcanic disturbance is near the point of this wedge.

VOLCANIC ROCKS.

A number of new chemical analyses of the Tertiary eruptive rocks have been made by Dr. W. F. Hillebrand, Mr. George Steiger, and Dr. W. T. Schaller for this report, and the petrography of the district has been carefully studied by Mr. L. C. Graton with interesting results. That the phonolite, nepheline syenite, trachytic phonolite, syenite porphyry, and andesite of Cross are all closely related types connected by intermediate varieties appeared highly probable in an early stage of the field work. Mr. Graton's studies, in connection with the chemical analyses, confirm this view and show clearly that all the volcanic rocks, including the basic dikes, are merely divergent eruptive facies of one general magma, characterized chemically by about 58 per cent silica, a large proportion of alkalies, the soda being usually somewhat higher than the potash, a small percentage of lime and magnesia, and a certain quantity of combined water. None of the massive rocks would now be called andesite. Though it can not be affirmed that andesitic fragments are entirely absent from the usually much altered volcanic breccia, none were recognized and the term "andesitic breccia" is certainly not applicable to this formation as a whole. It would be more accurate to describe it as a phonolitic breccia, although in places near the periphery it consists chiefly of particles of the older rocks through which the Tertiary eruptives broke.

None of the massive rocks erupted from the Cripple Creek volcanic center and now present in the district show any evidence of having been surface flows. They are for the most part intrusive porphyries, ranging in texture, however, from the granular so-called nepheline syenite near Independence to the nearly aphanitic phonolite of the smaller dikes and sheets. In the breccia of Rhyolite Mountain, however, and in a smaller area of breccia at the south boundary of the district mapped, on the east side of the canyon of Cripple Creek, some of the breccia fragments are vesicular.

Much difficulty was experienced during the mapping in an attempt to separate the rocks described and mapped by Cross as trachytic phonolite, syenite porphyry, pyroxene andesite, and augite-mica andesite. The more carefully their occurrences were studied, particularly in underground exposures, the more apparent it became that these rocks are not distinct, but are slight variants of one magma and, in some places, of one eruptive mass. New chemical analyses and the latest petrographic work show that this view is correct. The names "trachytic phonolite," "syenite porphyry," "pyroxene andesite," and "augite-mica andesite" have accordingly been dropped and the corresponding rocks have been designated "latite-phonolite." Although some of the augite-mica andesite of Cross is sufficiently distinct to be called "biotite trachyte," it has not seemed advisable to map this facies as a separate unit.

On the older map is shown an area of nepheline syenite near the town of Independence. Some important changes have been made in the geological boundaries in this part of the field, and the rock originally called "nepheline syenite" is in the present report described as syenite. A small area of similar rock has also been mapped on the north side of Battle Mountain. Nepheline, if present at all in these rocks, is a very subordinate constituent.

The syenite areas are difficult to map, as the rock in many places passes through imperceptible gradations into latite-phonolite.

Cross, in the first Cripple Creek report,[a] described the rock forming the summit of Bull Cliff and called attention to its peculiar character. It was mapped by him as phonolite, but he stated that it was widely different from the other phonolites and might be a distinct intrusion. Field examination in 1903 showed the rock to be a sheet capping the hill and resting upon breccia and latite-phonolite. In the Pilgrim tunnel, on the west side of Bull Cliff, the fact that this capping rock is younger than a dike of latite-phonolite is clearly shown.

We classify this rock as a trachydolerite. It apparently constitutes an interesting link, both in time and in chemical composition, between the phonolitic rocks and the basic dikes which were the final eruptive products from the Cripple Creek volcanic center.

FORM OF THE VOLCANIC NECK.

While it may be true that in a few places the breccia rests upon an uneven erosion surface of granite, gneiss, and schist, the evidence obtained during the season of 1903 shows that the main breccia mass fills a steep-walled chasm of profound depth in the fundamental rocks of the region. From the Conundrum mine, on the western slope Gold Hill, to Stratton's Independence mine, on the south slope of Battle Mountain, the contact plunges steeply down, with dips ranging in general from 70° to vertical. In some places the granite walls of this chasm actually overhang the breccia. It is certain that this entire southwest contact represents a part of the wall of the great pit formed by the volcanic explosions that produced the breccia. In most of the other parts of the contact where evidence could be obtained the walls are also steep. The general conclusion reached is that the principal breccia mass, with its associated bodies of intrusive rocks, is in the main a volcanic neck.

[a] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 37.

SEDIMENTARY DEPOSITS.

The hill occupied by the city reservoir on the northern edge of Cripple Creek is capped by a coarse conglomerate containing rounded bowlders of granite, gneiss, schist, and diabase up to a foot or more in diameter. Pebbles derived from the Tertiary eruptive rocks appear to be entirely absent. The bowlders are weathered and decomposed, and the deposit at its north end seems to underlie the volcanic breccia of Mineral Hill.

This conglomerate was mapped as breccia by Cross, as the exposures available for his examination indicated the presence of some volcanic material. He showed, however,[a] that the general material of the deposit was entirely different from the normal breccia and suggested that it was probably a remnant of a local lake deposit. The character of the conglomerate, which since Mr. Cross's visit has been well exposed in a street cutting, indicates that it is a stream deposit. The occurrence is of particular interest because it affords definite information concerning the original character of the surface of the region before the eruptions of the Cripple Creek volcano commenced.

On Grouse Hill and Straub Mountain occur some rather obscurely bedded grits which are remnants of a formerly more extensive deposit. The material consists chiefly of angular and rounded particles of granite, occasionally several centimeters in diameter. Quartz pebbles are abundant and there are scattered pebbles of a hard bluish quartzite. The usual color of these grits ranges from dark brown to brilliant red or yellow.

In describing these sediments Cross[b] referred to their great similarity to the upper Carboniferous grits of the Fountain formation. Believing, however, that they rested as a younger formation upon the rhyolite of Grouse Hill and Straub Mountain, he correlated them with the Miocene High Park lake beds, and deduced partly from this correlation the probable late Miocene age of the Cripple Creek volcano.

The relation between the rhyolite and these grits has been studied by Mr. Graton, who finds that the rhyolite is intrusive into the grits and the latter are thus older than the High Park lake beds. Fragments of rhyolite, it is true, occur in the grits near the intrusive contact, but these were probably introduced at the time of intrusion of the eruptive rock into the loose, porous deposit.

The origin and correlation of these grits, including a small mass of similar material found on Copper Mountain, in the northern part of the district, is doubtful. It is possible that they are remnants of the Fountain formation. But it seems more likely that, as suggested by Cross, they are composed of detritus blown from the throat of the Cripple Creek volcano at an early stage of eruptive activity, and that they have been protected from erosion by the induration consequent on the intrusions of rhyolite and phonolite and by cappings of phonolite.

The deposit seems to have been at least from 200 to 300 feet thick in the vicinity of Grouse Hill and Straub Mountain. The accumulation of this thickness of material upon what appears to have been in general a plateau surface is difficult to reconcile with the supposition that the grits were deposited in a lake. It is more probable

[a] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 101.

[b] Op. cit., pp. 53-55, 106-109.

that the material was thrown into the air by an explosive eruption and fell thickly upon the surrounding plateau, to be in some places partially reworked and distributed by streams.

AGE OF THE ERUPTIONS.

The fact that the grits of Grouse Hill and Straub Mountain can not be correlated with the High Park lake beds does not involve any great change in the assignment of a probable geological date to the Cripple Creek eruptions. Inasmuch as the accumulation of the grits probably marked the beginning of local volcanic activity, and as both grits and rhyolite are intruded by phonolite from the Cripple Creek center, it follows that the Miocene (or at least post-Oligocene) rhyolite was erupted within the period during which the Cripple Creek volcano was active.

GEOLOGICAL STRUCTURE OF THE DISTRICT.

CRYSTALLINE ROCKS OF THE PREVOLCANIC PLATEAU.

As appears from the accompanying map (Pl. II), the schist and gneiss occur chiefly in the northwest corner of the district. The two rocks are in irregular and intimate association and constitute a thoroughly metamorphosed complex of unknown derivation. It is probable, however, that the gneiss was originally a granitic rock and there is some evidence to support the view that the schist, which at the present time is composed of muscovite, quartz, fibrolite, and magnetite, is an extremely metamorphosed sediment. The two rocks exhibit intermediate facies and can not everywhere be distinguished. This metamorphism was probably effected in pre-Cambrian time and long antedates the eruptions from the Cripple Creek volcanic center.

The olivine syenite and Spring Creek granite occur in the extreme northwest corner of the district and are intrusive in the gneiss and schist.

The Pikes Peak granite is the most extensively developed formation in the district. It is prevalent on the north, east, and south sides of the central volcanic area and is the principal rock of the plateau country for miles in these directions. It is intrusive into the gneiss and schist, and probably also into the Spring Creek granite and the olivine syenite.

The Cripple Creek granite occupies a considerable area in the western part of the district, west and southwest of the town of Cripple Creek. It is clearly intrusive into the gneiss and schist and has invaded these rocks irregularly, not only in large masses, but in numerous dikes, as may be well seen at many points in the southern part of Cripple Creek town. The reddish color of the younger rock, contrasting with the gray tint of the gneiss and schist, renders these dikes readily recognizable. It is probably intrusive also into the Pikes Peak granite; for though no decisive evidence bearing upon this point was found within the district, yet the occurrence in the Pikes Peak granite of fine-grained granitic dikes which are similar in lithological character to the Cripple Creek granite, the absence of gneissic structure in the latter and its frequency in the Pikes Peak granite, particularly near the contact of the two rocks, are indicative of this relation. Shear zones, along which the sheared granite is often metamorphosed to schist, occur in the Pikes Peak granite, but not, so far as observed, in the Cripple Creek granite. Such schist bands are

particularly abundant in the vicinity of the contact between the two granites southwest of Guyot Hill. Cross and Mathews, from their studies in the Pikes Peak quadrangle, reached the same conclusion with regard to the relative age of these granites.

Before the Tertiary eruptions broke through the plateau the principal mass of Cripple Creek granite probably extended eastward to West Beaver Creek, for the granite between Bull and Ironclad hills and some masses near Cameron are of this type. In the southern part of the district, near Victor, are some small bodies of similar granite apparently intrusive in the Pikes Peak granite.

The various intrusive contacts between the pre-Cambrian rocks are unaccompanied by any important mineralization, even pyrite being notably lacking in these rocks, and the prevolcanic structure of the ancient crystalline plateau is of economic importance only in so far as it affects the distribution of the different rock types in the rim of the volcanic conduit. Practically no deposits of value occur, for example, in schist, but some of the most productive ore bodies in the district have been found in the Pikes Peak granite close to the irruptive contact. The Cripple Creek granite, moreover, where it forms a part of the rim has proved less productive than the gneiss. It is thus probable that the economic history of the district would have been different had not the prevolcanic structure determined that a large part of the volcanic neck, particularly between Guyot Hill and Goldfield, should be bordered by the Pikes Peak granite. It has already been pointed out that the principal volcanic eruptions broke through the pre-Cambrian rocks near the point of a wedge-like projection of gneiss, schist, Cripple Creek granite, Spring Creek granite, and olivine syenite into the Pikes Peak granite. It is possible that this was not a mere coincidence, but that the pre-Cambrian structure as revealed in this areal distribution of the rocks was an important factor in determining the point of eruption.

The granites and gneiss of the Cripple Creek district are cut by a number of diabase dikes that are older than the Tertiary eruptives and that may belong to the same eruptive series as the olivine syenite and anorthosite of Iron Mountain. So far as known, these dikes have no economic importance.

FORM OF THE VOLCANIC NECK.

It is essential to a clear understanding of the mutual relations of the Cripple Creek rocks to remember that the central part of the district is occupied by a volcanic neck similar in some respects to those described by Geikie in the south of Scotland. At the time of eruptive activity the region seems to have been a granitic plateau not differing greatly in the general character of its relief nor even in actual surface from the plateau of to-day. The first manifestation of volcanism of which there is any record was the formation, by one or more tremendous explosions, of a great chasm in this plateau. The granite above the volcanic hearth was shattered and blown into the air, falling back as fine fragments partly into the pit formed by the explosion and partly over the surface of the plateau. Eruptions of phonolite, latite-phonolite, and syenite followed, but do not appear to have issued in a simple sequence. Successive eruptive paroxysms probably shattered and comminuted the products of earlier outbursts. The breccia now occupying the greater part of the volcanic throat exhibits in many places such a thorough mingling of

different rock fragments as to indicate that the great chasm in the granitic rocks, after its initial filling with breccia and intrusive rock, was more than once partly or wholly cleared by renewed explosions and refilled with their products.

These eruptions undoubtedly built up a volcanic cone upon the plateau, but the materials of this cone have been removed by erosion very nearly to the original plateau surface. Consequently the main central area of breccia shown on the geological map more nearly represents a plan of the volcanic throat than it does the extent of the former cone. It is important to determine as closely as possible how much of this area represents the outline of the deep volcanic chasm or throat and how much is merely a residual portion of the practically vanished cone, and thus rests upon the old plateau surface. It is also important to ascertain, if possible the inclination and general character of the contact between the breccia which fills the volcanic throat and the granitic rocks through which the eruptive materials forced a passage. A convenient plan is to begin in Poverty Gulch, just east of Cripple Creek, and thence to trace the outline of the volcanic neck in a circuit past Anaconda, Guyot Hill, Elkton, Squaw Mountain, Victor, Bull Cliff, Ironclad Hill, and Globe Hill.

The contact is exposed at several places in the Abe Lincoln mine, in Poverty Gulch. For the first 360 feet in depth it seems to have a dip of 80° or 85° S. For the next 140 feet the general dip is probably not over 30°. A short distance east of the Abe Lincoln mine the Chicago tunnel enters Globe Hill from Poverty Gulch and extends eastward to the Plymouth Rock shaft, between Globe and Ironclad hills. The tunnel is chiefly in breccia, which near Poverty Gulch is composed largely of schist fragments. Lateral branches, however, penetrate solid schist to the north and south of the line of the main tunnel. The schist on the north is continuous with a mass exposed at the surface in Poverty Gluch. That on the south is continuous with the schist exposed at Fairview. The two contacts dip toward each other at from 35° to 45°. If these dips are maintained, the Fairview and Poverty Gulch schist masses should unite at a depth of from 200 to 300 feet below the tunnel.

In the Midget and Conundrum mines, on the west slope of Gold Hill, the contact between the ancient crystalline rocks and the breccia is irregular, is at many points poorly defined, and has not been exposed in a sufficient number of places to fully establish its form and character. All indications, however, point to an increasing steepness of the contact toward the south, and in the Good Will tunnel, which passes from granite into breccia somewhat less than a thousand feet south of the Midget shaft, the contact is nearly vertical. In the Abe Lincoln and particularly in the Conundrum and Midget mines the gneiss is more or less shattered for some distance from the contact, and the breccia is largely composed of gneiss and schist fragments.

While the contact as exposed in the Chicago tunnel and in the Abe Lincoln, Midget, and Conundrum mines is not so steep as it becomes farther south, the breccia of the northwest slope of Gold Hill clearly occupies a pit produced by explosive volcanic activity and does not rest in an eroded hollow in the prevolcanic plateau. Lying between the main rim of schist and gneiss on the west and the Fairview promontory of schist on the east, this pit is apparently a marginal embayment of

the central volcanic abyss. Its floor pitches steeply to the south and on an east-west line drawn through the summit of Gold Hill may attain a depth of from 1,500 to 3,000 feet below the present surface. This and other similar embayments in the rocks rimming the volcanic neck are doubtless due to the tendency of the volcanic forces to find relief in a lateral as well as in an upward direction as they neared the surface. They may be compared to the flaring enlargements noticeable on the side of issue of a bullet hole through plate glass.

At the Pointer and Mint mines, on the southwest side of Gold Hill, the granite and breccia are locally separated by an intrusive mass of syenite. The general dip of the pit wall in this vicinity, however, as shown by comparison of its outcrop with its exposure in the Ophelia tunnel, is between 70° and 80°. In the vicinity of Anaconda and in the Mary McKinney mine the contact between the granite and the breccia is nearly vertical, and continues so along its irregular course toward Elkton.

In the Elkton mine the contact between the granite and breccia is well shown. North of the Thompson shaft of the Elkton property the contact runs nearly east and west, while east of the shaft it runs nearly north and south. This shaft is thus situated within a local granite promontory which juts northeastward into the breccia of the volcanic neck. The contact as seen in the Elkton mine is irregular in detail, but it is clear from its position on successive levels that the promontory steeply overhangs the breccia. The granite as a rule shows considerable shattering near the contact, which, however, is usually fairly sharp and is too irregular to be a fault contact. Fragments of granite are abundant in the breccia, often for distances of more than 300 feet from the contact.

Although the original contact between the granite and breccia in the Elkton mine is not a fault plane, there has been faulting in the vicinity. The Thompson fault or so-called "Dead vein" lies usually just north of the contact. It strikes N. 72° W. and dips at 83° S. It is sometimes a simple fissure containing a foot or more of soft slickensided gouge, sometimes two or more narrower parallel fissures filled with similar material. The throw is apparently normal and the displacement probably not more than 100 feet. At a few points, as on level 4, the fault locally marks the contact between granite and breccia. The fault is an example, similar to others which will be described later, of local movement near the original contact. Such fault fissures in most cases more nearly approach a plane surface than does the adjacent granite-breccia contact. The breccia had filled the volcanic conduit and become somewhat indurated before the faulting took place.

Between Elkton and Victor the contact passes between Squaw and Battle mountains and is approximately vertical. It is well exposed on nearly all the levels of the Ajax mine and has in many places been drifted on for considerable distances. It is prevailingly steep, dipping north or northeast at angles ranging usually from 45° to 85°. The average dip is probably between 70° and 75°. Near the shaft, particularly on the upper levels, the contact has an east-west course. But, as is shown on Pls. II and V, the Ajax shaft is situated in an embayment in the granite between the Portland promontory on the east, presently to be described, and the northward turn of the contact, which carries it through the saddle between Squaw and Battle mountains on the west. This northerly turn is noticeable on all

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of the Ajax drifts that have followed the contact far enough to the west, and is particularly conspicuous on the lower levels. A north-south section through the Ajax shaft, showing the steep dip of the contact, is given in fig. 63 (p. 479). The apparent flatter dip below level 6 is partly real and partly due to the obliquity of this part of the contact to the plane of the section.

The breccia near the contact contains abundant fine granitic detritus and fits snugly against a wall of granite which is far too irregular to be a fault contact. Blocks of granite from 2 to 3 feet in diameter are sometimes found in the breccia at a distance of 100 feet or more from the conduit wall. The contact is generally sharp and definite, though on account of the granite fragments in the breccia it is not everywhere conspicuous. The granite close to the contact is seldom brecciated, though in places considerably jointed and even shattered.

In the Dead Pine mine, just east of the Ajax, the contact has been followed by an inclined shaft and found to dip north at 70°. The shaft of the Granite mine is in breccia, the various levels all running south across the contact into the granite. The general strike of the contact seems to vary from northwest to west, but as there are no drifts on it this point can not be accurately determined. The general dip is north at about 80°. The contact surface, however, is evidently very irregular, and there may be local southerly dips between levels 6 and 7 and between levels 9 and 10.

The Portland mine, north of Victor, affords better opportunities of studying the inclosing wall of the volcanic neck than any other mine in the district. The contact between the granite and breccia is an irregular surface which plunges steeply under the breccia to the north and east. Its dip is rarely less than 70°, is frequently approximately vertical, and in places forms what would be an overhanging cliff were the breccia removed. Some idea of the irregularity and general steepness of this contact may be had from Pl. V. As is there well shown, the granite in the Portland workings forms a bold promontory jutting into the breccia-filled funnel of the Cripple Creek volcano. Along the northern scarp of this promontory, west of the Portland mine, are the workings of the Granite, Dead Pine, and Ajax mines. Along the eastern declivity, south of the Portland, are the workings of Stratton's Independence mine.

The contact is well exposed on all the Portland levels from the 500-foot to the 1,000-foot. As a rule it is sharp and readily determined. The breccia for a few inches from the granite is hard, rather fine grained, and, as shown by microscopic study, is chiefly of granitic origin. It rests snugly against the rather minutely irregular wall of granite, which is not as a rule noticeably fractured or shattered. Usually there is no evidence of faulting along the contact, and there can be little doubt that the breccia was in the main originally deposited in the position it now occupies relative to the granite. Occasionally there has been some fissuring along planes adjacent and generally parallel to the contact. Such fissure planes, however, do not follow the irregularities of the actual contact and are not connected with extensive faulting.

On the 500-foot level a sharp contact between granite and breccia is well exposed in a short drift on the so-called "Shaft vein," just west of the Burns shaft. The contact here is less steep than is common on the lower levels, dipping north at about

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60°. It may also be well seen about 300 feet southeast of the Burns shaft in a crosscut east from the Portland vein. The contact is here sharp, the breccia resting closely upon an uneven surface of granite. The dip is abnormally low, being only about 15°, toward the east. This low dip is undoubtedly local, and if the breccia could be removed the granite at this point would probably be found forming a relatively flat bench or step with steep scarps above and below. The contours of Pl. V are strongly indicative of such changes of slope.

On the 600-foot level the contact, as exposed a short distance north and east of the Burns shaft, is definite and close. It is rather irregular, but nearly vertical on the whole. Near the Diamond vein, however, about 300 feet east of the shaft, the contact is a regular plane dipping about 35° NE. and exhibiting clear evidence of some faulting between the granite and the breccia; but the movement is apparently local and not connected with any great displacement. A moderate dip, here as on the 500-foot level, obtains on the crest of the granite promontory. It is 20° steeper, however, than on the level above, which fact, taken in connection with what is known of the contact below, indicates proximity to the outer edge of the granitic bench already referred to.

On the 700-foot level the contact between the granite and breccia is exposed in the main drift about 100 feet north of the Burns shaft. It is here sharp and close, rather irregular, and as seen in the drift nearly vertical. East of the Burns shaft the contact practically coincides with the No. 2 vein.

On the 800-foot level the contact is in part the east wall of the No. 2 vein. It is sharp and irregular in detail. The granite is sometimes shattered for a foot or two from the contact, which is here nearly vertical. Toward the north the contact soon swings westward, away from the No. 2 vein, and is again well exposed in the main northeast crosscut about 125 feet from the Burns shaft. This contact is remarkably close and definite and shows no evidence of faulting. Its course where cut by the crosscut is nearly north and south and it dips eastward at about 80°.

On the 900-foot level the contact between the granite and breccia is exposed in at least five places. North of the Burns shaft the granite shows some brecciation near the contact, and the latter is not so sharp and distinct as in other parts of the mine. Just east of the No. 2 vein, which is partly within the granite on this level, the contact is clearly exposed in a short crosscut. The granite is shattered, but not brecciated, for a distance of 2 or 3 feet from the breccia, while the latter contains abundant particles of microcline and some small fragments of granite, those seen being less than 3 inches in diameter. The contact here dips eastward at 75° to 80°. A little farther north a crosscut west of the No. 2 vein, which is here wholly in granite, exposes a close, definite, irregular, vertical contact of the latter rock with the breccia.

On the 1,000-foot level the contact is exposed about 100 feet north of the Burns shaft and along the No. 2 vein. In general it is approximately vertical and presents characteristics similar to those observed on the level above.

The granite-breccia contact is hardly so well exposed in the Independence workings as in the Portland. In general it is fairly distinct on the upper levels, the granite, as a rule, not showing much brecciation in its vicinity. In detail it is exceedingly irregular, being diversified by minor salients and reentrants. The

breccia near the contact is in some cases, as on the 1,400-foot level, so full of granite fragments, some of them of large size, that it is difficult to determine in a small exposure whether the rock seen is breccia or massive granite.

While in the Portland mine the contact between the granite and the breccia is generally convex toward the northeast, in Stratton's Independence mine it is concave. In the Portland the granite projects into the breccia as a steep promontory; in the Independence the breccia lies in the curved embayment on the east side of this jutting point of granite. The benched form of the contact surface described in the Portland is also well exhibited in the northern part of the Independence embayment. The general dip of the contact is at least 60° N. or NW. Further details of this portion of the contact will be found in the description of the Independence mine on pages 449 to 465.

The Golden Cycle shaft, 1,000 feet deep, is wholly in breccia, though the granite at the surface is only 1,400 feet distant to the southeast. This shows that the slope of the contact must be greater than 35°.

On Big Bull Mountain the Safety mine, another shaft higher on the northern slope of the mountain, and a tunnel and several pits on the northeast side all show a nearly vertical contact. Near Grassy Creek there are no deep workings near the contact. Its course, as shown on the map, is suggestive of a low angle of dip, and a shallow pit on the slope southeast of Cameron indicates that this part of the breccia may be merely resting on an old surface of erosion.

The workings of the New Century, Damon, Jerry Johnson, Sunshine, and Hoosier mines, though neither deep nor exclusive, all point to a very steep contact along the northeastern border of the breccia area. From Tenderfoot Hill to Carbonate Hill the contact is not explored by deep workings, but a zone of greatly shattered granite and schist bordering the fragmental volcanic material is indicative of violent eruptive forces and of a steep contact. At the C. O. D. mine the schist-breccia contact is fairly steep.

The island-like mass of shattered granite which forms parts of Bull and Ironclad hills lies almost in the center of the main volcanic area and derives exceptional interest from its rather remarkable position. The workings of the Bogart, Sheriff, War Eagle, and Ramona No. 2 mines show that to the south the contact of this granite with the breccia is steep. This is confirmed by the absence of granite in the American Eagle mine, though the bottom level, 1,500 feet deep, extends to within 400 feet of a point vertically under the contact at the surface. The character of the contact on the west, north, and east sides of the mass is unknown, though the outline of the granite as shown on the map (Pl. II, in pocket) indicates a high angle of dip.

Granite, unfractured and with a steep contact surface, appears on level 11 of the Isabella mine, about 800 feet vertically below the Emma No. 2 shaft house. This granite is of the Pikes Peak type, however, while that of the Bull Hill area and of the tongue which extends west of Cameron is of the Cripple Creek type. Whether this body of granite occurring at so great a depth represents the crater wall, of which the average slope from the surface down is in such case not much over 45°, or whether it is a huge fragment which parted from the side of the chasm above and sank into the pit, it is impossible to say.

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The general conclusion reached regarding this principal breccia mass, extending from Goldfield to Carbonate Hill and from Guyot Hill to Cameron, is that it occupies the throat of the main volcano. This is certainly true of the breccia between Gold Hill and Goldfield and between Victor and Altman. Whether the pit filled by this breccia is continuous with that north of Ironclad and Gold hills is not established, owing to the lack of deep workings at the head of Squaw Gulch. It may be that the schist mass of Fairview and the Granite mass of Bull Hill come together at a moderate depth and that the breccia of Globe Hill fills a separate vent, which only superficially coalesces with the great chasm to the south.

Of the form of the outlying breccia masses, including those of Mineral Hill, Rhyolite Mountain, Copper Mountain, and Mount Pisgah, less is known. Though the breccia in some places, as just north of the city reservoir in Cripple Creek, seems to rest upon a surface of erosion, in most cases it has steep contacts with the older rocks, and appears to fill local vents. On the east side of the Mineral Hill mass, for example, the contact as shown by the Aztec shaft, 60 feet deep, dips 45° W. A steep dip is indicated also by the relation of the contact to the topography on the northeast side of the hill (Pl. II).

At the Fluorine mine, on Copper Mountain, the breccia rests on a gentle slope of granite, but contains great fragments of the underlying rock, showing that the source of the breccia is near.

BRECCIA.

LOCAL BEDDING.

The general form and geological occurrence of the breccia have been partly outlined in the preceding section. The formation occurs mainly in the principal volcanic neck. There are, however, a few outlying masses, some of which seem to fill local volcanic vents, while others appear to be residuals of the formerly more extensive accumulations of breccia that lay upon the uneven surface of the pre-volcanic plateau.

As a rule, the volcanic breccia is a structureless agglomeration of fragments, varying in the character and size of its constituent materials from place to place, but showing no stratification and no definite arrangement of its particles. There are a few notable exceptions to this rule, however. In parts of the Captain stopes and in the southwest part of the 220-foot level of the Portland mine the breccia, which in these places is rather fine grained, shows well-marked banding due to the alternation of layers of relatively fine and coarse material. On the 220-foot level, where these layers are best shown, they are about a foot in thickness and the material resembles nearly horizontally bedded grits or coarse sandstones. This bedded structure, however, is never continuous for long distances and the bands pass gradually into the usual unstratified breccia. Similar nonpersistent stratification occurs at a few places in Stratton's Independence mine, in the southeastern drifts of the Isabella mine, in the Lucky Guss No. 2 mine, on the south slope of Bull Cliff, on the slope south of Cameron, and in the Elkton mine. A bed of very fine-grained, loose volcanic ash is exposed in the shallow Red Rock shaft near the Hoosier mine. In the Elkton the bands dip at about 40°. The lack of sharpness and persistency and the various attitudes in which this stratification occurs indicate that the sorting

and arrangement of the material was not effected in a body of water, which, indeed could hardly have existed within the conduit during the volcanic period. It would rather seem to be due to the winnowing action of winds on material thrown into the air, to a sorting by rolling down slopes, or to alternations in material thrown out by successive eruptive explosions.

CARBONACEOUS MATERIAL.

In the Doctor-Jackpot mine, just above level 15, or about 600 feet below the surface, the ore is accompanied by a black coaly material, of rather fragile character, which retains an original woody structure. Chemical examination of this material by Doctor Hillebrand shows that it is noncoking, gives an oily distillate, and is a bituminous coal with the following composition:

Composition of coal from Doctor-Jackpot mine.

Moisture	1.0
Volatile carbon	29.0
Fixed carbon	68.4
Ash	1.6
	100.0

Similar material, but with conchoidal fracture and no trace of an originally organic structure, occurs in irregular bunches in the breccia on the 550-foot level of the Morning Glory mine, particularly near the west end of the Ingham crosscut. This is also noncoking and its composition is as follows:

Composition of coal from Morning Glory mine.

Moisture	0.5
Volatile carbon	21.0
Fixed carbon	69.9
Ash	8.6
	100.0

Rickard[a] mentions the finding of similar coaly material in the Logan mine at a depth of 600 feet and of a silicified tree stump in the [Stratton's] Independence mine at a depth of 500 feet. In July, 1905, a carbonized tree trunk was found on the 800-foot level of the Elkton mine. A letter from Mr. E. M. De la Vergne, the manager of the mine, dated November 25, 1905, states that the log is 18 inches in diameter and was at that time exposed for a length of 5 feet. It lies in hard unfissured breccia, about 40 feet west of the Elkton basic dike, and the matrix shows the impressions of knots and bark. A specimen from this tree trunk, kindly supplied by Mr. De la Vergne, retains the rings of growth and other general woody structures, although the material is now altered to coal like that found in the Doctor-Jackpot mine. According to Prof. F. H. Knowlton the tree was undoubtedly a conifer and probably belonged to a species of *Pinus*.

In view of these various occurrences there can be no question that vegetation of the time of the Cripple Creek eruption was buried in the breccias to depths which, after erosion, are still to be measured by several hundreds of feet. This fact, more

[a] The Cripple Creek volcano: Trans. Am. Inst. Min. Eng., vol. 30, 1900, p. 384.

than any other, helps us to realize the force of the explosions that brecciated the rocks and the thorough mixing of the shattered material, whereby trees and presumably weathered surface rocks could be so deeply entombed. Such mixing could scarcely take place unless the materials now filling the volcanic neck had been actually blown into the air, leaving a great pit into which they fell back in chaotic confusion. The position of this carbonaceous material affords material support to the view, presented in subsequent pages, that the Cripple Creek ores were deposited at a very moderate depth; or, in other words, that the post-volcanic erosion has effected little more than the reduction of a comparatively small volcanic cone.

The presence of charred or carbonized wood is by no means uncommon in volcanic necks, and has been recorded by Archibald Geikie[a] in those of Scotland and by Cross[b] in the agglomerate of the Bassick neck in Custer County, Colo.

INTRUSIVE MASSES WITHIN THE VOLCANIC NECK.

The breccia, which constitutes the main filling of the volcanic funnel, incloses a number of masses of latite-phonolite and of syenite. These bodies are largest and most abundant in the part of the central breccia area lying between Victor and Cameron—that is, in the southeastern part of the volcanic neck. They are generally of very irregular shape and are undoubtedly in most cases intrusive into the breccia. Sharp contacts, however, seldom occur, as the adjacent breccia is often composed of fragments identical in petrographic character with the massive rock, and the massive rock itself is in many places greatly shattered. It is conceivable that some of these masses are remnants of larger intrusions solidified early in the volcanic period and partly shattered by later eruptions.

The syenite occurs only within the main breccia area. The largest mass, which is inseparably involved with latite-phonolite, is at the south end of the town of Independence, and with other bodies exposed in the workings of the Vindicator mine. A smaller mass lies just west of the Vindicator body and is exposed underground in the Last Dollar mine. A third intrusion is mapped on the north slope of Battle Mountain and has been reached underground in the workings of the Portland mine. A fourth mass occurs at the Pointer mine, on the southwest slope of Gold Hill, and a fifth near the Logan mine, on Bull Hill.

In Poverty Gulch are two dikes which were shown as andesite on the first geological map of the district. Though decomposed, they seem to be mainly syenite with perhaps some latite-phonolite facies. The longer dike is exposed in the workings of the Molly Kathleen mine, on the south slope of Tenderfoot Hill.

The Vindicator syenite mass, which in all probability consists really of several masses associated with latite-phonolite, gives place on the lower levels of that mine to latite-phonolite which is known to be continuous with the latite-phonolite of the Golden Cycle mine, north of Goldfield. The Last Dollar syenite body continues to at least 1,200 feet in depth, but shows many local gradual transitions to latite-phonolite. On the whole, latite-phonolite predominates underground in the Last Dollar and is probably connected with the syenite and latite-phonolite of the Vin-

[a] On the Carboniferous volcanic rocks of the basin of the Firth of Forth—their structure in the field and under the microscope: Trans. Roy. Soc. Edinburgh, vol. 39, 1880, p. 471.

[b] Geology of Silver Cliff and the Rosita Hills, Colorado: Seventeenth Ann. Rept. U. S. Geol. Survey, 1896, pt. 2, p. 311.

dicator and Golden Cycle mines. The Battle Mountain syenite and latite-phonolite are also facies of a single intrusive mass.

The latite-phonolite occurs mainly as irregular stock-like bodies or in thick sheets. A good example of the former type of occurrence is found in a biotitic variety (biotite trachyte) which is exposed over a large part of the northern slope of Battle Mountain and in the workings of the Portland and Dead Pine mines. The No. 3 shaft of the Portland mine was started in this rock and continued in it to a depth of about 1,000 feet. It then passed out of the latite-phonolite into breccia, the irregular contact between the two rocks here dipping to the west. A narrow tongue of the latite-phonolite passes through the saddle of Battle Mountain, extends southward nearly to the granite, and is reached in some of the western workings of the Portland mine and in a northeast crosscut in the Dead Pine mine. This intrusive body was described by Cross as a mica andesite, but on account of its unsatisfactory surface exposures was not mapped by him. Underground workings have since thrown considerable light upon the shape and extent of this intruded body.

Another irregular mass of latite-phonolite which sends out a number of dike apophyses lies between Battle Mountain and Goldfield. This rock was mapped by Cross as augite andesite and was thought to be a remnant of an early surface flow that had been partly brecciated by later volcanic explosions. It has not been so well exposed underground as the micaceous facies of Battle Mountain, but has been cut at a sufficient number of places in the Portland and Independence mines to demonstrate its irregular intrusive character. The adit level of the Portland mine is in this rock for about 1,000 feet from the portal. Owing to the general eastern dip of its western contact, the latite-phonolite lies to the east of the principal Portland workings on the 500-foot and lower levels. It occasionally shows syenitic facies.

The large area of latite-phonolite extending from Bull Hill to the saddle north of Battle Mountain, though connected with dikes, seems to be in the main a thick, irregular intrusive sheet. The shaft of the Blue Bird mine penetrates this sheet and passes into breccia at a depth of from 300 to 400 feet. The same relation is shown in the Dante, Gold Sovereign, and other mines in the vicinity, which at depths of a few hundred feet at most pass out of latite-phonolite into breccia. The flat bottom of the sheet is exposed also in the Lower Trail tunnel in Arequa Gulch, above Elkton. The mass of latite-phonolite reaching from Independence to Altman also has a nearly horizontal under contact near the Shurtloff No. 2 shaft, which is reported to pass into breccia at a depth of about 500 feet. On the east side of the mass, however, the workings of the Deadwood No. 1 mine show the contact to be nearly vertical for a depth of at least 300 feet.

The shape of the large body of latite-phonolite that underlies the town of Altman and extends down through Independence is unknown. The southwest contact of the mass with the breccia is very steep at the Findley mine, for on the 900-foot level syenite (probably the equivalent of the latite-phonolite on the surface) is reached 130 feet east of the shaft.

The contact of the breccia with the latite-phonolite or syenite, between the Vindicator and Lillie shafts, is almost vertical for a depth of 1,000 feet. No breccia has been found underneath the Vindicator area of syenite. In all of the lower levels

of the Vindicator latite-phonolite prevails, but it contains two or three smaller masses of syenite which are usually separated from the latite-phonolite by sharp contacts, although in some places there is a gradual transition.

A very persistent dike of latite-phonolite traverses the breccia in the Hull City mine, from the massive rock in the Vindicator to some point in the Findley ground.

The Zenobia and Pharmacist mines show that the large mass of latite-phonolite north of Altman is overlain on its western side by breccia. The arm extending from the main mass to Bull Cliff is exposed in the Isabella mine where, at a depth of about 1,000 feet, it contracts rather rapidly to a narrow dike.

Little is known of the shape of the intrusive masses of Big Bull Mountain, as they are unexplored by deep mines.

Two masses of latite-phonolite are exposed on the south slope of Gold Hill and in the workings of the Anaconda mine. The eastern mass was mapped by Cross as syenite porphyry, while the western one was represented by two separate dikes of andesite. A mass of latite-phonolite of unknown size is cut in a west crosscut from the Anaconda tunnel toward the E. Porter Gold King mine, but this body is not known to reach the surface. Like the two occurrences mapped it is apparently intrusive into the breccia, although the contact is, as usual, rather indefinite.

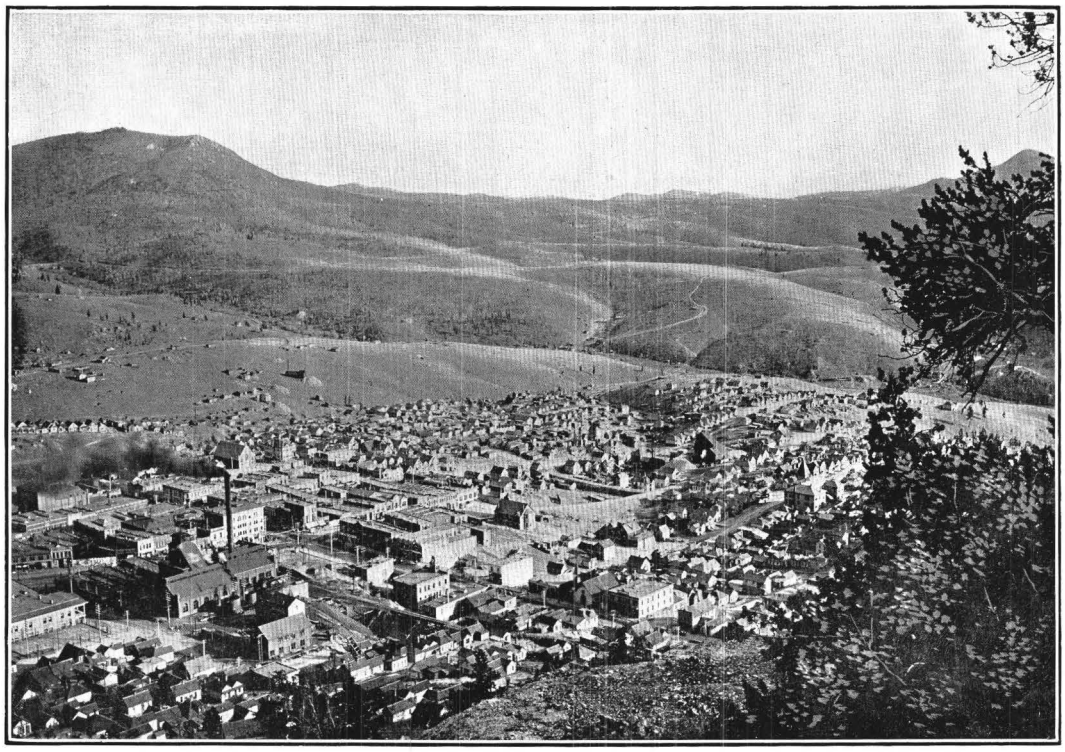
As has been already noted, the syenite usually shows gradations into latite-phonolite, indicating that the two rocks are facies of a single intrusion of magma. In some places, however, as in the Vindicator mine, the two rocks are in eruptive contact, showing that one facies had solidified before the intrusion of the other. It is not always clear, in such cases, which is the later rock.

The peculiar trachydolerite of Bull Cliff is probably an intrusive sheet whose upper surface has been uncovered by erosion. It is clearly younger than the latite-phonolite and is probably younger than the latest eruption of phonolite; but it is older than the basic dikes described in a subsequent section.

OUTLYING INTRUSIVE MASSES.

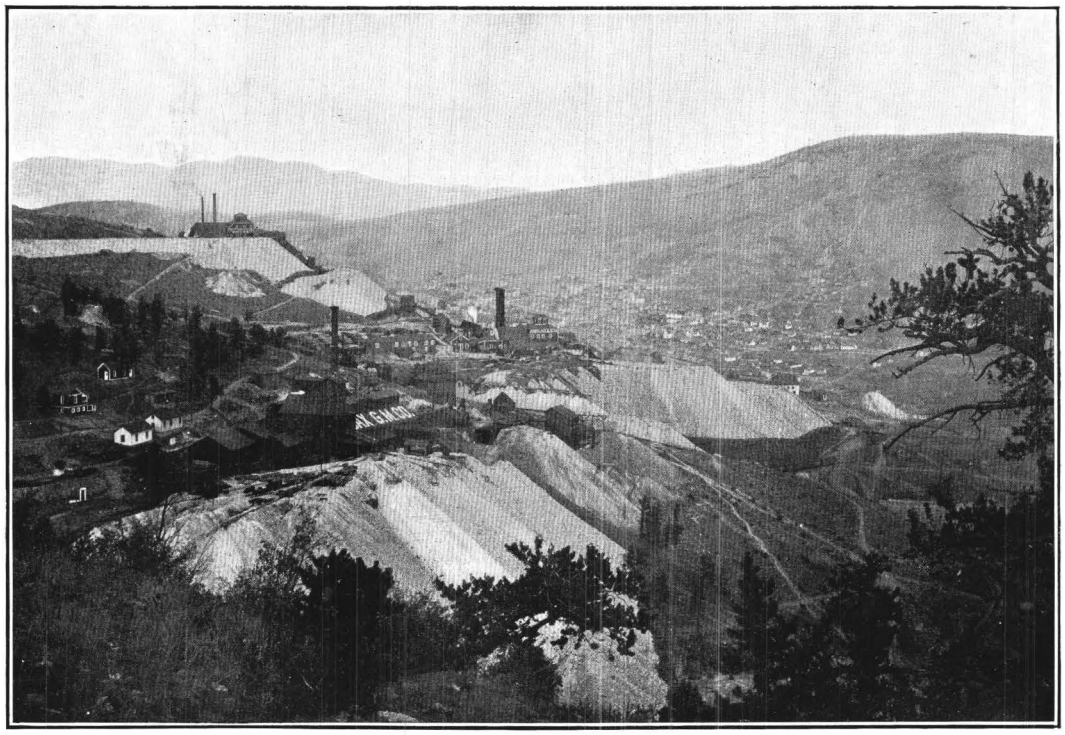
While the intrusive masses (exclusive of small dikes) in the breccia of the volcanic neck are nearly all syenite and latite-phonolite, the outlying intrusions derived from the Cripple Creek volcanic center are nearly all phonolite. In most cases, as on Pisgah, Rhyolite, Copper, Trachyte, and Straub mountains and on Grouse Hill, the phonolite bodies of considerable area seem to have the form of irregular sheets, which, however, may be merely the upper expanded parts of plug-like intrusions. These sheet-like bodies are sometimes directly connected with dikes. Between such sheets and the phonolite dikes later described no sharp distinction can be made. The phonolite sheets are rarely associated with important deposits of ore.

The phonolite mass of Beacon Hill is an eruptive plug filling an elliptical conduit in the Pikes Peak granite. As this plug is encircled by productive ore deposits it has been exposed at a number of points in the El Paso, Gold Dollar, and smaller mines in the vicinity. The contact dips steeply into the hill, the average angle being near 75°. If this dip should continue downward at the same angle, the bottom of the phonolite would be found at an approximate depth of 2,200 feet. The walls of the conduit, however, are likely to become steeper or more irregular at greater depth.



A. VICTOR, FROM SQUAW MOUNTAIN.

The shaft house of the Gold Coin mine is in the left foreground, and that of the St. Patrick mine in the middle-ground.



B. BATTLE MOUNTAIN MINES, FROM SQUAW MOUNTAIN.

Goldfield is in the distance, with Big Bull Mountain and Pikes Peak on the sky line.

The contact is usually sharp and in many cases minutely irregular. In places, particularly on the west side of the hill, the granite is only slightly brecciated at the contact. Elsewhere, as in the Gold Dollar mine, the two massive rocks are separated by as much as 15 feet of breccia composed of mingled fragments of phonolite and granite. In the open cut and stopes of the Prince Albert mine, on the east side of the hill, bodies of similar breccia are inclosed in the phonolite.

The orifice now sealed by the phonolite was probably formed by a local explosive eruption and was partly filled with breccia, this breccia being subsequently forced out and replaced by the intrusion of the massive phonolite. It is possible that greater erosion of the district would expose similar plugs which are now capped by thick irregular sheets.

DIKES OF THE VOLCANIC PERIOD.

The breccia and latite-phonolite and the surrounding pre-Cambrian rocks are cut by abundant dikes of phonolite, ranging in width from a few inches to 400 feet. While many of these phonolitic dikes belong to late phases of the eruptions, much phonolite was erupted at earlier periods and these masses contributed their fragments to the final breccia produced by the volcanic explosions. The diversity in age of the phonolite intrusions is shown by one phonolite dike cutting another, as may be seen half a mile east of Galena Hill, or by phonolite dikes cutting breccia composed of phonolite fragments, as may be seen in the mines of Raven Hill. In a general way there is a rough radial arrangement of the phonolite dikes around the main volcanic neck; but the dikes are often exceedingly irregular and not all of them conform to this plan.

The number of these dikes is vastly greater than can be indicated on a geolgoical map of the scale used in this report. They are found in practically all the mines of any size and in many cases do not appear at the surface. They can be studied to particular advantage in mines situated in the granite, such as the Gold Coin, Dead Pine, Granite, and Independence, their green-gray color and aphanitic texture contrasting much more strongly with the granitic rocks than with the volcanic breccia. In the Gold Coin mine the remarkable irregularity of some of the dikes is clearly shown. They branch and coalesce; they swell and pinch out; they change abruptly in course and dip; or they turn sharply into irregular, nearly horizontal sheets, in some cases resuming the vertical dike-like form a few feet away.

The phonolite dikes are of much economic importance in the Cripple Creek district, as will be pointed out in the section devoted to the ore deposits.

The last eruptions from the Cripple Creek volcanic center were the basic dikes. Like the phonolite dikes, they show a certain tendency to radiate from the central part of the district. They are less abundant, however, than the phonolite dikes and apparently nowhere extend more than 2,000 feet from the volcanic neck, while most of them are found within the breccia. Generally nearly vertical, few of them are over 5 feet wide and they are usually fairly regular in trend. They occur characteristically in zones, of which the individual members seldom continue for long distances. Usually as one dike of such a zone pinches, another appears in a parallel fissure a few feet away. In some places the two dikes are seen to be

connected; in others they appear to be entirely separate. The basic dikes decompose readily and are not well exposed except in the mines. Though many of them have no known connection with ore deposits, others, such as the Elkton-Raven, Conundrum, Strong, Anna Lee, North Star, Dolly Varden, Pinto, and Block 8 dikes either contain ore or are closely associated with ore bodies in other rocks.

TOPOGRAPHIC DEVELOPMENT.

INTRODUCTION.

Erosion in its various forms is at the present time the only agent of importance that is shaping the topography of this district by sculpturing its surface. But during past times constructive as well as destructive forces were at work, and during the epoch of eruptions the former were of sufficient intensity to overcome the work of the latter by building mountains of tuffs and ashes and lavas, which erosion again is in a fair way to obliterate. It is difficult to trace the physiographic history of a small district without going beyond its borders, and yet a little light may be thrown on the subject by a study of the surface forms near Cripple Creek.

In attempting to trace the topographic development we shall find it impossible to go further back than to the time just antedating the volcanic eruptions, that is, the middle or end of the Tertiary age. The inquiry resolves itself into three parts: (1) What were the surface forms previous to the volcanic eruptions? (2) What were the surface forms at the close of the volcanic epoch? (3) What changes have been effected since that time?

PREVOLCANIC CONDITIONS.

Broadly regarded, the region is an undulating plateau, a truncated upland with elevations of from 9,000 to 10,000 feet, above which some points rise to individual prominence. This plateau is deeply scarred by the abrupt canyons of Oil and Beaver creeks, which drain southward into Arkansas River.[a] In the local area this plateau finds expression in the rolling hills southwest of Cripple Creek and in Beaver Park in the northeast corner. The individual hills rising above this are represented by Trachyte, Rhyolite, and Big Bull mountains, and the volcanic complex of hills clustering about Bull Hill. The incised canyons are represented by Wilson Creek, Cripple Creek, and Spring Creek. If it were always possible to distinguish between intrusive and effusive igneous contacts the task of mentally restoring the prevolcanic surface would be much easier. No decisive evidence regarding this surface is offered by the whole southwestern contact line of breccia and granite. But on Big Bull Mountain, along Grassy Creek, and on parts of Carbonate and Mineral hills, as well as on Copper Mountain, there is some good evidence that the breccia rests in general on an old surface of granite and other rocks. It is inferred with some certainty that Big Bull Mountain existed as a rather prominent point in prevolcanic times, and that undulating hills along the north side of Grassy Creek and the summits of Tenderfoot and Carbonate hills formed part of this prevolcanic surface. The points mentioned belong to the

[a] See Geologic Atlas U. S., folio 7 (Pikes Peak), U. S. Geol. Survey, 1894.

general plateau referred to above and the coincidence suggests that this plateau is of prevolcanic age. Still better evidence is obtained from certain detrital deposits which belong to the volcanic epoch or to the one just preceding it. In the city of Cripple Creek, at the reservoir, situated on a spur of Mineral Hill, at an elevation of 9,600 feet, lies a small deposit of nonvolcanic conglomerate with large waterworn bowlders of granite, gneiss, and diabase (p. 22); it is not more than 50 feet thick and is apparently overlain by the breccia which caps the spur north of the reservoir. There is good reason to consider this as prevolcanic gravel filling a depression in the general surface of the plateau, whose antecedent slopes rise gently on the north, east, and west to a height of several hundred feet, while the natural outlet of the hollow would have been southward or perhaps into the area now occupied by volcanic rocks.

On Straub Mountain and Grouse Hill rest detrital rocks of granitic origin with a maximum thickness of 150 or 200 feet. They are poorly sorted, consist mostly of sand and fine gravels, and are believed to have been deposited as a result of the first explosive action preceding the actual volcanic outflows. (See p. 22.) Flat bodies of phonolite are intrusive in these sands, and as shown on Grouse Hill were once covered by them to an unknown elevation. As shown in fig. 2, which is an east-west section through Brind and Straub mountains and Grouse Hill, these deposits rest on an even surface gently sloping westward and rising more rapidly northward. The lowest point of their underlying surface is on the west side of Grouse Hill, where its elevation is 8,950 feet. To the south the basal granite rises again very gently, as seen from the contour lines in the Pikes Peak folio, so that there exists here a distinct depression, the upper continuation of which most likely should be traced through the flat amphitheater of upper Wilson Creek and into the volcanic area at Victor between Big Bull and Squaw mountains. From here one branch probably connected with the upper amphitheater of Cripple Creek, in the center of which lies the gravel deposit referred to above, while another one seems to have headed northward, passing by Cameron and having its source in the plateau about Gillett.

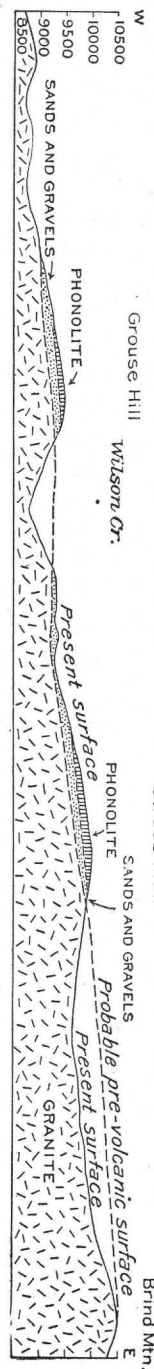


Fig. 2.—Geological section across Grouse Hill and Straub Mountain, showing prevolcanic surface and postvolcanic erosion.

To sum up, there is good evidence that the surface of this area as it was in the last part of the Tertiary period is well represented by the irregular granitic plateau with general elevations of 9,500 to 10,000 feet, which, though greatly dissected, now extends to the south and southwest of Cripple Creek. The undulating country of Beaver Park plateau about Gillett belongs to this plateau. The erosion effected in it by the present Beaver Creek probably does not amount to more than 100 feet. Above this plateau rose flat-topped hills such as Big Bull Mountain,

Cow Mountain, and the several projecting shoulders of Pikes Peak. Other eminences like Trachyte, Rhyolite, and Brind mountains may also have had a similar form before erosion, attacking them from several sides, had sharpened their summits. This truncated topography probably resulted from the long-continued action of erosion; the plateau is regarded as a peneplain; its higher summits may possibly be remnants of an older and higher plateau.

EPOCH OF CONSTRUCTION.

This lofty, rolling granitic plateau became, in middle or late Tertiary time, the scene of intense volcanic activity. Violent explosions with almost inconceivable force blew a hole through the granite, scattering its débris over the surrounding country. A remnant of this detritus is still believed to be preserved at the lowest outlet of the prevolcanic drainage on Grouse Hill and Straub Mountain. Repeated explosions filled the volcanic neck with breccias, and the result was the upbuilding of a volcanic cone on the granitic plateau. Final intrusions of phonolitic magmas occurred in the breccia, in the surrounding granite, and even, as on Grouse Hill and Straub Mountain, in the granitic débris. The question may now be asked, What was the height of this cone? This query has more than academic interest, for another highly important question hinges on this point, namely, At what depth below the surface were the gold-bearing veins formed?

Recognizing the fact that the sections (Pl. II, in pocket) of the present topography entirely fail to represent the volcanic mountain which must have existed, and that near the summits of the volcanic hills are intrusive bodies of granular rocks, we may conclude that a great part of the accumulated lavas and breccias and tuffs have been carried away. The height of the mountain must have been less than one-third the diameter of its base. The steepest slopes of large volcanic cones are rarely over 30° and toward the base the slopes become very much less steep.

If the summit attained 15,000 feet—about 5,000 feet above the present highest elevation—the base of this cone must have had a radius of at least 5 miles and probably very much more. As the prevolcanic surface is reasonably well preserved, we should expect to find breccias and tuffs—at least in small patches—scattered over the plateau, especially in the slightly eroded basin of West Beaver Creek near Gillett. This is not the case. The breccias and phonolite found outside of the main area are very clearly due to local eruptions. Hence an original elevation of 15,000 feet seems improbable. On the other hand, the phonolite of Grouse Hill is evidently an intrusive sheet in the granitic detritus now underlying it, and small patches of the same granitic sand are found on the summit of the phonolite. Hence we are justified in concluding that a thickness of at least several hundred feet of volcanic material once rested on top of this phonolite. From a tentative reconstruction of the cone as shown in fig. 3, it would seem as if its summit could scarcely have exceeded 13,000 feet. On this basis the vicinity of Victor would have been covered to a depth of about 2,000 feet and Bull Hill to a depth of about 2,500 feet. While these figures are merely tentative, they clearly show that it is very improbable that of 5,000 or 10,000 feet of volcanic material have been eroded—a conclusion that is strongly supported by the occurrence of carbonaceous material in the breccia as described on page 31.

EPOCH OF DESTRUCTION.

Since the volcanic forces ceased, erosion has had full sway to destroy what they built up. It is natural that volcanic cones should fall an easy prey to the action of atmospheric agencies, and their destruction is usually early and complete. But a special reason contributed to render this process unusually rapid in this case. Before the volcanic epoch the streams flowing on the plateau were sluggish in their action and slight in grade. After that epoch there occurred a general elevation of several thousand feet, whereby the old peneplain became a high plateau. The causes of this elevation, as well as its exact extent, can not be discussed here; their consideration properly belongs to the study of a wider area. At any rate the streams became rejuvenated and began to cut back rapidly into the plateau, especially from the southern side, belonging to the drainage of the Arkansas. To this Quaternary and still active epoch of erosion must be credited the deep canyons of the several branches of Cripple Creek, Spring Creek, and Wilson Creek. The canyon of the latter between Grouse Hill and Straub Mountain is an especially well-marked and striking case. That the branches of Cripple Creek and Spring Creek have also eroded their canyons below the plateau surface in comparatively recent time is very evident from even a cursory study of the contour map.

There is no evidence of a glacial epoch within the Cripple Creek district except in the northeast corner of the area, where the glaciers from Pikes Peak reached down and pushed their moraines almost to Gillett. That the glacial epoch had some influence on the topography of this vicinity is certain.

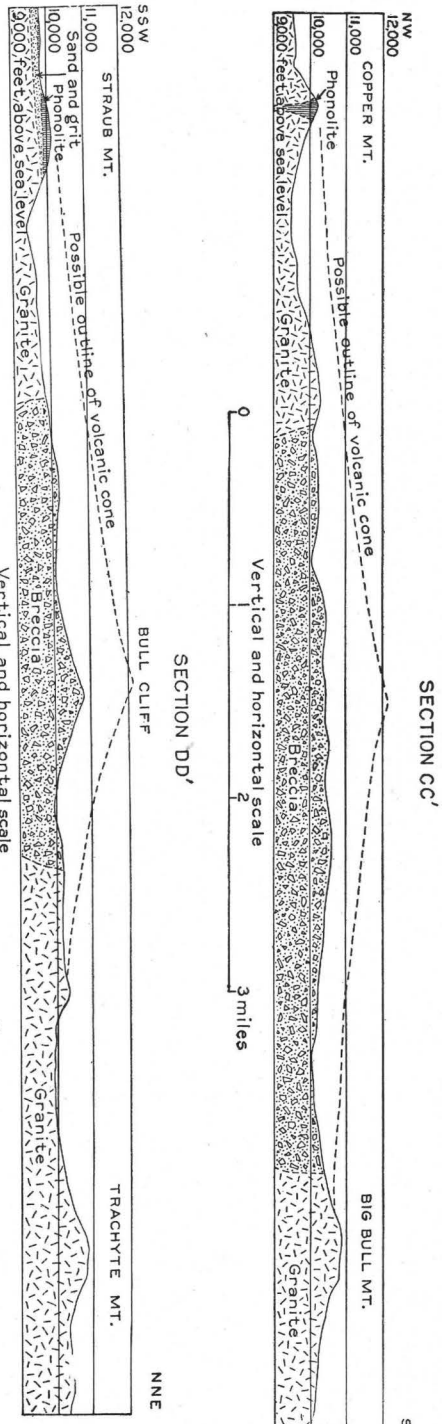


FIG. 3.—Sections showing possible outline of the Cripple Creek volcanic cone at the close of the volcanic epoch.

It seems probable that before the glaciation the basin near Gillett drained northward into Oil Creek (see Pikes Peak folio), but that later this drainage was diverted southward to West Beaver Creek.

The drainage of the volcanic area presents some interesting features. A fairly uniform volcanic cone will immediately develop a radial drainage system which is very apt to be superimposed upon the underlying rocks when these are reached by erosion. This kind of drainage is in fact indicated by Wilson Creek above Goldfield, by Arequa Gulch, and by Squaw Gulch, but to the north and east there is no indication of such a radial drainage. This shows, we believe, that the volcanic cone was not symmetrical, the southwest slope being much more prominent than the others, and also that the horizontal extent of the base of the volcano was probably confined within the limits of the special map. Had the deposits covered Big Bull Mountain and sloped uniformly eastward, gulches leading in that direction would surely have been established. The southward turn of upper Wilson Creek at Goldfield indicates that Big Bull Mountain existed at the close of the volcanic epoch and that it diverted the course of the gulch to correspond to an old prevolcanic drainage channel. On the north slope toward Cameron there are no indications of deep gulches in the volcanic area and it seems very unlikely that Grassy Creek, which in its flat course shows little evidence of the rejuvenating influence of the uplift, could have been established had not a slight depression existed between the volcanic hills and the granitic ridge west of Calf Mountain.

CHAPTER III.—DESCRIPTION AND PETROLOGY OF THE METAMORPHIC AND IGNEOUS ROCKS.

By L. C. Graton.

INTRODUCTION.[a]

PLAN AND SCOPE OF THE INVESTIGATION.

The rocks of the Cripple Creek district were made the subject of an extended petrographic study by Mr. Whitman Cross in connection with his examination of the geology of the region in 1894. At that time mining developments in the district were only well begun, and the geological worker had in most cases to be content with such information as could be derived from natural exposures. For various reasons—forest covering, presence of soil and slide, and in many cases profound decomposition of the rocks—the data thus obtained were in large part meager and unsatisfactory. Decomposition caused most trouble in the most critical portion of the district—the volcanic area—and made particularly difficult of attainment a good knowledge of the breccia and the basic dike rocks. In spite of these facts, that portion of Mr. Cross's report[b] which deals with the description of the rock formations not only gave the first insight into the nature and relations of these extremely interesting rocks, but furnished an excellent conception, broad and at the same time detailed, of the petrology of this district. His work is so well known to petrographers that further comment is hardly necessary.

The present investigation was conducted under much more favorable circumstances. That portion of the district which is of greatest petrographic importance is now prospected to a degree probably unequaled elsewhere. Developments ranging from shallow pits and trenches to very extensive mine workings actually honeycomb the rocks near the surface. These openings in several ways lend aid to the study of the geology and petrology. They furnish definite, satisfactory exposures of the rocks; they enable fresh material to be collected almost at will, and the deeper workings, reaching in some cases to a depth of 1,500 feet, afford an understanding of structural relations which no amount of surface study could give. With the conclusions reached by Cross already in hand, more attention could be given to details in this later work. Furthermore, a somewhat greater length of time was available for this examination than was at the disposal of Mr. Cross. Finally, this

[a] The writer wishes to acknowledge his obligation to the authors of this report for their unfailing interest and cooperation in his work. He owes much to Mr. Ransome for suggestions and helpful criticism both in the field and in the office. The larger part of the office work has been done under the direct supervision of Mr. Lindgren, for whose advice, criticism, and aid he is deeply indebted. To both these gentlemen are due his thanks for the opportunity to study and describe this most interesting group of rocks. The value of this chapter has been much increased by a careful criticism by Mr. Cross.

[b] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 20-58.

report is not only based on the studies of the writer, but also embodies those results of the extended investigations of Mr. Lindgren and Mr. Ransome which have a bearing on petrography.

Under these advantageous conditions the work was carried on so far as possible independently and as if original, and it is gratifying to know that it sustains the main conclusions of Mr. Cross. On the other hand, results which differ from his have been obtained in some instances and considerable that is new has come to light. Such differences, however, are in many cases unessential and may often be explained by the difference in conditions of work already noted.

While the present account of the petrology of the district thus comprises much that is contained in the earlier report, it has been deemed advisable to present it in full. This decision has been largely based on the fact that the early report is out of print and also on the belief that this independent verification of Cross's principal results can not fail to add to their value. Moreover, an adequate presentation of such features as are new and different can hardly be given without a full statement of the results common to both investigations.

The essentially economic character of the study of which the petrology is but a part has rendered it desirable that the conclusions reached and the distinctions recognized in the mapping and in the petrographic descriptions be of practical application not only by the experienced petrographer but by the miner as well. Minor variations within rock masses or among different bodies of the same general type have consequently not been made prominent, though they have been noted and described. While this desideratum has been borne in mind, it has, nevertheless, been the endeavor to make the treatment scientifically accurate and to bring out such petrologic principles as are exemplified by the rocks. It may not be inappropriate to state that the descriptions and conclusions here given are based on a study of the large collections of rocks, with numerous thin sections, from the Pikes Peak quadrangle and the Cripple Creek district made by Mr. Cross and kindly placed by him at the writer's disposal, and also of the specimens, numbering about 750, with very many thin sections, collected during the resurvey of the district. Each rock type is thus very well represented, and nearly all the important rock masses have been studied by means of numerous specimens. It has been sought throughout to make this a study of geological units—rock masses—instead, as is so often the case, of particular, individual hand specimens. It is believed that the large number of specimens has made possible a fairly satisfactory achievement of this aim.

In view of the close relation existing between the processes of rock alteration and those of ore deposition, especial attention has been given to the subject of decomposition and alteration of the mineral components of the rocks.

OUTLINE OF THE ROCK FORMATIONS.

The rock formations of the Cripple Creek district may be divided into two very distinct groups. One comprises ancient crystalline rocks, which make up a great portion of the Colorado range and the plateau to the west and upon which Paleozoic and later sediments have been deposited. These rocks originally occupied the entire area of the district.

In Tertiary time, as a part of the great eruptive activity manifested in this general region, a volcano broke through these fundamental rocks at about the center of the area. The products of this Cripple Creek volcano, together with a minor occurrence of a rock of about the same age, but having a different source, constitute the second group.

ANCIENT CRYSTALLINE ROCKS.

The rocks of the older division embrace granites, gneisses, and schists, and in addition a small area of olivine syenite and numerous dikes of diabase which cut the first three named above. All are probably of pre-Cambrian age.

GRANITE.

The granites of the district may be divided into a number of varieties, each distinctly recognizable in the field. They were described by Cross and named, respectively, Pikes Peak, Cripple Creek, and Spring Creek types. No attempt to separate them on the map was made by him. Dr. E. B. Mathews, who assisted Mr. Cross in the mapping of the Pikes Peak quadrangle, has made a somewhat detailed study of the granites within that area and has published his results in the Journal of Geology, volume 8, 1900, pages 214–240.

PIKES PEAK GRANITE.

The Pikes Peak variety, the most extensively developed rock in the district, occurs to the north, east, and south of the area occupied by the volcanic rocks and for long distances in those directions beyond the limits of the region shown on the map. It is a light-pink to red coarse-grained rock, noticeably deficient in dark constituents, and much of it rather poor in quartz and hence consisting largely of an alkali feldspar which in some cases gives to it a porphyritic appearance through the development of more or less idiomorphic columnar individuals up to over an inch in length. Many of these large feldspar crystals are so arranged as to give to the granite a rather pronounced flow structure, and this drawn-out appearance is increased in many places by shearing. At some points, as on Calf Mountain, the shearing has been sufficient to transform the granite into a gneiss, with tails or schlieren of the quartz, feldspar, and mica fragments, and knots or augen of the feldspar phenocrysts. Not uncommonly even these traces of original texture are obliterated over small areas, and the equivalence of the resulting even-grained much foliated gneiss to the Pikes Peak granite is established only through marginal gradations into more massive rock. The extreme degree of foliation is reached along certain narrow zones where shearing has been so intense that a true schistose structure has been developed. Weathering causes a marked disintegration of the rock, furnishing a medium-grained angular gravel, composed either of separate mineral grains or of small fragments of the rock. This disintegration, with the formation of gravel, unquestionably has much to do with the even slopes of many of the granite hills. The massive rock is thus covered, and more advanced stages of decay are not often observed.

Under the microscope microcline with its characteristic twinning is seen to be generally the most abundant constituent and is usually fairly fresh. Plagioclase

is another important component and proves to be a sodic oligoclase. Beside the prevailing albite twinning lamellæ arranged according to the pericline law are sometimes seen. The mineral is often turbid through kaolinization. Orthoclase is more variable in amount, from fairly abundant to rare, but is on the whole less common than plagioclase. Microperthite is plentiful in some specimens, while less regular intergrowths, resulting in uneven extinction, are occasionally found.

Quartz, though present in varying amount, is exceeded in abundance only by microcline when the group as a whole is considered. It occurs in irregular grains, ranging in size from exceedingly small ones up to those several millimeters in diameter. It is not much cracked, gives simultaneous extinction, and is glassy, but contains countless small fluid inclusions arranged in intersecting lines or planes which appear to have no definite crystallographic direction, or are crowded in certain parts. Another class of inclusions consists of minute hair-like rods or needles, without definite arrangement and usually of dark color. A few of the largest are brown and very strongly refracting, and it is possible that they are all composed of rutile. Several small rounded grains of quartz with the same orientation are sometimes seen penetrating an individual of feldspar, and more typical micrographitic intergrowths occur as small patches giving arborescent figures in polarized light; sometimes the orientation of one of the constituents is similar to that of a near-by individual of the same mineral. A decrease in the amount of quartz may produce a syenitic facies of the granite, like that from the Ajax mine, an analysis of which is given on the next page.

Biotite is the only ferromagnesian mineral present and is rarely abundant. It occurs in isolated plates or as clusters of irregular scales and is usually greenish brown in basal sections and yellowish parallel to the vertical axis. Chloritization is sometimes considerably advanced, producing a material ranging from strongly pleochroic to almost colorless. Locally, along with the chlorite, small granular particles of epidote and of black iron ore separate out along cleavage planes. The colored chlorite apparently contains much of the iron of the mica, for separation of iron oxide is a less common accompaniment of the green than of the colorless variety.

Of the accessory minerals, apatite in the usual prismatic habit and magnetite in large and small grains are the most common. Zircon is at times comparatively abundant. In numerous instances it is dull and in reflected light appears whitish and opaque as if through decomposition. Here and there a fragment of titanite is present. Some of the small brownish crystalline particles included in the quartz appear to be referable to rutile, while prismatic or rounded grains of a different character of brown, noticeably pleochroic, correspond to allanite. Minute corroded fragments of biotite when cut somewhat inclined to the base are readily confused with the latter mineral. Flakes of hematite or limonite, probably secondary, are sometimes present in the quartz and feldspar. Near mineral-bearing fissures pyrite and occasionally fluorite and zinc blende are introduced and the feldspars are partially sericitized.

With the exception of the gneissic structure sometimes developed as above mentioned, the texture of these rocks is typically granular.

The chemical character of this type of granite is expressed in the following analyses, made by Doctor Hillebrand:

Analyses of Pikes Peak granite.

	I.	II.		I.	II.
SiO_2	77.03	66.20	SO_3	.....	None.
Al_2O_3	12.00	14.33	Cl	.....	Trace.
Fe_2O_3	.76	2.09	F	.36	(?)
FeO	.86	1.93	FeS_2	.....	.12
MgO	.04	.89	MnO	Trace.	.13
CaO	.80	1.39	BaO	Trace.	.18
Na_2O	3.21	2.58	SrO	None.	Trace.
K_2O	4.92	7.31	Li_2O	Trace.	Trace.
H_2O-	.14	.48		100.55	99.74
H_2O+	.30	.83	Less O for F	.15	0.
TiO_2	.13	.65		100.40	99.74
ZrO_2	.....	.02			
CO_2	.....	.36			
P_2O_5	Trace.	.25			

I. Pikes Peak granite. Typical. Sentinel Point, western part of Pikes Peak massif. Jour. Geol., vol. 8, 1900, p. 237.
II. Pikes Peak granite. Local syenitic facies. Ajax mine, level 6.

CRIPPLE CREEK GRANITE.

Extending from the volcanic area westward beyond the mapped district is a light-red granite, which differs in texture from the Pikes Peak type and which has received the name Cripple Creek type. It is a medium, fairly even-grained rock, with an occasional feldspar larger and more idiomorphic than the rest, causing a slight porphyritic appearance. Quartz is somewhat more abundant and more evenly distributed than in the Pikes Peak granite, and the same may be said of mica. To this type is assigned the island-like mass of granite in the breccia on Bull and Ironclad hills.

Concerning the correlation of the dikes and irregular masses of finer grained granite found cutting the Pikes Peak granite, there may be some doubt. Mathews refers some of them to the Cripple Creek type and some to a separate division which he calls the "fine-grained type." But from such evidence as could be obtained both in the field and with the microscope, the smaller areas appear to be composed of a rock which corresponds closely with the Cripple Creek variety, and where it was possible to define their boundaries, they have been mapped as such. It is not unnatural that the smaller masses should in general have a finer grain than the large areas. The Cripple Creek granite has suffered much less shearing and deformation than the Pikes Peak type.

The results of the weathering of this rock contrast in some respects with those produced by that of the coarser grained variety. Instead of crumbling to angular gravel, this granite yields on disintegration subangular blocks of large and small size. This probably accounts for the apparent abundance of the dike granite in the Pikes Peak variety, fragments of the finer grained rock littering the surface of the coarser grained rock. On this account also the mode of alteration of the

Cripple Creek granite is more readily studied than in the Pikes Peak type. Biotite loses more or less iron, which distributes itself through the partially kaolinized feldspar and deepens the red color of the rock. Further change leaves the biotite conspicuous though lusterless and gives to the rock a dirty brownish-red color. Along phonolite dikes a common decomposition leaves the rock porous through removal of much of the quartz and mica.

A microscopical examination of this rock confirms the conclusion that its composition is not very unlike that of the Pikes Peak variety. Microcline is probably the most plentiful constituent, and is usually comparatively fresh. In some instances, besides the usual crosshatching due to the combination of albite and pericline twinning, individuals are twinned according to the Carlsbad law. Occasionally a fine microperthitic intergrowth is present, and the mineral then becomes microcline-microperthite, but whether the other component is orthoclase or plagioclase could not be determined. Orthoclase, the next abundant feldspar, is usually untwinned and more or less turbid through the development of kaolin and highly polarizing aggregates of muscovite flakes. Plagioclase is in general less common than in the Pikes Peak type, but is more variable in composition, having been found from albite to calcic oligoclase, inclusive. It is twinned polysynthetically and is usually turbid like the orthoclase. In a specimen from the Alpha tunnel the plagioclase appears to have been the earliest feldspar to crystallize; its grains are often corroded, but where inclosed in microcline, as is not uncommon, it has good form and the turbid interior is surrounded by an even, narrow border, perfectly clear and of slightly higher extinction angle. A few grains of ordinary microperthite are present. Quartz occurs as usual in the granites, in irregular grains of varying size and showing inclusions similar to those in the Pikes Peak type. It is sometimes present as poikilitic grains in the microcline, and locally shows a tendency toward a definite intergrowth. Little patches of typical micropegmatite occur at places.

The micas complete the list of essential constituents. Biotite, though seldom abundant, is the more common, occurring as brown or greenish-brown isolated plates of not very high birefringence. A frequent product of alteration is chlorite, often associated with epidote and black iron ore. Fully as common is a bleaching of the biotite and transformation into muscovite, a process which can be clearly observed in some sections. Muscovite occurs in three ways—secondary from biotite, as just noted, secondary from feldspar, and primary. In the second case the aggregate sericitic mass resulting from the weathering of much of the feldspar seems to arrange itself into shreds and patches having similar orientation, thus producing grains of muscovite. In the last case clear muscovite, often corroded, comes up sharply against and sometimes penetrates perfectly fresh biotite of different orientation; it also occurs between grains of other components.

In addition to these principal constituents several minerals are present only in grains of microscopic size. Magnetite, apatite, zircon, and titanite occur in rapidly decreasing abundance. Small grains of tourmaline are sometimes seen, and show pleochroism in strong yellows, greenish brown, and blues. Prismatic crystals of brown color and marked pleochroism are more certainly referable to allanite than similar grains in the Pikes Peak variety. A few grains of rutile are present.

Fluorite is present in sections from several localities and in a few instances appears to be primary, inclosing magnetite and tourmaline, penetrating individuals of quartz and occurring as sharp interstitial grains between perfectly fresh individuals of other minerals, and also included in feldspar. Cleavage is noticeable and the color ranges from colorless through pale pink to patches showing very deep purple. Traces of crystal form occasionally exist and minute fluid inclusions are sometimes observed. Although some fluorite, known to have been introduced into the granite through later fissures, occurs in much the same manner as above described, certain facts support the view that the mineral is in other cases an original constituent of the rock. Fluorine is known to occur in several minerals in the pegmatite veins which cut the granite of the peak. Moreover, Mathews's descriptions of fluorite in the granites of the Pikes Peak quadrangle furnish almost convincing evidence as to its primary nature, and perhaps most conclusive of all is its distribution in remote and widely separated parts of the quadrangle, an area of nearly 1,000 square miles, and in localities removed from vein mineralization. But it can be stated that within the limits of the Cripple Creek district primary fluorite is a rare constituent of the granites.

Pyrite occurs in the granite near mineralized fissures, as in nearly all of the specimens from mine workings. Besides the epidote derived from the decomposition of biotite, this mineral sometimes occurs as faintly pleochroic aggregate patches scattered through the more decomposed rocks. Small areas of carbonate are occasionally seen, and hematite and limonite result from the weathering of magnetite.

These rocks have the hypidiomorphic-granular texture of the typical granite.

An interesting result of shearing of this granite is the production, along certain very narrow zones, of sericite and sillimanite.

SPRING CREEK GRANITE.

The Spring Creek type is not extensively developed, occurring only on the southwestern half of Red Mountain and on the hill to the south on the opposite side of Spring Creek. It is a bright-red, even-grained rock, containing conspicuous rounded grains of quartz 1 or 2 mm. in diameter. No specimen of very fresh material could be obtained.

The color is found to be due to staining of the turbid feldspar grains with limonite. While orthoclase is probably the most abundant feldspar, the twinning of plagioclase is often seen, but further determination is impossible. Microcline is sparingly present and possibly a little microperthite. Quartz is abundant in clear grains which sometimes show related orientation when embedded in the feldspar. In a small dark fragment here and there and an occasional patch of secondary epidote, there is indication that a little biotite was originally present. Muscovite appears in the feldspar as small flakes, some of which have the same orientation and are parts of so-called skeleton crystals. Several small grains of fluorite were considered by Cross to be primary, but to the writer appear rather as of later age than the consolidation of the rock.

RELATIVE AGE OF THE GRANITES.

Within the limits of the area mapped, little evidence as to the relative ages of the Pikes Peak and Cripple Creek granite is furnished by the contact of the two

rocks in the southwestern part of the district. But from the smaller amount of shearing and deformation which the Cripple Creek type has undergone, and from the presence in the Pikes Peak granite of innumerable dikes of a granite which is almost without question assignable to the Cripple Creek variety, the Pikes Peak granite may undoubtedly be considered the older. This was the conclusion reached by Cross and Mathews in a much larger field. No evidence as to the relative age of the Spring Creek granite was obtained.

PEGMATITE.

Closely related to the granites is pegmatite, which forms innumerable dikes or veins in various parts of the district. They are rather common in the Pikes Peak granite and locally occur in the gneiss, but only rarely cut the Cripple Creek granite. It is believed that most if not all of the pegmatite veins were a late phase of the eruption which produced the Cripple Creek granite, for in several places, notably along the Florence and Cripple Creek railroad south of Hollywood, typical well-defined veins of pegmatite seem to grade directly into dike granite similar in character to that of the main mass west of Cripple Creek.

The dikes are usually narrow and of red color, being made up principally of a potash feldspar with considerable quartz and smaller amounts of muscovite and well-crystallized magnetite. Occasionally the proportion of quartz is much greater, and the dike then may be mistaken for a quartz vein. Prospecting at several places has revealed their barren nature.

An examination under the microscope of one of the more "graphic" of these pegmatites reveals abundant microcline, all arranged with the same orientation. Quartz, present in about equal amount, penetrates the microcline granophyrically. Muscovite, often showing beautifully its skeleton structure, is less plentiful and has different orientation in different individuals. A few grains of magnetite are also present.

GNEISS.

Rocks of granitic texture, showing marked foliation, but no distinct banding,[a] occur at numerous places in the district. They belong to several varieties, but because of small and indefinite extent all but two have been omitted from the map. Of these two, both have been given the same color, since the mass on Calf Mountain is small and its origin is not absolutely certain.

WOMACK GNEISS.

The type of gneiss which has the greatest development underlies most of the town of Cripple Creek and forms the ridge to the northwest. It also extends as a band averaging a third of a mile wide from the slope of Gold Hill westward beyond the boundary of the area shown on the map. A mass of similar character occurs on the ridge northeast of Cameron and there meets the Pikes Peak granite, but the nature of the contact is not well shown and the mapping of the rocks at that

[a] The rocks thus described do not fall under the definition recently brought forward by Van Hise, who applies the term gneiss to a banded rock the bands of which are petrographically unlike one another. (Mon. U. S. Geol. Survey, vol. 47, 1904, p. 782.)

place is approximate only. The rock takes its name from Womack Hill, which stands at the eastern edge of the town of Cripple Creek and whose western slope is made up of this gneiss. On the old map the rock was not distinguished, but was shown partly as granite and partly as schist.

The origin of the Womack gneiss is not certainly known; it was probably derived by pressure from a granitic rock which, to judge from the small amount of quartz present in some places, may have been locally of syenitic or monzonitic character. There is no evidence that it is related to the Pikes Peak granite, and it is certainly older than the Cripple Creek granite, for it is frequently penetrated by narrow stringers and dike-like intrusions of the latter, as can be well seen in the various railroad cuts near the Short Line station and along the streets in the vicinity of the Warren School in Cripple Creek. It seems probable, therefore, that it has been derived from a third distinct granite, which, because of the greater deformation it has suffered, is thought to be older than either of the others.

It is a rather dark, brownish-gray rock of medium grain and fairly uniform texture, carrying an abundance of red feldspar and deep-brown mica, and apparently not much quartz. It is characterized by a gneissic structure which varies from schistosity to a foliation so massive that the hand specimen shows almost no banding, and only larger exposures reveal the true foliated nature of the rock. Weathering changes the color to a dirty gray-brown, leaves the biotite conspicuous, and thereby exaggerates the schistose appearance.

Under the microscope orthoclase is seen to be the most abundant feldspar. Plagioclase is next in importance and is albite or sodic oligoclase. It generally shows albite and in some cases pericline twinning, but is occasionally untwinned. Microcline occurs in varying amounts, but is seldom abundant. Quartz is found to be more plentiful than a megascopic examination would indicate. Inclusions are almost absent in some specimens, but in others they occur in profusion. As in the granites, they are fluid-filled cavities. Undulatory extinction is rather common. The feldspars often hold small oriented grains of quartz, while little patches of micropegmatite in arborescent patterns are not uncommon. Biotite is the prominent ferromagnesian silicate and occurs in irregular large and small plates, frequently corroded, and sometimes contorted. Pleochroism from light yellow to deep greenish brown is marked, and the absorption parallel to the cleavage is so great that many basal sections are practically opaque. The mineral doubtless holds a large percentage of iron. Chloritization is common and decomposition along the cleavages into epidote and magnetite is not infrequent. Muscovite occurs sparingly as an original constituent, and sometimes is clearly derived from biotite with the separation of iron oxide. Apatite is always present, and sometimes is comparatively abundant. Titanite varies in amount, but is on the whole rather plentiful in very irregular grains. Crystals of zircon are by no means rare, and occasionally a minute prism of tourmaline and a small lath of primary epidote are seen. The most important accessory is magnetite, which frequently attains considerable prominence. In addition to the foregoing constituents, the gneiss northeast of Cameron contains abundant sillimanite.

In the undulous extinction of the quartz, the contortion of the mica, and sometimes distinct cataclastic structure, together with a rude arrangement of the constituents in parallel position and in bands, there is additional evidence of deformation.

OTHER VARIETIES.

Reddish to dark-gray gneissic rocks, usually of finer grain than the type just described, occur as streaks and patches within the Cripple Creek granite, particularly near the contact with the Womack gneiss.

Biotite is the prominent constituent, though feldspar is plentiful, particularly in the less foliated types. In some cases there seems to be a direct gradation into the Cripple Creek granite, suggesting that they have been derived from it through shearing; but their lithological similarity to the Womack gneiss makes it probable that they are masses of that rock which have been caught up in the granite at the time of intrusion. The microscope shows that they are practically identical, as to mineral composition, with the Womack gneiss, except that orthoclase has been largely changed to microcline by the crushing which has taken place.

Another variety of gneiss is that derived by shearing of the Pikes Peak granite. As mentioned in the description of that rock (p. 43), deformation has in some places been sufficient to produce an augen gneiss or even a still more foliated rock. Gneissic facies of this kind exist in the neighborhood of the contact with the Cripple Creek granite in the southwestern part of the district, on Beacon Hill and near the Thompson mine. Still greater shearing has produced a rock which is with difficulty recognized as having been derived from the Pikes Peak granite. All the large feldspar crystals have been destroyed and biotite appears to have been formed under the metamorphosing conditions that obtained. The resulting rock is a dark, micaceous, decidedly foliated gneiss. It occurs in several places as narrow zones, and in the southeastern part of the district is frequently encountered in small, ill-defined areas. A mass on the southern slope of Calf Mountain can be roughly outlined and, as has been stated, has been mapped with the Womack gneiss. The rock in that locality bears considerable resemblance to the Womack variety, of which it may possibly be an included fragment in the Pikes Peak granite. If that be the case, the Pikes Peak granite is certainly of later age than the gneiss. But marginal gradations into fairly massive granite and the occurrence of narrow strips of similar rock along near-by shear zones make it probable that the gneiss has been formed directly from the Pikes Peak granite.

Related to the foregoing, and probably representing even more intense metamorphism, are the narrow, dike-like zones of dark-colored foliated rock—for example, the so-called "schist vein" encountered in the Ajax mine and the similar occurrence in the cut on the Low Line of the electric railway near the point where it passes under the Florence and Cripple Creek Railroad west of Victor. These are made up of clear, untwinned feldspar, a few grains of quartz, abundant green biotite, and considerable actinolite, with small amounts of apatite, sphene, and magnetite. Recrystallization has doubtless occurred, but crushing is evident notwithstanding.

SCHIST.

The foliated rocks of granitic texture have been described in the preceding paragraphs as gneisses. Besides these, however, there occur in the district areas of decidedly foliated and cleavable rocks, the origin of which is not clear, but which can be easily mapped and are here described under the name of schist. More specifically, they are quartz-muscovite schists. The areas designated as schist on Cross's map contain, besides the above rocks, several masses of what is in this report considered as gneiss.

A microscopic examination would seem to indicate two different types—one exceedingly schistose through the development of silvery or purplish muscovite in flakes up to a centimeter or more in breadth, the other more dense and massive, gray to nearly black, and apparently mica-free. But in reality these two types can not be separated; they grade into each other. The denser type is found carrying muscovite in increasing amount until it can not be distinguished from the more schistose. That this gradation is areal as well as constitutional can be seen in the schist mass northeast of the town of Cripple Creek, where the northwestern portion is chiefly of the denser type and the rock becomes more and more schistose toward the southeast.

Rocks of this kind form a northwestward-trending belt about half a mile wide and 4 miles long, reaching from Cameron to the base of Red Mountain, interrupted, however, by areas of later volcanic rock. In a general way this belt separates the Pikes Peak granite on the northeast from the gneiss on the southwest. A smaller belt of like direction and similarly interrupted reaches from the western slope of Gold Hill to the foot of Mount Pisgah, and possibly beyond. This strip roughly marks the line between gneiss and Cripple Creek granite. An area of schist surrounded by breccia, near Fairview station, on the High Line, may represent a continuation of this belt. An uneven narrow band of schist of the same character as the foregoing rocks follows the contact between the Cripple Creek and Pikes Peak granites west of Beacon Hill.

The microscope shows that all the rocks have a pronounced schistosity. Their most characteristic component is an aggregate mass of sericite, which shows by the parallel, almost fluidal arrangement of its minute shreds that the rocks have been much sheared. In the denser rocks sillimanite occurs very frequently with the sericite, in a similar way, forming bands, parallel to the schistosity, of small fibers and prisms. One or both of these minerals constitute a base or matrix in which are found individual grains of other constituents. Both are seen encroaching indiscriminately on all the other minerals, regardless of physical character or chemical composition.

Quartz is often plentiful, occurring as lenses or augen, with numerous smaller grains forming tails at each end. In many specimens it is penetrated by needles of sillimanite and shreds of sericite, and in some it is in this way almost destroyed. Strain shadows and cracks are of common occurrence. A few small grains of fresh microcline are noticeable in one or two specimens. Turbid patches, many of them nearly destroyed by the advancing sericite, in some cases show albite twinning and extinctions corresponding to albite and oligoclase albite, while in others they show no twinning and are probably orthoclase. Careful examination by convergent polarized light reveals the presence of numerous clear grains of untwinned feldspar,

probably for the most part orthoclase, with cleavage sometimes distinct. Muscovite is generally rather abundant, especially in the more foliated types, as irregular, ragged flakes which often appear to have resulted from recrystallization of the sericite base, while in several instances they are seen to have been derived from biotite. Biotite itself occurs in considerable amount in a few specimens and sparingly in some others, and at times gives evidence of its former abundance through the presence of pseudomorphic areas of sericite and strongly pleochroic chlorite, with the excess of iron separated out along the original cleavages as magnetite.

In some of the darkest, least schistose rock from the area south of Red Mountain there occur, along with abundant sillimanite, numerous grains of a mineral which has been identified as corundum. It forms hexagonal prisms up to 1 mm. long and half as broad, terminated sometimes by the unit pyramid. Sometimes it forms hexagonal plates 0.8 mm. across, and frequently it occurs in irregular grains. An imperfect rhombohedral cleavage is visible in some individuals. At times a patchy but distinct pleochroism in blue is seen in parts of a crystal. The refractive index is noticeably high. Isotropic sections give a uniaxial figure of negative character. The double refraction, as compared with that of other minerals in the section, appears somewhat higher than the recorded value for corundum, but owing to its excessive hardness the grains of this mineral are found to be considerably thicker than the rest of the slide, and as a result its interference colors are proportionally increased. Prisms and irregular grains, as well as ill-defined, radiating patches, of epidote are often observed. Apatite is common in some specimens, and not infrequently small particles of zircon are seen. Both these minerals are present in broken or contorted grains. Magnetite is usually very plentiful in large and small grains, which at times take the form of octahedrons.

Where feldspar and biotite are found sillimanite appears to be in process of formation, occurring in aggregates of very minute fibers radiating in all directions, with larger prisms in the interior of the mass. It appears to be an intermediate product in the process which finally results in the formation of the extremely schistose muscovite rocks. In such specimens, too, there are bands of quartz and feldspar grains which exhibit sometimes true granitic texture and at others typical cataclastic structure.

Cross regarded the schists that he found in the course of his study of the Pikes Peak quadrangle as, for the most part, inclusions of exceedingly metamorphosed ancient sediments, but he thought that some, if not all, of these particular foliated rocks of the Cripple Creek district have been produced from Archean gneisses. A study of the occurrence of these rocks and of their character as revealed by the microscope would point to the same view, but chemical evidence obtained later makes it appear probable that the schists were not derived from granitic gneisses. The following partial analysis by W. T. Schaller of a representative muscovite schist suggests, rather, by the low silica and high alumina, potash, and water, a relation to the phyllites or clay slates. The material was collected near the mouth of the Cripple Creek and Gold Hill tunnel.

Analysis of muscovite schist.

SiO_2	51.88	K_2O	5.55
Al_2O_3	23.86	TiO_2	.76
Fe_2O_3	7.24	P_2O_5	.07
FeO	1.89	Loss on ignition	6.05
MgO	1.43		
CaO	.21		99.62
Na_2O	.68		

OLIVINE SYENITE.

A rock of considerable petrographic interest occurs on Iron Mountain, in the northwest corner of the district. It is just outside the boundary of the area shown in the first Cripple Creek map, and is not shown nor mentioned in the Pikes Peak folio. Only a portion of the mass is included within the area mapped in this report, and its southern and eastern limits are concealed by slide and alluvium. There is reason to believe that on the north a sharp contact exists with the Pikes Peak granite, which is probably the older. This rock in its most common development appears as a dark-brown or reddish-brown, rather coarse-grained aggregate of Carlsbad twins of feldspar, with smaller amounts of a black mineral with pyroxenic cleavage and a dark-brown mineral of rather vitreous luster and uneven fracture.

The feldspar is almost exclusively microperthite—an intergrowth of orthoclase and albite—usually in Carlsbad twins, and commonly partially kaolinized. Quartz occurs very sparingly in irregular interstitial grains, which, nevertheless, sometimes show corrosion. Individuals of pyroxene up to half a centimeter in size exhibit at best only rude crystal form. The mineral is generally brownish yellow of varying intensities, but near the border frequently becomes greenish and sometimes deep green. Pleochroism is very slight, except in the green portions, and even there it is not marked. The angle of extinction is between 40° and 45°, but it was impossible to tell which one of the bisectrices lies nearest to the vertical axis. Cleavage is particularly good for pyroxene, and cross sections show, besides the prismatic, a pinacoidal cleavage sometimes of even better development. The second cleavage is probably parallel to the orthopinacoid, though this could not be determined with certainty. These properties and the character of the rock indicate that the mineral is diallage. It is more resistant to alteration than the other constituents. Olivine is present in almost the same amount as the pyroxene and in grains but little smaller. Good crystal faces are almost wholly lacking, but numerous individuals give a suggestion of the characteristic olivine outline. The mineral appears almost contemporaneous with the pyroxene, yet holds numerous crystals of apatite and grains of iron ore, which are uncommon in the bisilicate. The color ranges from a faint pink to a fairly strong but clear and transparent brown. The mineral is nearly isochroic. Besides the usual irregular cracks, two sets of cleavages are present, at right angles and of different degrees of perfection. The rough surface attests to the high index of refraction and the interference colors are less brilliant than usual because of the high double refraction of the mineral. The axial angle lies in the basal pinacoid, is smaller than for ordinary olivine—giving interference figures whose hyperbolas curve

markedly—and is acutely bisected by the axis of least refraction. Alteration products are of several kinds. Very commonly the mineral is changed along cracks and cleavages to feathery serpentine which is of exceptionally strong color—deep bluish green—and noticeably pleochroic, probably because of richness in iron. The serpentine is not always confined to the olivine boundary, but often fills cracks and spaces throughout the rock. A less frequent decomposition produces pseudomorphic, mixed aggregates of limonite and chalcedonic silica, much as in the decomposition of iron-rich garnets. Still another product of alteration is a material of brownish-yellow color, forming scaly aggregates. When crystallization is more complete the mineral appears in good-sized foils showing intense pleochroism—strong brownish yellow across the cleavage and deep green or sometimes brown parallel to it. The transformation from olivine is beautifully shown in some cases. This mineral has the cleavage, high double refraction, and characteristic surface of mica, which it is beyond question. Not uncommonly a chlorite of beautiful deep-blue color accompanies the mica. Occasionally the olivine is changed to talc and limonite. The brown color, distinct cleavage, comparatively small optical angle, negative character, and the nature of the alteration products all point to an olivine rich in iron, like hyalosiderite.[a]

Apatite is very abundant in well-formed prisms of noticeable size. Black iron ore is likewise plentiful in large, irregular grains. A very little zircon is present in grains which reach a size of 3 mm.

The combination of alkali feldspar, olivine, and diallage is unusual, and justifies the application of the name olivine syenite. Somewhat similar rocks have recently been found in Wisconsin.[a] This rock also resembles in some respects the perthitophyres of Chrustschoff.[b]

Of equal interest are the segregations which have taken place in this magma. In the southern half of the mass covered by it occur small inclosed areas, connected by gradual transitions with the main mass, where an increase in the amount of feldspar and a corresponding decrease in olivine give a pyroxene syenite with accessory olivine. In such cases the rock is red, usually of finer grain than the olivine syenite, and then sometimes porphyritic through the development of a few large feldspar crystals. In a few cases the olivine nearly or quite disappears and the prominence of quartz becomes such that the rock is a pyroxene granite.

Along the eastern edge, and particularly at the north end of the mass, the rock gradually becomes much darker in color—almost black. Feldspar is less prominent than in the olivine syenite and is of green color. Olivine is more abundant, but in less characteristic macroscopic grains. Iron ore is very plentiful, and frequently apatite occurs in beautifully sharp green needles up to half a millimeter in cross section. Occasional glistening flakes of mica are seen. In thin sections feldspar is found still to be the most important constituent. It belongs to the plagioclase series and ranges from oligoclase to labradorite inclusive, the most abundant variety being a sodic labradorite. Albite, Carlsbad, and pericline twinning are often beautifully exemplified. Diallage occurs as in the main rock, but has the purple or lavender tint indicative of appreciable titania content.

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[a] Cf. Weidman, S., Jour. Geol., vol. 12, 1904, pp. 551-561.

[b] Tschermaks Min. u. petrogr. Mittheilungen, vol. 9, 1888, p. 476.

Twinning parallel to both the vertical pinacoids is sometimes seen. The olivine, strangely enough, appears to contain less iron than that previously described. It is nearly colorless and the cleavage is less perfect. Its decomposition products are practically the same, however, and it is still rich in iron. Both pyroxene and olivine possess better crystallographic form than in the foregoing rocks. Black iron ore and apatite are especially abundant. Large and small grains of beautiful deep-red mica are associated with the ore. This facies is an olivine gabbro.

At the northern limit of the mass the rock is much finer grained, and a sharp line between it and the Pikes Peak granite suggests that it is a contact facies. Feldspar is abundant in imperfect laths, but is not so plentiful as above. It corresponds to the composition Ab_3An_4. Diallage is very common in irregular grains. It is still more deeply colored than that just described and exhibits a slight pleochroism in lavender and brown. Besides the titanic oxide thus contained, it is frequently filled with several definitely arranged series of minute dark needles, doubtless of rutile, the so-called sagenite. Olivine was originally present in large amount, but is now wholly altered into the products already mentioned. The red mica is rather plentiful, and, as before, always occurs near the abundant iron ore, which is probably titaniferous. Apatite is common, but less so than farther from the contact. The texture is granular and rudely ophitic.

Beginning at the contact and passing to the inclosed segregations one encounters (1) the doleritic contact facies of olivine gabbro, (2) olivine gabbro, (3) olivine syenite—the principal rock of the mass, (4) pyroxene syenite, with accessory olivine, (5) pyroxene granite.

This intrusion thus presents a very typical example of magmatic differentiation.

ANORTHOSITE.

Closely related to the olivine syenite is a rock which occurs in it as a dike 10 to 20 feet wide, just inside its contact with the granite. This rock is not particularly conspicuous, although detached pieces appear on the surface, but it has been exposed in several prospect holes. It is nearly white and is composed of individuals of plagioclase up to 10 cm. across, which show cleavage and excellent albite twin lamellæ more than a millimeter thick. The freshest grains have a darker-colored, bluish interior and suggest labradorite. A few small grains of dark minerals are present between the feldspar individuals.

The material is too decomposed to permit a determination of the exact character of the feldspar, but the decomposition products, zoisite and epidote, occurring side by side, indicate that it holds considerable lime, and it is probably a calcic labradorite. Sericite also results in considerable abundance from the decomposition of feldspar. Small scattered grains of diallage have the same character as that in the olivine gabbro. A few fragments of the red mica are also seen. The original presence of olivine can not be affirmed, but patches made up of serpentine, limonite, and talc (?) probably result from the decomposition of that mineral.

This anorthosite dike is thus seen to have a mineral composition such that it must be considered as belonging to the olivine-syenite group. It is, in fact, an extreme facies of the olivine-syenite magma.

DIABASE.

Numerous dikes and small masses of finely granular, dark rocks cut the granites, gneisses, and schists, but are not intrusive into the later volcanic rocks of the district. This difference serves to distinguish them from the basaltic rocks of somewhat similar appearance which occur principally in the younger volcanics. These older rocks are usually decomposed at the surface into a greenish mass with characteristic concentric disintegration, but at no great depth fairly fresh rock is usually encountered. They occur principally in and northwest of the town of Cripple Creek and along the northern slopes of Brind and Straub mountains. Cross assigned them to the Algonkian or early Cambrian.

Feldspar is developed in laths parallel to the brachy-axis which are frequently twinned according to the Carlsbad and pericline laws, in addition to the common albite twinning. It is usually turbid through kaolinization. The composition of the greater part corresponds to calcic labradorite, but in several instances there occur narrow outer zones of a clearer, more alkalic variety, which is sometimes even orthoclase. Pyroxene is present in considerable amount and seems to be diallage. It usually shows a slight pleochroism in purple, and doubtless carries a small percentage of titanium. A common decomposition product is a brownish-green fibrous amphibole corresponding to uralite. In other cases the pyroxene alters into a brownish-yellow aggregate of micaceous aspect. Olivine itself was not seen, but the freshest specimens hold patches of secondary material, built of fibers arranged in the characteristic net-like manner and possessing the outline of olivine. This secondary material is yellow or brown, somewhat pleochroic, and gives high polarization colors like those of muscovite. Carbonates and a little serpentine are also present in some of these areas. Numerous grains of deep reddish-brown biotite of strong pleochroism, or in a few cases ordinary brown biotite, occur in irregular flakes. Apatite and magnetite are usually plentiful as accessories, the latter mineral often being present in the grill-like skeleton crystals frequently seen in rocks of this character. Carbonates, sericite, and abundant epidote and limonite are formed on the decomposition of these rocks.

The laths of feldspar are arranged among the other constituents in the manner known as the ophitic texture, which is characteristic of the dolerites or diabases.

It is apparent that these rocks possess many resemblances to the doleritic contact facies of the olivine-syenite mass. The character of both monoclinic and triclinic feldspar and of the pyroxene and the presence of olivine and red mica relate the two rocks very closely and make it probable that many if not all of the diabase dikes of the Cripple Creek district are connected with the olivine-syenite intrusion. One or two dikes which contain ordinary biotite and in which olivine was not detected may be of different age.

TERTIARY VOLCANIC ROCKS.

The younger group comprises mainly the rocks of the Cripple Creek volcano. These are phonolite, leucitophyre (?), latite-phonolite, trachyte, syenite, trachydolerite, vogesite, monchiquite, and volcanic breccia. In this group is also included an areally unimportant occurrence of rhyolite, which had a different source, but

belonged to the same general period of Tertiary time as the rocks of the Cripple Creek volcano.

To one acquainted with the work of Cross it is at once apparent that the present nomenclature of this group differs from that adopted by him. His names for the rocks of the Cripple Creek volcano were phonolite, trachytic phonolite, syenite porphyry, biotite andesite, pyroxene andesite, nepheline syenite, and basalt, the latter including plagioclase basalt and nepheline basalt. This difference arises from different conceptions of the characters of the rocks rather than from unlike definitions of the rock names. While this difference of views will be dealt with under each rock type recognized in the present report, a general comparison of the names used in the two papers is given at this place.

The phonolite of Cross corresponds exactly to the phonolite of this report, with the one exception that the mass occurring on the summit of Bull Cliff was thought by him to be a peculiar phase of phonolite, while further study shows it to be a trachydolerite. The trachytic phonolite, syenite porphyry, and pyroxene andesite established by Cross have been found impossible of separation, and are here named latite-phonolite. Microscopic and chemical examination of the rock formerly named biotite andesite show that it is a biotite trachyte, but is closely related to latite-phonolite. Nepheline has not been found in the granular rocks called nepheline syenite by Cross, and they are now described simply as syenite. Study of fresher representatives of the basic dike rocks than those collected by Cross indicates that they fall into three groups, namely, a second type of trachydolerite corresponding to his plagioclase basalt, monchiquite corresponding to his nepheline basalt, and vogesite, a rock probably not seen by him. The breccia, of course, is the same in both cases, though, as will be shown, there is a divergence of opinion concerning its composition.

PHONOLITE.

GENERAL DESCRIPTION.[a]

Definition.—The phonolites are in general dense, fine-grained, porphyritic rocks of medium light to dark color, characterized by a large amount of alkalies, particularly soda, and considerable alumina, together with low bivalent bases and insufficient silica to form free quartz or to combine with all of the abundant alumina and alkalies in the ratio of feldspar. The essential mineral composition of phonolite is in consequence alkali feldspar, nepheline, and an alkali pyroxene which usually contains ferric iron. Phonolite is a rare type of rock in the United States.

Occurrence.—Rocks of this description occur in the Cripple Creek district as large and small bodies in and about the central volcanic area. The larger masses represent irregular intrusions from isolated local vents, and now, because of their greater resistance to degradation, form the summits of several of the Cripple Creek hills. As indicated on the map, phonolite occurs on Trachyte, Rhyolite, and Copper mountains, to the north, and on Big Bull and Straub mountains and Grouse Hill, in the southern part of the district. It also forms the crests of the hill east of Cameron, the hill east of Victor Pass, Beacon Hill, and the ridge west of the town

[a] A comprehensive and detailed description of these phonolites was given by Cross, General geology of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 25-41.

of Cripple Creek. The smaller bodies are sometimes also of irregular outline, as on the ridge west of Cripple Creek Gulch, but usually appear in definite sheetlike forms or dikes. They are abundant in both the volcanic rocks and the outlying granite, and exhibit a rude radial arrangement about the main eruptive center.

Outside the mapped area also the rock occurs at various points within a radius of over 7 miles from the summit of Bull Hill. Besides numerous dikes in the granite, masses of notable size form the summits of Nipple Mountain, Miter Peak, Little Pisgah Peak, the hills south of Straub Mountain, the hill east of High Park, Mount Pisgah, and Cow Mountain. Phonolite is also exposed in several places on the southwestern slope of Pikes Peak to an altitude of 11,000 feet.

Eruptions of phonolite took place at several different times. This rock furnished part of the material of the volcanic breccia and later invaded it as dikes. In the granite dikes may be found of at least two ages, and the larger intrusive masses may represent still another eruption.

Appearance.—In a few places outside the district proper these rocks have a marked porphyritic texture. In general, however, they are almost aphanitic, with only occasional phenocrysts of glassy feldspar up to 1 cm. in size, or of pyroxene in small dark needles, or crystals of one of the sodalite group of minerals. When fresh they are usually dense and dark gray or greenish, with often a dull greasy appearance. Most of them have a platy structure or fissility, which often aids in distinguishing them from other varieties, and which in some cases, particularly in narrow dikes, becomes pronounced.

With the exception of the Beacon Hill mass, which is considerably altered, the larger bodies are comparatively fresh. Few of the dikes, however, are unaffected at the surface by the atmospheric agencies. Decomposition effects a bleaching and exaggerates the fissility. Incipient weathering causes the rocks to assume a grayish color, and on more complete change they become light yellow or greenish yellow, or at times reddish. Oxide of manganese sometimes imparts to much decomposed rocks a brown color distributed either throughout their mass or as a coating along cracks and joints.

Of this prevailing appearance there are one or two noticeable modifications. Some of the rocks are mottled by small lighter-colored spots or blotches, usually drawn out in the direction of the fissility, and probably caused by a slight decomposition of the feldspar microlites in those places. In other cases the mottling is due to small dendritic patches rich in ægirine needles. Textural modifications are of two kinds. The most fissile rocks frequently contain small narrow druses, and in these cavities sharp trapezohedral crystals of colorless or yellowish analcite may often be seen. The second modification, which frequently accompanies the first, is caused by the development of megascopic nephelines. This mineral then occurs in stout hexagonal columns up to 2 mm. in size, possesses the usual oily luster, and is commonly red. Phonolites of this type occur on the western slope of Rhyolite Mountain, on the hill west of the town of Cripple Creek, and on Grouse Hill and Straub Mountain. When they weather, nepheline is one of the first constituents to be attacked and is readily removed, giving to the resulting mass a characteristic pitted surface.

MINERALOGICAL CHARACTER.

The characteristic mineral constituents of these phonolites are alkali feldspar, nepheline, sodalite, nosean, analcite, ægirine, and ægirine-augite. As accessory minerals occur titanite, apatite, magnetite, and occasionally small amounts of a blue amphibole, biotite, and zircon. Olivine occurs very sparingly in one rock. A few minerals are present in grains so small as to be indeterminable.

Feldspar.—The feldspars are limited to the potash-soda varieties. In fresh rocks the phenocrysts are clear and glassy. They are usually tabular parallel to well-developed clinopinacoidal faces. Other crystallographic boundaries are in general only poorly defined, though occasionally smooth faces parallel to the base and, still less commonly, good orthopinacoids are seen. Intersecting cleavages are nearly always apparent, the basal being a little more prominent than the clinopinacoidal. Carlsbad twinning is prevalent and in one rock mass the Baveno law also is exemplified. No indication of polysynthetic twinning nor of microperthitic intergrowth was observed. The feldspars of the groundmass present two definite habits, with probably all gradations between. In some rocks they are typically microlitic, being developed in rude laths parallel to the edge 010:001. Cross sections are nearly equidimensional, but as in the phenocrysts the clinopinacoid is more perfect than the base. Carlsbad twinning is almost universal and a transverse parting, probably parallel to an orthodome, is often observed. In other rocks, and at times even in parts of the same section with the microlitic feldspars, the groundmass is a granular aggregate of feldspar grains which utterly lack definite crystallographic faces.

Both the porphyritic and the groundmass feldspars are, so far as observed, monoclinic. Although Cross mentions the presence of anorthoclase, no indication of triclinic character could be detected. Sections from the orthodiagonal zone exhibit cleavages at right angles, with extinction parallel. In sections from this zone which are cut perpendicular to a bisectrix, it is ascertained that the axial plane is in the usual position—at right angles to the clinopinacoid—that the ortho-axis is the bisectrix of least elasticity, and that the feldspar is optically negative. Sections parallel to the clinopinacoid show the perpendicular emergence of $\mathfrak{c}$, and a maximum extinction angle relative to the trace of the basal cleavage of about $+9°$. The maximum double refraction is always low and the refractive index is noticeably lower than that of Canada balsam. These feldspars then appear to be entirely homogeneous and monosymmetric. The relatively high extinction angle in clinopinacoidal sections may be attributed to normal isomorphous replacement of potash by soda. The feldspars of these rocks may therefore be called soda-orthoclase.[a]

The most abundant product of hydrometamorphism of the phonolite feldspars is kaolin, probably accompanied by a little finely divided silica. The groundmass feldspars are frequently less kaolinized near individuals of ægirine than elsewhere. In certain rocks, however, some of the phenocrysts have been partially changed into a colorless isotropic material, of lower index than the feldspar, which is probably analcite. This alteration is not seen in very much decomposed rocks. The analcite almost always occurs in patches within the feldspar crystal, and the process by which it is formed is not revealed. Close to mineral veins the feldspars are partially changed to sericite.

[a] Cf. Pirsson, L. V., Am. Jour. Sci., 3d ser., vol. 47, 1894, p. 342.

PLATE VII.

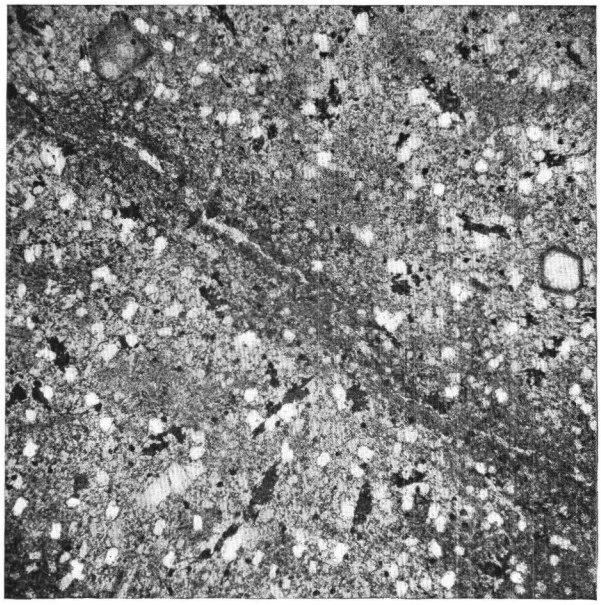
Photomicrographs of Phonolite.

A, Phonolite (456 C. C.) from northern slope of Big Bull Mountain. Composed of soda-orthoclase, nepheline, nosean, sodalite, analcite, and ægirine. Characteristic texture due to abundance of nepheline. Veinlet crossing the plate is filled with analcite. Ægirine in small needles is particularly abundant near the veinlet. Magnified 28 diameters.

B, Phonolite (209 C. C.) from summit of hill northeast of Cameron. Ragged individuals of ægirine inclosing prisms of nepheline and surrounding cores of ægirine-augite. Magnified 28 diameters.

C, Phonolite (455 C. C.) from hill east of Bull Cliff. Trachytic flow texture of groundmass and phenocrysts of soda-orthoclase and ægirine-augite. In the upper left-hand corner of the plate are crystals of nepheline inclosed by analcite. Magnified 28 diameters.

D, Phonolite (251 C. C.), 2,000 feet N. 30° E. of Copper Mountain. Nepheline (*N*) somewhat turbid through decomposition, and ægirine (*Æ*) inclosed in a large individual of primary analcite (*A*). Holes in the section are indicated by *H*. Magnified 28 diameters.



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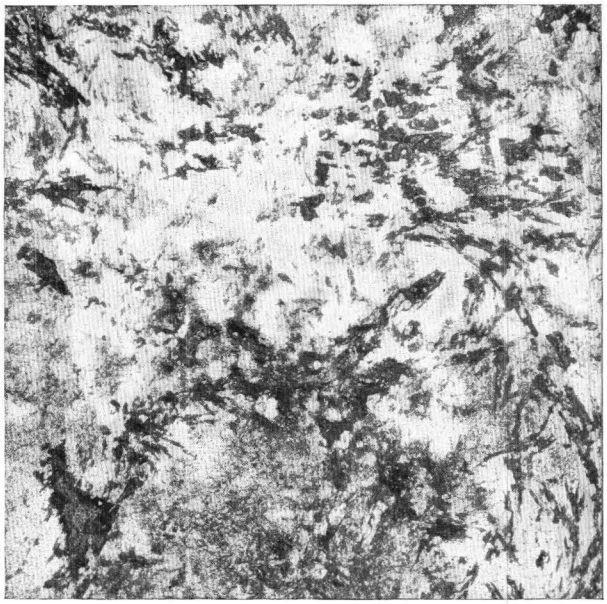

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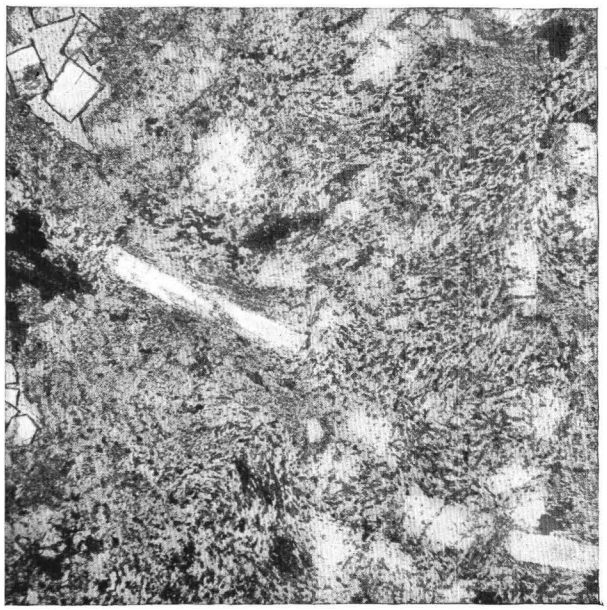

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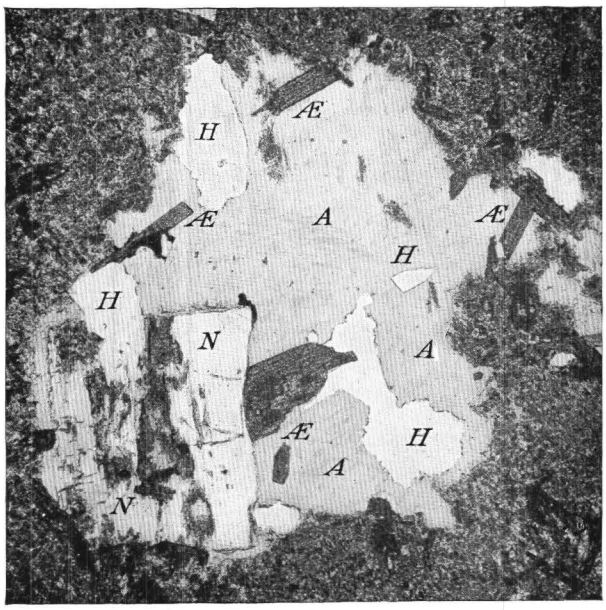

D

PHOTOMICROGRAPHS OF PHONOLITE.

Nepheline.—The distinctive mineral of these rocks, as of phonolites in general, is nepheline. It is a common constituent of every section studied and in several rocks makes up a large amount of the whole. It almost invariably exhibits automorphic development and occurs in the usual habit of hexagonal prisms bounded by basal planes. These crystals vary in size from 2 mm. down to a few thousandths of a millimeter. Their distribution through the rock is usually fairly uniform. The large crystals are naturally less abundant than the small ones. Nepheline appears to have cyrstallized at different times in different rocks. In some it is older than the feldspar and ægirine phenocrysts and was formed when the groundmass was still fluid. In other rocks it is limited wholly to the groundmass, where it occurs with and between the feldspar microlites. In the majority of cases, no matter how small its crystals, it is older than the ægirine phenocrysts and occurs thus as abundant minute inclusions in the pyroxene. Occasionally the nepheline incloses small needles of ægirine and blue amphibole. Particularly noticeable is the partial or complete surrounding of nepheline crystals by analcite, while at times the two minerals are mutually allotriomorphic.

In addition to its usual morphological and optical characters, the presence of nepheline is frequently indicated by the rock texture. Minute needles and interstitial grains of ægirine are commonly abundant in the groundmass, but seldom penetrate the nepheline, and the resulting numerous clear spaces, usually of rectangular outline, are often striking. Many of the larger nepheline crystals inclose numerous small flakes or scales of limonite or hematite, and this is doubtless the cause of their red color when viewed megascopically.

A peculiar feature of some of the nepheline of these rocks is its behavior between crossed nicols. In some rocks a part of the nepheline, frequently a portion of a definite crystal, appears in polarized light as an aggregate of irregular elongated grains having indistinct boundaries, resembling almost exactly the subtrachytic groundmass, of which it frequently seems to form a part. This appearance is most noticeable in the larger individuals, but on careful observation it is found to be a property of much of the nepheline. Intergrowth of nepheline and feldspar is at once suggested, but the refractive index seems to be absolutely uniform throughout the crystal. This reason and also the freshness of the nepheline in parts so affected exclude the possibility of alteration products as the cause. The only other plausible explanation of the phenomenon is that the nepheline is optically anomalous.

The common alteration products of this mineral are zeolites. They occur as small granular aggregates or as radially arranged fibers and cause the nepheline to become turbid. Their refractive index is low and they polarize more or less faintly, but in no case was their exact character determinable. Stilbite is probably one of these products. Cancrinite was not identified. In much-weathered rocks nepheline may be completely removed. Sericite sometimes develops as pseudomorphs after nepheline near the walls of mineral veins, often before the feldspars show any sign of alteration.

Sodalite and nosean.—Both chlorine-bearing and sulphuric anhydride bearing members of the sodalite group are important constituents of these phonolites.

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Owing to their similar properties and development they are not readily distinguishable. But careful study under the microscope, in connection with a consideration of the chemical analyses, leads to certain conclusions, which accord with microchemical tests performed by Cross. The variety bearing sulphuric anhydride is principally nosean, though an occasional decomposed crystal incloses a small grain of calcite when the remainder of the rock is almost carbonate free, and this may indicate the presence of hauyne. It occurs in clear-cut dodecahedral crystals from 0.1 to 2 mm. in size and often has a pale-bluish or greenish color, particularly when inclosed in feldspar. It is characterized by exceedingly small, dark inclusions arranged in two or more series of definite, parallel lines. These inclusions tend to be most numerous near the periphery of the crystal and sometimes fail entirely in the interior. At times, however, they are so abundant throughout that the mineral becomes almost opaque. Embayments due to corrosion are frequently observed. Sodalite is on the whole considerably more abundant than nosean and is sometimes a prominent constituent. It also occurs in dodecahedrons, but fully as commonly in forms which give square or elongated rectangular sections. Occasionally the crystals attain the size of the largest nosean individuals, but usually they are much smaller, sinking to less than 0.001 mm. in dimension. Regular gradation in size aids in making certain the identification of the smallest particles. The crystals usually show a clear outer border surrounding a dull-brownish interior whose color is probably due to inclusions.

These two minerals were among the very first to crystallize from the phonolite magma and in consequence occur as inclusions in all the other important constituents, though they are not common in nepheline. They lose their isotropic character on weathering and are transformed into a faintly polarizing aggregate of, probably, a zeolitic mineral. Sericite forms occasionally.

Analcite.—Lindgren[a] was the first to regard analcite as a primary constituent of igneous rocks, and with that view numerous later observers have concurred. Cross considered the analcite of the Cripple Creek phonolites to be primary, and this seems the only possible conclusion. Beside its occurrence in the drusy cavities as already described, this mineral is seen in irregular masses up to 1 mm. in size, which suggest filled cavities. In such places it is apt to be intimately associated with sharp, fresh crystals of nepheline and of ægirine. It also occurs in even the densest rocks as small veinlets, and here too ægirine is unusually abundant. In a few instances, as already remarked, it appears to have crystallized at about the same time as the nepheline, but it is generally seen to have been the last product to solidify. These rocks seem to have crystallized under pressure sufficient to retain water in the magma, and Cross concludes[b] that the analcite formed "when the excluded water contents of the magma had been concentrated by a kind of differentiation, in spots or along certain planes." Soda also appears to be concentrated in these places, as shown by the development of large nephelines and the especial purity and abundance of the ægirine. On account of the chemical composition of these parts of the magma, it appears that on holocrystalline development analcite is practically the only mineral known to exist in igneous rocks which could utilize the water and excessive soda.

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[a] Tenth Census, vol. 15, 1886, pp. 727–729; Proc. California Acad. Sci., 2d ser., vol. 3, pp. 51–57.

[b] General geology of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 36.

The analcite is always clear, frequently shows distinct cleavages at right angles, possesses the rough surface due to very low refractive power, and is practically isotropic, but frequently shows irregular patterns of the faintest polarization.

Ægirine and ægirine-augite.—These pyroxenic minerals are the only dark silicates of importance in the phonolites. Ægirine is the more abundant and is frequently present alone. It is purest and best developed where inclosed in analcite and there appears as narrow prismatic laths that are flatly tabular parallel to the orthopinacoid and terminated by low dome faces. Very small prism and clinopinacoidal faces may occasionally be seen in cross sections. The mineral occurs in varying amount in different rocks. It ranges in size from prismatic phenocrysts several millimeters long down to the most minute needles and irregular grains in the interstices of the groundmass. A common mode of occurrence is "as a grain elongated parallel to the prism, full of included nepheline and feldspar crystals, and with an outer zone which reaches out among the adjacent mineral grains as an oriented cement. It is frequently the case that the growth beyond the comparatively solid core is mainly on the ends. Sheaf-like bundles of curving and forking ægirine needles occur in some rocks, usually in the denser varieties, and the forms assumed are sometimes very delicate."[a] Ægirine laths are frequently seen wrapped around crystals of nepheline. Grains of magnetite are often the cores of ægirine individuals. Numerous irregular, disconnected grains, having similar optical orientaiton over a considerable distance, occur in lines or planes through the rock and along both sides of analcite veinlets. The optical properties are as usual for the species. The angle $\mathfrak{a}:\dot{\mathfrak{c}}$ is about 5°. The plechroism is intense: $\mathfrak{a}$ = blue green, $\mathfrak{b}$ = green, $\mathfrak{c}$ = greenish yellow to bright yellow, and $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$. Double refraction is high. The ends of some of the purer prisms sometimes show the brilliant yellows of acmite, and at times that variety occurs alone.

The combination of this soda-iron molecule in an augitic pyroxene is rather common. The resulting ægirine-augite occurs most frequently as solid cores to a surrounding mantle of ægirine. From the center outward the properties grade progressively from those of pale green, almost isochroic augite with extinction angle $\mathfrak{a}:\dot{\mathfrak{c}}$ of over 40°, to those of pure ægirine. The ægirine habit appears to dominate the crystals, although clinopinacoids are more developed than in ægirine.

The principal recognizable product of the alteration of these minerals is limonite. Carbonates sometimes result from the ægirine-augite.

Blue amphibole.—A blue mineral was observed by Cross in some of the phonolites and considered by him to be probably a soda-lime amphibole. Material recently collected shows the mineral with better development than in the specimens that he studied. It occurs mainly in stout prisms, usually much smaller than the maximum size of 0.1 mm. Cross sections have characteristic amphibole outline, bounded by prisms and prominent clinopinacoid faces, and occasionally narrow orthopinacoids. A section approximately at right angles to $\dot{\mathfrak{c}}$ gave a prism angle of 123° 40′. Prismatic cleavage is present as usual, but is less perfect than in commoner varieties and often can not be seen in the prism zone. In many cases the crystals have definite terminal planes consisting of the base, which makes an

[a] Cross, W., op. cit., p. 28.

angle of $\pm 73°$ with the vertical axis, and a negative orthodome which is less prominent and somewhat steeper. Low clinodomes are sometimes present, and in a few instances a negative orthodome is seen which is approximately perpendicular to the vertical axis.

Cross sections show that the axial plane occupies the normal position, in the plane of symmetry, and that one of the optic axes lies very near to the vertical axis. The maximum extinction angle observed was $\mathfrak{a}:\mathfrak{c} = +43° 30'$, $\mathfrak{a}$ lying in the obtuse angle β. The optical angle is therefore large, but the axis of greatest elasticity may bisect it acutely. Pleochroism is marked, as follows: $\mathfrak{a}$ = deep grayish or greenish blue, $\mathfrak{b}$ = dull olive, with sometimes a tinge of purple, $\mathfrak{c}$ = light yellow or greenish yellow. $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$, absorption along $\mathfrak{a}$ and $\mathfrak{b}$ being nearly equal. The index of refraction could not be determined definitely, but is about 1.65 to 1.70. The double refraction probably never exceeds 0.025. Axial dispersion is noticeable, but its character was not determined. The foregoing description applies to what seem to be the most distinctive and characteristic sections. The mineral appears to vary in composition, however, and in some sections the angle of extinction ranges from 20° at the periphery to over 40° at the center. Other well-formed crystals show uniform extinction $\mathfrak{a}:\mathfrak{c}$ = about 25°. In such sections the absorption colors are a little lighter and of slightly different character, $\mathfrak{a}$ = grayish blue, $\mathfrak{b}$ = dull olive, $\mathfrak{c}$ = light yellow. This last variety corresponds to the description given by Cross.

Its association throws considerable light on the chemical character of this mineral. It frequently occurs, like ægirine, as ragged patches filled with inclusions of nepheline and feldspar. At other times it is a more or less fibrous aggregate. It sometimes surrounds, sometimes is surrounded by individuals of ægirine. Minute poikilitic grains of ægirine are abundant, and in numerous cases a definite micropegmatitic inclosure of ægirine may be observed. It appears, therefore, almost beyond question, that this amphibole is chemically related to ægirine.

So far as known no one species yet described corresponds to this mineral. Its properties suggest a combination of two amphibole molecules analogous to ægirine-augite. Crocidolite is similar in some respects, but arfvedsonite agrees most closely, particularly with the variety of lower extinction, and may easily be one of the combining molecules, while the other one is unknown.

Other minerals.—Titanite occurs in the small lozenges or the lath-shaped forms it often assumes in phonolites. It is brown, shows strong absorption, and is often twinned parallel to the orthopinacoid (100). Apatite forms small hexagonal prisms and needles. A little magnetite is present in small grains, which often approach octahedrons. In some cases a grain of magnetite is inclosed at the center of an ægirine individual. A few foils of brown biotite of strong absorption occur in part of the Trachyte Mountain mass. Very small grains or rounded crystals of zircon may be seen in several rocks. Scattering grains of olivine, apparently as inclusions, and now showing resorption, occur in a rock collected by Cross from Rhyolite Mountain.

In several of the Cripple Creek phonolites is found a mineral whose identity is not certain. It has a development and distribution similar to ægirine, from which it is not always to be distinguished. "It occurs in minute needles, colorless

or pale yellowish, isolated or grouped in loose bundles. * * *. The needles reach a length of 0.1 mm. by an average diameter of but 0.015 mm. * * * In certain needles extinction takes place parallel to the prismatic axis, and in such cases there is no definite dichroism. In other needles there is an oblique extinction and here there is a strong, clear yellow color for the axis nearly normal to the prism, while that near ć is colorless, as before."[a] The mineral is therefore probably monoclinic, but owing to absence of definite cross sections in the slides examined its optical orientation can not be determined. Cross regarded the mineral as probably låvenite, and the unfailing presence of zirconia seems to support this view, for zircon does not seem to be sufficiently abundant to account for the amount of that oxide found. The weak pleochroism, however, and the impossibility of securing reliable data make any conclusion open to question.

Two additional minerals of uncertain identity occur in almost the same manner. They are sparsely scattered through the groundmass and resemble the irregular grains and patches of interstitial ægirine. Both are colorless in the minute grains seen, and in both the refractive power is noticeably high. One has moderate double refraction and extinction, sometimes parallel and at other times over 40°. Its properties suggest a pyroxene, but in its mode of occurrence it does not correspond to that mineral. The other mineral has a similar arrangement of elasticity axes, but the double refraction is high. Except for the oblique extinction it resembles zircon.

A mineral of brownish-yellow color is closely associated and sometimes intergrown with the blue amphibole in slide rock northeast of Copper Mountain. It occurs in aggregates of minute grains, which appear to be rudely rectangular. The index of refraction is below that of the blue amphibole, while the double refraction is somewhat higher and extinction is parallel. Further determination was impossible.

Two unknown minerals occur included in some of the analcite. One is present in minute, irregular particles, arranged as streams across the analcite grains or crowded near the margin. It has higher index than the analcite and polarizes very faintly. The other mineral occurs as exceedingly small needles extending into the analcite from surrounding mineral grains. It has rather high index, high double refraction, and parallel extinction.

Besides the alteration products already mentioned in the description of the important constituents, carbonates, fluorite, and pyrite frequently occur as secondary minerals near veins.

TEXTURE.

Since texture is very largely dependent on the development of the component minerals of a rock, the texture of these phonolites has already been partly described. The rocks are holocrystalline and porphyritic, though phenocrysts are often rare. The groundmass consists of feldspar microlites with interstitial grains of sodalite, ægirine, and the two unknown minerals of ægirine-like habit. Flow structure is

[a] Cross, W., General geology of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 30-31.

nearly always to be seen, but it is obscure or pronounced according to the development of the second-generation feldspar. Automorphic development of the feldspars of the groundmass produces the typical trachytic texture which is characteristic of these rocks. In several cases the groundmass feldspars are of poor crystallographic form, and then usually associated with small nepheline grains, the resulting texture approaching microgranular.

CHEMICAL CHARACTER.

The chemical nature of the phonolite magma is expressed in the following analyses by W. F. Hillebrand, to which is added the analysis by L. G. Eakins, of a bowlder found a few miles north of Cripple Creek, and described by Cross.

Analyses of phonolites from Cripple Creek.[a]

	I.	II.	III.	IV.	V.	VI.
SiO_2	58.98	58.78	59.00	58.64	58.85	60.02
Al_2O_3	20.54	20.03	20.07	19.62	20.06	20.98
Fe_2O_3	1.65	1.87	1.58	2.17	1.83	2.21
FeO	.48	.49	.65	.42	.51	.51
MgO	.11	.16	.10	.37	.18	Trace.
CaO	.67	.83	1.05	1.24	.95	1.18
Na_2O	9.95	9.36	8.34	8.39	9.01	8.83
K_2O	5.31	5.50	5.63	5.26	5.43	5.72
H_2O-	.19	.31	.24	.34	.27	.70
H_2O+	.97	1.57	2.03	2.40	1.74	
TiO_2	.24	.29	.29	.20	.25	.....
ZrO_2	.20	.17	.20	.09	.16	.....
CO_2	.....	.....	.26	.23	.12	.....
P_2O_5	.04	.03	.05	.03	.04	Trace.
SO_3	.20	.12	.07	Trace.	.10	.....
Cl	.288	.58	.24	.14	.31	.....
MnO	.26	.15	.12	.20	.18	.....
BaO	None.	None.	Trace.	Trace.	Trace.	.....
SrO	None.	None.	None.	Trace.	Trace.	.....
Li_2O	Trace.	Trace.	Trace.	Trace.	Trace.	.....
	100.07	100.24	99.92	99.74	99.98	100.15

I. Miter Peak, south-southwest of Grouse Hill.
II. One mile south of Straub Mountain.
III. Dike. Northeast slope of Big Bull Mountain.
IV. Dike. Southwest slope of Rhyolite Mountain.
V. Average of the preceding four analyses.
VI. Between Cripple Creek and Florissant, Colo. Cross, W., Proc. Colorado Sci. Soc., vol. 2, 1887, p. 167.

A noticeable feature of these analyses is their very close agreement, though they represent rocks from separated localities and of markedly different appearance.

The most striking chemical feature is the richness in alkalies and the low amount of bivalent bases. In these respects the Cripple Creek rocks possibly surpass the average phonolite. The ratio of potash to soda is rather greater than usual. The considerable amount of combined water is accounted for by analcite. Of phonolites described from other localities, the most similar are from the Black Hills, South Dakota. The rocks from these two areas show many mineralogical as well as chemical likenesses.

[a] Cross, W., Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 38, 39.

A calculation of the average analysis, No. V, gives a good idea of the relative amounts of the various minerals present:

Mineral composition of phonolite.

Soda orthoclase	51.19	Apatite	.09
Nepheline	11.27	Titanite	.61
Analcite	11.41	Magnetite	.48
Nosean	.89	Other minerals, hygroscopic water, water of hydration, etc	3.01
Sodalite	4.25		
Ægirine	4.16		
Augite	2.64		100.00

This computation is complicated by the presence in the rocks of kaolin, a little sericite, and perhaps a small amount of zeolites, resulting largely from the feldspar. Careful examination of thin sections of the specimens analyzed led to the conclusion that not more than 0.75 per cent H_2O on the average has been introduced by the hydration of original minerals.

The ratio of K_2O to Na_2O in the soda-orthoclase was assumed to be 33.57:17.32, or approximately 2:1.

The nepheline was considered free from potash.

The following composition was assumed for augite: CaO, MgO, FeO $(Al,Fe)_2O_3.3\ SiO_2$, Al:Fe″′ being 4:1.

It is probable that the titania is not present wholly as titanite, but occurs mainly in other minerals.

The zirconia forms very little zircon and probably is mostly united in other minerals.

SUMMARY.

From the preceding discussion it is obvious that the phonolites of the Cripple Creek district are a particularly well-defined group of rocks, and that chemically, mineralogically, and texturally they are typical of the recognized phonolite family.

LEUCITOPHYRE (?).

In examining a thin section of a specimen of breccia from the dump of a shaft about a quarter of a mile north of the Mint mine, on Gold Hill, there was observed a small fragment of a rock which has not been seen elsewhere in the district. The hand specimen shows a fairly coarse breccia with much granite and latite-phonolite and two fragments of a fine-grained, purplish-brown rock, which holds an occasional small phenocryst of feldspar and in which the hand lens reveals, in addition, abundant minute whitish specks evenly distributed through the mass. Under the microscope the rock shows considerable alteration. The feldspar phenocrysts have a patchy, uneven extinction and are either microperthite or anorthoclase. The most conspicuous constituent is the mineral observed by the hand lens. It forms crystals of sometimes square and sometimes hexagonal, but usually octagonal, outline, which attain a maximum size of 0.5 mm. The original material is decomposed into a zeolite of weak refractive power and low aggregate polarization. The mineral can have been only leucite or analcite. In those rocks which contain phenocrysts of analcite, the analcite is seldom abundant and generally occurs in

good-sized individuals of imperfect crystal outline. But the mineral in question is abundant in sharp crystals of small size, and hence is probably not analcite. On this account, as well as because of the general character of the rock in which it occurs, the mineral is considered to be leucite. A number of small rectangles of nepheline, now somewhat altered, occur in groups here and there. A few grains now replaced by carbonate suggest the original presence of a sodalite mineral. The outlines of what were probably pyroxene phenocrysts are preserved in a few cases. Several good-sized grains of magnetite are present. The groundmass is quantitatively important, but now much decomposed. The only recognizable constituent is orthoclase in narrow laths. The interstices between the feldspar are turbid and stained deep brown, probably by iron, which may have resulted from the oxidation of minute grains of ægirine such as occur in the phonolites. The texture is trachytic, with fluidal structure imperfectly shown, and with a trace of intersertal texture suggests a relation to basalts.

This rock could probably never have been present in great amount or it would have been detected elsewhere. The existence, however, of even a small amount of a potash-rich leucite rock as a product of a magma essentially sodic[a] is of more than passing interest.

LATITE-PHONOLITE.

GENERAL DESCRIPTION.

Necessity for a new division.—There are present in the Cripple Creek district numerous intrusive masses which give evidence of close relationship. They are composed of rocks, similar or identical in appearance, which study shows to be so closely related that they constitute a definite and distinct rock type. Although this type shows certain mineralogical and chemical relations to phonolite, trachyte, latite, and trachydolerite (or essexite), and although its extreme facies, if considered by themselves, might, perhaps, be placed in some of these well-known families, nevertheless when account is taken of the close interrelation of all the facies it becomes plain that even the extremes are bound more closely to one another than to somewhat similar rocks within the near-by divisions. This type, therefore, though well defined, does not correspond with any of the rock groups generally recognized, but instead occupies an intermediate position. In view of the principal relationships which these rocks show and which it is desired to emphasize, they have been given the name latite-phonolite.

Definition.—It is proposed to apply the name latite-phonolite to those porphyritic rocks which have a composition intermediate between that of phonolite and that of latite. To make this term definite and specific it will be well to give exact definitions of both latite and phonolite. Phonolite is used, in the sense already employed, to designate a rock containing high alkalies and alumina with moderate silica and low bivalent bases, characterized by the presence as phenocrysts of alkali feldspar, nepheline, and an alkali pyroxene. Latite,[b] a rock intermediate between trachyte and andesite, and the porphyritic equivalent of monzonite, contains moderate amounts of silica, iron, magnesia, and lime, plentiful alumina, and notable alkalies of which potash is most prominent, and is commonly

[a] See p. 113.

[b] Ransome, F. L., Am. Jour. Sci., vol. 5, No. 29, 1898, p. 372.

characterized by phenocrysts of soda-lime feldspar and ferromagnesian silicates in a groundmass rich in potash.

Latite-phonolite differs from phonolite in having lower alumina and alkalies and more iron, magnesia, and lime. It differs from latite in having somewhat lower silica, iron, magnesia, and lime, and higher alumina and alkalies, with soda predominant over potash. It is intermediate between latite and phonolite, chemically, in having each essential oxide present in an amount which lies between the average present in latite and that in phonolite; mineralogically, in that the amount of minerals high in alumina and soda—such as nepheline—of the phonolites is smaller in the latite-phonolites, that part of the alkali feldspar of the phonolites unites with the lime-rich feldspars of the latites to give a rather alkalic plagioclase, and that the dark silicates are intermediate in composition between those of phonolite and those of latite. The group thus broadly characterized shows, as is not uncommon in high alkali rocks, a notable prominence of lime over magnesia.

Such a composition, of course, allows the development of orthoclase and albite molecules, and the considerable lime, low magnesia, and plentiful alumina necessitate the formation of a comparatively small amount of the anorthite molecule. Both orthoclase and sodic plagioclase are thus characteristic minerals of this group. For true phonolite nepheline is considered one of the essential components, but in this group, at least, it seems desirable to make the distinctions chemical rather than mineralogical by giving to each of the minerals analcite, sodalite, and nosean a classificatory rank equal with nepheline. The last two minerals have practically the same ratios of silica, alumina, and soda as nepheline, and in analcite only the silica is a little different; it is probably only because of the presence in the magma of water, chlorine, or sulphuric anhydride, respectively, that these minerals form instead of nepheline. Pyroxene or amphibole are common constituents. They are often alkalic, always low in magnesia, and contain a large percentage of the total lime of the rock. Mica, if present, must, on account of the low magnesia, be an iron-rich variety, like lepidomelane. Apatite and sphene are often noteworthy accessories and help to utilize the lime.

The characteristic minerals of the latite-phonolites are therefore orthoclase, sodic plagioclase, a soda feldspathoid (including analcite), and some mineral of the pyroxene, amphibole, or mica groups. The proportions of essential oxides considered to represent a typical latite-phonolite are here given:

Typical composition of latite-phonolite.

SiO_2	55.00	MgO	1.00
Al_2O_3	19.00	CaO	4.00
Fe_2O_3, FeO	4.50	Na_2O	6.50
		K_2O	4.50

These rocks show affinities to several surrounding types besides phonolite and latite. The relation to trachyte is in many ways very close. In fact, the term trachyte-phonolite is almost as correctly applicable to these rocks as latite-phonolite. Silica is lower than in trachyte and alumina and ferric iron a little higher, while lime is noticeably more abundant. The amount of alkalies is slightly greater, but the ratio of soda to potash is inverted. These chemical differences from trachyte

reveal themselves principally in the presence of lime-bearing feldspars and of nepheline, analcite, sodalite, or nosean, minerals which contain a higher ratio of alumina and alkalies to silica than the alkali feldspars. The alkali-syenite porphyries of Rosenbusch show close relationships to this group. The trachyphonolites or oligoclase-sanidine phonolites of Boricky[a] are very similar and would be included in this type. The monzonite-porphyries differ, of course, in the same way as their equivalents, the latites, having lower alumina and alkalies and notably higher magnesia. The trachydolerites (or essexite porphyries), which partake in part of the alkaline character of phonolite, though richer in bivalent bases than latite, present certain relations to this type.

The latite-phonolites of the Cripple Creek district include the trachytic phonolites, syenite porphyries, and andesites described in the earlier report. The recent study, with its greater advantages, has shown the impossibility of making such a separation. Individual rock masses frequently exhibit as wide variations as are found in the whole group. Although these rocks are decidedly variable in texture, and not exactly identical in composition, all the evidence—areal, structural, macroscopic, microscopic, and chemical—goes to prove that they are intimately related and are variants of a well-defined rock type. The connection of these latite-phonolites with the true phonolites of the district, as shown by the transition members and by the chemical composition (see p. 79), is an interesting feature, and since latites are absent in the district and it is desired to bring out the close connection between all these volcanic rocks, this relation to the phonolites rather than to the latites is emphasized in the following description. In the other direction these rocks grade texturally and constitutionally into the essexitic syenites, which are described on page 84. They are holocrystalline porphyries made up of monoclinic and alkali-rich triclinic feldspars, abundant pyroxene, and analcite, sodalite, or nosean, while amphibole and biotite are often present. A biotite facies of trachytic composition is described on pages 77–78.

Occurrence.—These rocks are less abundant than the phonolites in the Cripple Creek district and are found principally in the vicinity of the volcanic center. Like the phonolites, they are in part older and in part younger than the breccia. They rarely occur in the outlying granite, and then only as small dikes. Large intrusive masses, of which many are now reduced in size through brecciation, occur in and on the slopes of the amphitheater between Battle Mountain, Bull Cliff, and Bull Hill and extend over on the southwestern slope of the latter. Bodies of considerable size also occur on the southeastern slope of Battle Mountain, on the northeastern sides of Bull Hill and of Bull Cliff, on the gentle slope north of Big Bull Mountain, and south of the summit of Gold Hill. Mine workings show that a number of these large masses are flat and that in some cases they have a greater extent than their surface exposures would indicate. In one case, that of the crescentic mass near the Isabella mine, the latite-phonolite body narrows rather rapidly to a dike about a thousand feet below the surface. Smaller masses or irregular dikes are found near Anaconda and near the Gold King mine in Poverty Gulch and are seen in several other places underground.

[a] Archiv der Naturwiss., Landesdurchforschung von Böhmen, vol. 3, pt. 2, 1884, pp. 42–49, 60.

Appearance.—The latite-phonolites are dark-gray to black rocks, usually of rather fine grain. They are porphyritic in texture and contain small prismatic phenocrysts of pyroxene and tablets of feldspar up to 2 cm. diameter. Small scales of brown biotite are observable in some varieties, and fresh, smoky apatites in short hexagonal crystals up to 2 mm. diameter in cross section are frequently seen. Occasional small, resin-yellow crystals of titanite are apparent in hand specimens. The groundmass is compact and dark in color. Some of the rocks, however, appear to be granular, and only with the aid of the microscope are found to contain a microlitic groundmass. This phase marks the gradation into the granular syenites. Small included fragments of syenite appear in the zone of transition to the granular rock. In some specimens these inclusions appear to be partially dissolved and absorbed by the surrounding rock, which there contains more hornblende—a prominent mineral of the inclusion—than elsewhere.

Upon weathering the feldspars and the groundmass become dull and lighter colored, giving a gray color to the rock. More complete change usually produces a light yellow color, as in the phonolites, and at such times the pyroxene phenocrysts may be entirely removed, giving the characteristic porous or pitted appearance seen near the Blue Bird mine. Even in the most decomposed portions apatite remains fresh and glassy and often serves to identify the rock.

MINERALOGICAL CHARACTER.

General statement.—The essential minerals of these latite-phonolites are alkali and soda-lime feldspars, analcite or sodalite or nosean, pyroxene, both augite and ægirine-augite, and a brown hornblende. Biotite sometimes becomes important and produces a type somewhat different from the common one. The close relation to the true phonolites is shown among other ways, by the presence of nosean, sodalite, and analcite. Titanite, apatite, and black iron ore are noteworthy accessories and a few minerals present in smaller amount will be mentioned and briefly described later. Among the decomposition products are kaolin, sericite, chlorite, serpentine—and possibly talc—epidote, green mica, rutile, quartz, and carbonates.

Variations in the mineralogical character of this group make it more complex than the phonolites; but as will be seen later, the chemical composition is notably constant, and therefore requires a nice equilibrium between the amounts of the alkali-rich and the iron, magnesia, and lime-bearing minerals. The presence of nosean, sodalite, or analcite is offset by an increase in pyroxenes or hornblende and a decrease in feldspar. The groundmass feldspars are almost without exception alkali-feldspar. When the feldspar phenocrysts are abundant, they are usually rather alkalic; when decidedly calcic, they are never numerous.

A decrease in the amount of bivalent bases and consequent increase in silica causes the ferric iron to enter largely into the formation of a brown mica, which must therefore correspond to the variety lepidomelane. The rock thus produced is rather different from the pyroxene-rich type and while showing close chemical affinities is distinguished by the name biotite trachyte. It occurs on the northern slope of Battle Mountain and the northwestern slope of Mineral Hill. Varying amounts of botite in the more typical latite-phonolites show the close relation of the two varieties.

Feldspar.—Orthoclase is common in phenocrysts from 0.05 up to more than 1 cm. in size. Columnar crystals parallel to the clino-axis have fairly good basal and pinacoidal faces. Tablets parallel to the clinopinacoid are usually of poor crystallographic outline, though the base is sometimes well developed. Carlsbad and occasionally Baveno twinning is seen. Cleavage appears to be less perfect than in the phonolites. The angle of the position of extinction with the basal cleavage sometimes indicates soda-orthoclase. The usual product of decomposition is kaolin, while sericite forms near mineral veins.

Several species of triclinic feldspar occur as phenocrysts. Microcline is present sparingly in a few rocks. Microperthite, with its characteristic patchy and flaky extinction, is frequently seen. A few individuals may be referable to anorthoclase, but not with certainty. The most important phenocrysts of these rocks belong to the ordinary plagioclase group, and range from albite to labradorite inclusive. The variety which is by far the most plentiful appears to correspond to a composition between albite and oligoclase, while species more calcic than oligoclase are uncommon. Calculation from analyses shows that only about 1 per cent of the total lime of the rock enters into the plagioclase. The phenocrysts are usually tabular parallel to the brachypinacoid and have rather imperfect crystallographic boundaries. In some cases, however, they occur as stout prisms bounded by well-developed pinacoids, base and macrodome. Albite twinning is almost invariably present, but because of the frequency with which clinopinacoidal sections showing no twinning are met, the importance of plagioclase is at first underestimated. Carlsbad and pericline twinning sometimes also occur, and in one case albite and Baveno twinning occur in the same individual. Zonal structure is very common. The change is gradual and uniform and follows the usual order of solidification. Particularly in those rocks with abundant feldspar phenocrysts and subordinate groundmass it is common to find the plagioclase bounded by a zone filled with minute gas bubbles and opaque inclusions, and then surrounded by a narrow rim of clear orthoclase. This orthoclase mantle appears to develop more on the pinacoids than on the base, sometimes leaving the latter face wholly uncovered. Occasionally a micropegmatitic or perthitic intergrowth of plagioclase and orthoclase is observed. Small brownish isotropic patches of irregular form occur without definite distribution through some of the larger individuals and represent inclusions of glass. Microlites or small irregular grains of pyroxene are sometimes also included in the plagioclase.

Kaolin is the chief product of weathering. Epidote results under certain conditions from alteration of the calcic feldspars. A very interesting decomposition results in a pseudomorphic change of the feldspar into a colorless isotropic material of low refractive index. The transformation begins along cracks and cleavages, forming a meshwork around unaltered kernels, and in most specimens the plagioclase has been entirely replaced. This decomposition has been noted only in those plagioclase individuals which are surrounded by the mantle of orthoclase, and in every case the monoclinic feldspar remains clear and unaltered. When a thin section containing this decomposition material was warmed with dilute hydrochloric acid and then treated with fuchsine, the area within the orthoclase rims absorbed the dye. This test strengthens the conclusion drawn from the

optical properties—that the mineral is analcite. In some cases grains of calcite are embedded in the analcite and probably owe their existence to the presence of lime in the original feldspar.

Another decomposition product of the feldspars, perhaps both orthoclase and plagioclase, appears as a foliated or fibrous mass usually oriented parallel to some face of the feldspar phenocryst. It is colorless, has a refractive index somewhat higher than that of Canada balsam, and gives parallel extinction and interference colors in yellows and reds of the first order in sections of usual thickness. These properties and the mode of occurrence correspond to alunite. But a test of a rock in which it was abundant failed to give a reaction for sulphuric acid, and alunite is hence excluded. The mineral corresponds in some ways to hydrargillite, but its identity is not established. Sericite results to some extent from the plagioclase also in the vicinity of mineral veins.

Of the groundmass feldspars, orthoclase is by far the most abundant. Albite specimens are present in a few. The habit of these youngest feldspars is similar to that in the phonolites. The lath forms are most common, but small flakes of iregular outline are often observed.

Pyroxene.—This mineral group is an important constituent of the latite-phonolites. Phenocrysts up to 1 cm. or more in cross section, frequently as anhedrons,[a] but more often of definite crystal form are, because of their habit, and the composition of the magma, necessarily augite. They are usually of pale green color, slightly pleochroic to light greenish yellow. Prismatic cleavage is fairly well developed. $\mathfrak{c}$: $\dot{\mathfrak{c}}$ is always over 40° and frequently rises to 58° or 60° in which case the colors are deeper, the pleochroism more marked, and the mineral becomes ægirine-augite. The interference colors are rather high. Arrangement in zones of slightly different composition is a rather common feature, and twinning parallel to the orthopinacoid is not unusual. Large individuals sometimes inclose grains of feldspar, and in certain instances an interpenetration with hornblende is well shown.

Pyroxene is generally abundant in the groundmass. In some specimens it occurs in little bundles and sheaves of green needles and grains, much as in the phonolites. In a few others it forms narrow laths with intersertal distribution. The most common occurrence is as microlites and small rounded grains rather evenly scattered among the groundmass feldspars.

The most common alteration is to carbonates, black iron ore, and chlorite; occasionally quartz also may be seen. Serpentine is sometimes a product, epidote forms at times, and not infrequently a mass of light-green secondary mica (described on p. 77) replaces and retains the form of the pyroxene individual.

Hornblende and biotite.—Hornblende is not unfailingly present, but usually occurs in individuals of fairly good form and moderate size. Occasionally it becomes quite prominent. It is strongly pleochroic in browns and yellows and shows absorption as follows: $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$, $\mathfrak{c}$ and $\mathfrak{b}$ often being not very different. Cleavage is distinct as usual. Twinning is not uncommon. The maximum extinction angle in clinodiagonal sections is 26°. Intergrowth with pyroxene is common and sometimes the latter is completely surrounded by a fairly even rim of hornblende. Corrosion has

[a] Pirsson, L. V., Bull. Geol. Soc. America, vol. 7, 1896, p. 492.

sometimes taken place and resorption, or magmatic alteration into pyroxene and magnetite, is a usual phenomenon. The borders of pyroxene grains sometimes have the same orientation as the hornblende core, but are as frequently without definite arrangement. They seem to have about the same composition as the original augite. Magnetite is less plentiful in the rocks containing considerable unchanged hornblende. Chlorite, serpentine, and the secondary green mica often result from decomposition.

Biotite is frequently absent, but in many specimens occurs sparingly. In a few varieties it becomes the predominant ferro-magnesian constituent owing to a slight variation in the chemical character of the rock, as already noted (p. 71). It is probably related to the variety lepidomelane. It is reddish brown, with strong absorption and sensibly parallel extinction. Corrosion is common and frequently the foils are bent or broken. Resorption with the production of abundant magnetite, a little pyroxene, and probably some feldspar, occurs in most rocks which contain it. Chlorite and the green mica are common alteration products.

Nosean, sodalite, and analcite.—As has been stated, these minerals are of interest as indicating a close relation of these rocks to the phonolites of the district. It may also well be repeated that in those rocks in which these minerals are at all plentiful the richness in alkalies which they indicate is offset by a greater abundance of the lime and ferromagnesian minerals than in the phonolites. In a very few specimens none or only a slight amount of these minerals has been detected.

Nosean is present in many rocks and occurs as in the phonolites in phenocrysts of good size, usually with the grill-like inclusions. It is often decomposed into a more or less faintly polarizing aggregate, probably of zeolites. Other decomposition products are analcite and sericite. The occasional presence of grains of calcite among the decomposition products in rocks which do not elsewhere contain much calcite may indicate that some hauyne is present.

Sodalite is found in all the nosean-bearing rocks and in a few others. It is almost always in the form of minute grains or crystals between the other groundmass crystals, or included in the larger feldspars, but occasionally attains sufficient size to be regarded as a phenocryst, and then shows a clear border and a brown center crowded with inclusions.

Analcite is of still more general distribution and occurs usually in irregular interstitial grains of small size. In a very few cases it occurs in individuals which may be idiomorphic, but with this exception its mode of occurrence and properties are exactly as in the phonolites. Small, sharp crystals of augite and of titanite which occur embedded in it sometimes entirely separated from other constituents necessitate the same conclusion as to its origin as was reached in the treatment of the phonolites—that is, it is a primary or original constituent of the rock. The analcite derived from the decomposition of feldspar is of course wholly distinct in origin and mode of occurrence.

Apatite.—This mineral is always present to some extent, usually associated with iron ore, and often occurs in numerous crystals of notable size. It forms stout hexagonal prisms up to 2 mm. in cross section, and is usually terminated by the unit pyramid and sometimes also by the basal pinacoid. Shapeless, irregular grains are not common, but well-formed crystals have sometimes been corroded. In many

rocks the apatite crystals are crowded with minute inclusions, which probably give the smoky color to the mineral in the hand specimens. A high power reveals considerable as to the nature of these inclusions. Some are approximately equidimensional and rarely reach the maximum diameter of 0.001 mm. From this shape they pass by all gradations to the most common form, that of exceedingly slender rods of a maximum observed length of less than 0.01 mm., and a cross section which is often no more than 0.00002 mm. in diameter and perhaps less. Their distribution throughout the crystals is not uniform. Near the prism faces they are always crowded and near the terminal planes they diminish in number to almost complete absence. Within the body of the crystal they may be very evenly disposed or on the other hand be so crowded about certain lines or along planes that portions of the crystal sometimes become opaque. Red or black irregular compact grains of small size but of much greater dimensions than those of the inclusions can often be seen, near the edges, to be thus built up of innumerable inclusion individuals so closely packed that they have coalesced. The larger or stouter forms are distributed mainly along lines or planes, which may be slightly curving and which from all appearances have no relation to crystallographic directions.

In spite of this lack of uniformity of distribution as regards number and size, they have a definite crystallographic arrangement or orientation. The larger inclusions can be seen to possess in general very perfect negative crystal form, though some are irregular. The slender forms have their long direction parallel to the vertical axis and are arranged in rows parallel to the three other axes.

Great numbers of the inclusions, particularly the larger, stouter ones, have a much lower refractive index than the apatite, and the width of their black borders suggests that they are fluid inclusions. This idea is confirmed by the presence, in many, of a minute round particle with a still broader black rim which can in some cavities be seen to be in constant motion and to be influenced by gravity and which is beyond question a gas bubble. Some cavities contain, in addition to the liquid and the gas, a tiny angular speck which is probably a salt crystal separated out from the liquid.

These inclusions, when obviously fluid, range from nearly or quite colorless through light yellows and reds to brownish yellow, brownish red, or deep red. Many of the long and very narrow ones seem to be composed of a solid material, which is sometimes red and sometimes black and opaque, with all gradations between. Examination of aggregates of these solid inclusions shows that they are composed of hematite.

The foregoing facts appear to justify the following conclusion: At the time of the formation of the apatite—that is, near the beginning of the crystallization of the magma—water was present in addition to the chlorine or fluorine, or both, of the apatite, and it held ferric iron and possibly other bases, in solution. Later a change of conditions caused a precipitation of part or all of the iron as hematite, and the small solid grains within the liquid may be crystals of a different material. The yellow colors may be due to more or less concentrated ferric solutions, maintained possibly by pressure or by a small amount of some reagent, such as chlorine. Depending on the amount of hematite which has been deposited on the walls of the cavity, the liquid appears more or less red or the inclusion seems to be wholly solid.

Many of the apatites thus filled with inclusions exhibit a noticeable pleochroism. E is violet and O is smoky brown, and the absorption is E>O.

Inclusions somewhat analogous in character and arrangement have been described in rock-forming apatites from Persia[a] and from Montana,[b] but in neither case were fluid-filled cavities mentioned. As observed in both these descriptions and also by Washington,[c] the abundance of inclusions in the apatite in these rocks appears to bear a definite relation to the degree of resorption of the hornblende, and in this case of biotite also. If the above assumption as to the origin of the inclusions in the Cripple Creek rocks is correct, there may be some connection between the excess of iron indicated in the inclusions and the later separation of magnetite in the resorption process.

In a specimen of the biotite trachyte from the Portland mine well-formed crystals of apatite, reaching a maximum diameter of about 1 mm., are rather common and on casual examination under the microscope appear to be of normal structure. In parallel light, however, indistinct traces of a fibrous structure are seen, and when the nicols are crossed the mineral polarizes in a peculiar manner, giving aggregate, feathery extinction due to minute fibers confusedly radiating from numerous centers or nuclei. The appearance is similar to that which often results from the filling of a cavity by quartz deposited from solution. The single and double refraction and other optical properties show that apatite is the only mineral present and no explanation of the phenomenon has been found.

Aside from these pecularities, the occurrence of apatite in these rocks is of considerable interest. The number and size of the crystals is rather unusual. A noticeable fact is that in the sodalite-bearing rock specimens of this group the amount of apatite is considerably less than usual. This may be due to some adjustment or equilibrium between soda, chlorine, and phosphoric anhydride. It is possible that there is a concentration of chlorine in the soda-rich (sodalite-bearing) varieties and of phosphoric anhydride in those holding less soda.

The presence of water (the liquid can hardly be anything else) in the inclusions is also of interest when taken in connection with the occurrence of primary analcite.

Titanite.—Although not unfailingly present, this mineral is a common accessory of the latite-phonolites, and sometimes is noticeably abundant. It occurs at times as irregular grains, but is more frequently idiomorphic in the diamond-shaped forms or the narrow laths, as in the phonolites. Some of the crystals reach a size of over 1 mm. The mineral has a brown color and the strong absorption sometimes amounts almost to pleochroism. Twinning is occasionally seen.

The manner of decomposition of the titanite of these rocks is rather interesting. At the outer edge of the crystal is formed a narrow rim of material, only slightly transparent, of very high refractive index and double refraction, which corresponds to rutile. Narrow arms of this mineral sometimes also extends across the inner portion of the crystal. Within this shell of rutile calcite is plentiful and frequently fills the entire cavity, but in many cases there is also present a small amount of a mineral of rather low double refraction and an index near that of Canada balsam,

[a] Blaas, J., Tschermaks Min. u. petrogr. Mittheilungen, vol. 3, 1880, pp. 477–479.
[b] Merrill, G. P., Proc. U. S. Nat. Mus., vol. 17, 1894, pp. 642–643.
[c] Washington, H. S., Magmatic alteration of hornblende and biotite: Jour. Geol., vol. 4, 1896, p. 279.

which exhibits aggregate fibrous polarization and can. with certainty be called chalcedony. These three minerals thus form a somewhat complex decomposition pseudomorph after titanite. (See Pl. XVII, *E.*) The alteration appears to take place with equal readiness away from and near mineral veins.

Other minerals.—Magnetite occurs rather abundantly, particularly in those varieties holding numerous small grains of pyroxene. There is in this fact a possible significance that the two minerals have resulted from the magmatic resorption of hornblende, but it seemed impossible to reach any conclusions as to this matter. The mineral occurs especially near crystals of apatite and is usually of later formation. Oxidation changes it more or less completely to hematite and often it furnishes on decomposition an opaque, nearly white, material whose identity could not always be established, but which is in some cases certainly a carbonate. Grains of partially decomposed black iron ore are sometimes surrounded by minute particles of titanite, indicating that part of the iron ore is titaniferous.

Small brownish crystals of zircon occur in a few varieties.

In one or two rock masses, particularly in the biotite trachyte on the western slope of Mineral Hill, small interstitial grains of primary quartz are evenly distributed through the groundmass.

The green secondary mica mentioned as a product of the decomposition of pyroxene, hornblende, and biotite does not seem to correspond to any of the varieties described in the text-books. It varies from deep grass-green through light and greenish yellows to strong yellow or yellowish brown, but is always distinctly separable by its color from ordinary biotite. It occurs uniformly as aggregates of small fragments, shreds, or fibers which sometimes have an imperfect radial arrangement. It is analogous to sericite in texture, but somewhat coarser grained. Pleochroism is noticeable in the deeper-colored masses. The polarization colors are sometimes rather lower than for either biotite or muscovite, but frequently are very brilliant and always have that peculiar character distinctive of the micas. Either it has a variable composition or it is built up by the addition or subtraction of substance in the minerals from which it forms, for it completely and pseudomorphically replaces pyroxene, hornblende, and biotite, and it is almost certain that those minerals do not have identical composition. This change is not limited to the vicinity of mineral veins where metasomatism is likely to take place, and it is consequently probable that the mineral is variable in composition.

Near mineral-bearing veins fluorite, carbonates, pyrite, and sometimes a little quartz and chalcedony may be introduced into the rock, either as isolated grains or as veinlets. In many cases, pyrite partially or completely replaces magnetite, and on that account a rock with considerable unaltered magnetite may usually be safely assumed to be at some distance from a vein.

TRACHYTIC FACIES.

As has been previously stated (p. 71), a rock which occurs on the northern slope of Battle Mountain and northwest of the summit of Mineral Hill differs in appearance from the ordinary latite-phonolite by containing numerous small flakes of dark-brown biotite. It is the same rock that was called augite-mica andestite by

Mr. Cross. Microscopical and chemical study indicate that, though the rock is closely related to the latite-phonolites, it does not conform to the type as do the other varities, and the differences are sufficient to put it with the trachytes; it is called a biotite trachyte. The Battle Mountain mass appears to be an intrusion distinct from the latite-phonolites, but many of the latter contain biotite in amounts reaching considerable importance.

This biotite trachyte contains numerous phenocrysts of feldspar, orthoclase, albite, microperthite, and oligoclase or oligoclase-albite being present in decreasing amount. Biotite is abundant in scales 1 or 2 mm. across, which are sometimes bent and frequently show the common magmatic alteration into augite and magnetite. As has been shown on page 74, from the chemical character of the rock this mica must be an iron-rich species, probably related to lepidomelane. Phenocrysts of augite are occasionally present. Apatite and sphene are rather common in crystals of more than ordinary size and grains of magnetite are numerous. Small interstitial grains of quartz occur sparingly in the Mineral Hill rock. Very little analcite, sodalite, or nosean has been detected in most specimens. The groundmass is imperfectly trachytoidal and consists almost wholly of orthoclase. The chemical character of this rock, showing its trachytic nature and its relation to the latite-phonolites, is expressed in an analysis given with those of the latite-phonolites on the next page.

TEXTURE.

These rocks all contain a more or less important groundmass made up of feldspar and pyroxene microlites and grains and of particles of iron ore, with sometimes plentiful small crystalline grains of sodalite. As in the phonolites, the development of the feldspars controls the character of the texture. The most common form is as small laths with parallel arrangement showing beautifully the flow movements of the magma and giving a trachytic texture similar to that of the phonolites. Likewi e a less perfect crystallographic development of the groundmass feldspars leads to a microgranular texture, though fluidal structure can usually be distinguished. Abundant development of feldspar in the form of phenocrysts leaves the groundmass very subordinate, and in that case it is usually microgranular with little or no indication of a flow structure. The very small amount of glass included in some of the feldspar phenocrysts is hardly sufficient to warrant classing these rocks as other than holocrystalline porphyritic. The principal textural differences between the latite-phonolites and the phonolites proper are the greater tendency of the former toward phanerocrystalline development, the somewhat coarser grain of their groundmass, and their more frequent and decided deviation from the characteristic trachytic texture.

CHEMICAL CHARACTER.

The accompanying analyses show the chemical character of the latite-phonolites, their range in composition, and their relation to the phonolites:

Analyses of latite-phonolites from Cripple Creek.

	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	56.01	58.05	54.88	54.43	62.79	59.38	58.85
Al_2O_3	17.92	17.66	18.53	19.01	19.10	19.47	20.06
Fe_2O_3	4.20	3.51	2.93	2.85	2.29	1.60	1.83
FeO	2.52	1.65	1.92	1.93	.36	1.19	.51
MgO	2.04	1.55	1.26	.99	.40	.36	.18
CaO	4.80	4.58	4.15	4.33	.87	1.96	.95
Na_2O	4.92	5.80	6.65	6.92	6.23	7.80	9.01
K_2O	4.21	4.06	4.90	5.07	5.58	5.83	5.43
H_2O-	.31	.35	.38	.31	.25	.11	.27
H_2O+	1.10	.87	1.75	1.68	.84	.69	1.74
TiO_2	1.20	.91	.93	.96	.71	.58	.25
ZrO_2	.02	.02	.03	.04	.02	.10	.16
CO_2	None.	None.	.13	.14	Trace.	.....	.12
P_2O_5	.55	.40	.27	.25	.12	.08	.04
SO_3	None.	.04	.36	.42	None.	.37	.10
Cl	Trace.	Trace.	.14	.22	Trace.	.22	.31
FeS_2	.04	None.	.10	.07	.10	.....	.....
Cr_2O_3	None.	None.	.....	.....	.....	.....	.....
NiO	None.	n. d.	.....	.....	.....	.....	.....
MnO	.13	.13	.25	.08	.07	.15	.18
BaO	.16	.19	.18	.21	.14	.13	Trace.
SrO	.06	.08	.11	.21	.03	.03	Trace.
Li_2O	.....	.....	Trace.	Trace.	Trace.	Trace.	Trace.
	100.19	99.75	99.82	100.07	99.90	100.05	99.98

I. Latite-phonolite, Portland mine, level 6.
II. Latite-phonolite, Anaconda mine, adit level.
III. Latite-phonolite, Portland mine, adit level.
IV. Latite-phonolite, 3,300 feet S. 10° E. from Bull Cliff.
V. Biotite trachyte, Portland mine, 500-600 foot level.
VI. Latite-phonolite, south slope Bull Cliff. Cf. Cross, W., Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 43.
VII. Average analysis of Cripple Creek phonolites (V of table on p. 66).
Analyses I and II by George Steiger; III-VI by W. F. Hillebrand.

I. A gray rock, showing numerous small phenocrysts of pyroxene and a few of feldspar in a fine-grained groundmass. The microscope shows the larger feldspar crystals to be between oligoclase and andesine, often bordered by orthoclase. The pyroxene is pale green, slightly pleochroic, and has a large extinction angle. Aggregates of pyroxene and magnetite grains in some cases possess the outline of hornblende, while in others the resorption is seen to be destroying biotite. Some large grains of magnetite and large apatite crystals are present. All these are contained in a predominant trachytic groundmass which is a little decomposed, but seems to be made up almost exclusively of orthoclase laths, with a very small amount of sodalite in tiny grains. Analcite can not be identified. This facies is closely related to the latites and is the extreme in that direction of the latite-phonolite type. It occurs in the Portland mine, but has been found in few other places. The specimen is slightly decomposed.

II. A rather light-gray rock, containing occasional small feldspar phenocrysts and many small lath-shaped prisms of pyroxene, which indicate direction of flow, in a very finely granular groundmass. In thin section the larger feldspars are seen to be orthoclase, microcline, and microperthite, with a larger amount of a zoned plagioclase, which corresponds to oligoclase-albite. The phenocrysts of pyroxene usually have good crystal outline and are not uncommonly twinned; micropegmatitic intergrowth with hornblende and with feldspar is sometimes seen. Hornblende is not plentiful and is usually surrounded by a zone of pyroxene and magnetite, indicating resorption. A few foils of biotite are present. Irregular grains of magnetite are common. Apatite and titanite occur sparingly in sharp crystals. Small grains of sodalite and patches of analcite are inclosed in fresh feldspar phenocrysts. The groundmass is very fine grained, but shows a distinct trachytic texture. The minute feldspar laths are too turbid for identification, but are probably orthoclase. Microlites of pyroxene and tiny grains of magnetite are plentiful. This specimen is from the Anaconda tunnel. The rock appearing above on the surface was designated on the earlier map as syenite-porphyry.

III. A finely granular rock of rather dark-gray color, containing plentiful phenocrysts and irregular grains of pyroxene and noticeable yellow crystals of sphene. Under the microscope it is found to be composed mainly of large and small crystals of feldspar, often of diamond-shaped outline. These crystals are as calcic as oligoclase in the interior, and are bordered by a zone of orthoclase. Pyroxene is fairly plentiful, both in sharp crystals and irregular grains. It is light green, noticeably pleochroic, and has an extinction angle corresponding to ægirine-augite. Hornblende is not uncommon, but is usually surrounded by resorption rims. Analcite occurs in partially decomposed masses, sometimes giving a suggestion of crystalline outline. Nosean is fresher, in crystals of square outline. Apatite, magnetite and noticeable titanite are the accessories. The groundmass is decidedly subordinate. Microlites of feldspars, some of which seem to be albite, and tiny grains of sodalite, pyroxene, and magnetite are the chief constituents. This specimen represents much of the mass occurring on the south slope of Battle Mountain, in the vicinity of the Portland mine.

IV. A rather dark-gray rock, containing small phenocrystic grains of feldspar, pyroxene, and a little hornblende in a predominant fine-grained groundmass. Microscopic examination reveals abundant feldspar, usually in individuals of imperfect crystallographic form. Many of the larger phenocrysts are orthoclase, often intergrown with a finely striated oligoclase-albite. Some sodic plagioclase has both albite and pericline twinning resembling microcline; outer zones of orthoclase are commonly present. The pyroxene corresponds to ægirine-augite in composition, but possesses the augite outline. Hornblende, which is not plentiful, occurs nevertheless in individuals of good size. It has suffered some resorption. Nosean is rather prominent in turbid crystals of good size. Analcite is also common, but is somewhat decomposed into other zeolites, probably stilbite and natrolite. Sodalite is not readily distinguished, occurring as minute crystals in the somewhat turbid groundmass. Apatite, magnetite, and titanite are prominent accessory constituents. The groundmass, though not as abundant as the hand specimen indicates, is prominent notwithstanding. It is composed chiefly of laths of orthoclase, with small grains of pyroxene, sodalite, and magnetite, and has the trachytic texture.

This specimen from Bull Cliff is a good representative of the latite-phonolite type, both in composition and appearance. Masses of the same variety occur south of Altman, in the vicinity of the Last Dollar mine, on the north slope of Big Bull Mountain, and probably on the north and west slopes of Bull Hill, though decomposition at those places is too great to justify a conclusion.

V. This specimen is described on page 71. It represents masses on Battle Mountain and on Mineral Hill.

VI. This is a dark-gray rock, rather granular in appearance, with large and small phenocrysts of feldspar, and only little pyroxene visible. The microscope shows that the larger phenocrysts are orthoclase, probably rich in soda; the smaller ones are a soda-rich plagioclase, some being albite, some oligoclase-albite. The pyroxene crystals, which are well developed crystallographically, are ægirine-augite. Original hornblende is almost wholly resorbed. Nosean is comparatively abundant in clouded crystals. Sodalite, which is of lighter color, is less common as phenocrysts, but is plentiful in small grains and crystals in the groundmass. Analcite can not be identified with certainty, but is probably present as inclusions in some of the feldspar phenocrysts. Nepheline is absent. Magnetite, apatite, and titanite are present in irregular grains and in sharp crystals. The groundmass is beautifully trachytoid, consisting principally of tiny laths of orthoclase, with microlites of pyroxene, sodalite, and magnetite. This rock is closely related in chemical composition to the phonolites. The specimen is from the same mass as No. IV and thus affords a good illustration of variation in a single mass.

The characteristic chemical features of these rocks are high alkalies, with plentiful alumina and moderate amounts of the bivalvent bases. The amounts of phosphorus pentoxide (from apatite) and of titania (mainly from sphene) are noteworthy. The main distinctions from the phonolites are greater variability in composition, lower alkalies, and higher lime, magnesia, and iron.

Of the specimens analyzed, Nos. III and IV best represent the type and their agreement in composition is very close. It is interesting to note, in passing, that No. IV has a predominant groundmass, while in No. III the groundmass is subordinate—a good example of different textural development with constant composition. A calculation from the analyses of these two specimens, in connection with a study of the thin sections, gives an idea of the proportionate amounts of their mineral constituents. The appended list is approximate only, because of the number of independent factors entering into the calculation:

Mineral molecules in latite-phonolite.

Orthoclase	29.75	Hornblende	5.63
Albite	26.10	Apatite	2.37
Anorthite	3.08	Titanite	2.36
Sodalite	2.74	Magnetite	1.96
Nosean	3.53	Other minerals, hygroscopic water, water of hydration, etc	6.63
Analcite	4.60		
Ægirine	1.02		
Augite	10.23		100.00

PLATE VIII.

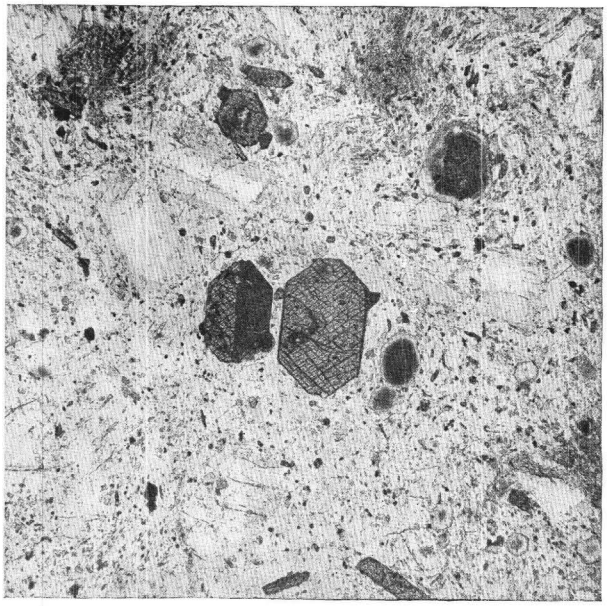
Photomicrographs of Rocks.

A, Latite-phonolite (624 C. C.) from southern slope of Bull Cliff. Composed of soda-orthoclase, plagioclase, nosean, sodalite, ægirine-augite, and augite. Augite shows twinning. Nosean is crowded with dark inclusions except at the border. Magnified 28 diameters.

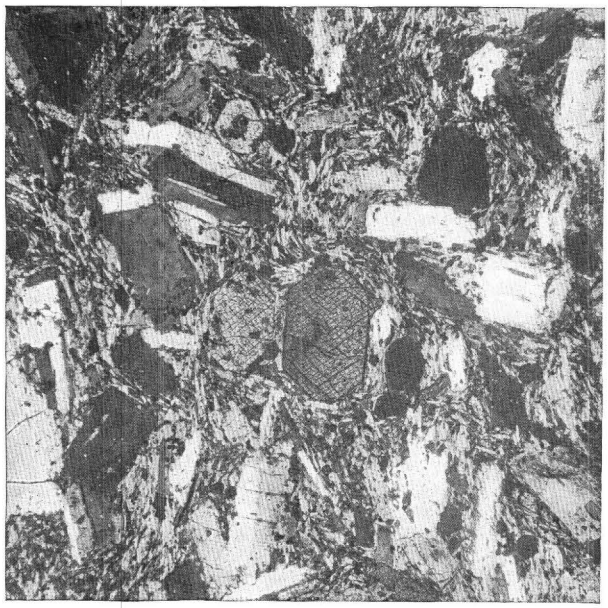
B, Same with crossed nicols. Shows flow structure. Magnified 28 diameters.

C, Syenite (333 C. C.) from dump of Last Dollar mine. Composed of soda-orthoclase, ægirine-augite, augite, and hornblende. Magnified 28 diameters.

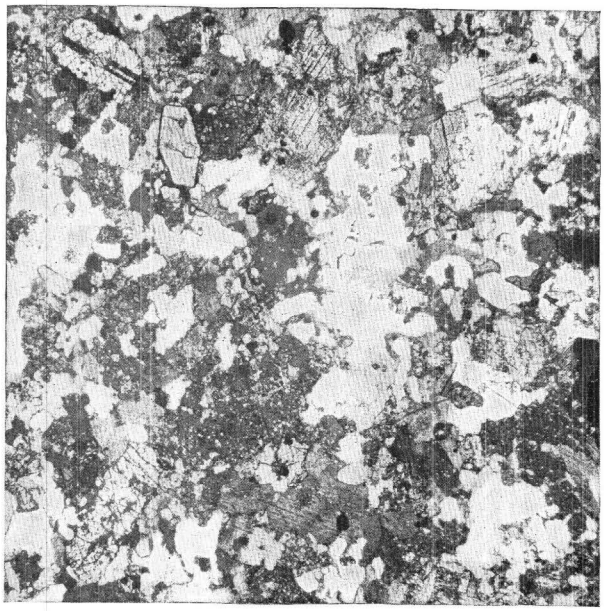
D, Trachydolerite (381 C. C.) from summit of Bull Cliff. Composed of orthoclase, analcite, augite, biotite, and magnetite. Magnified 28 diameters.



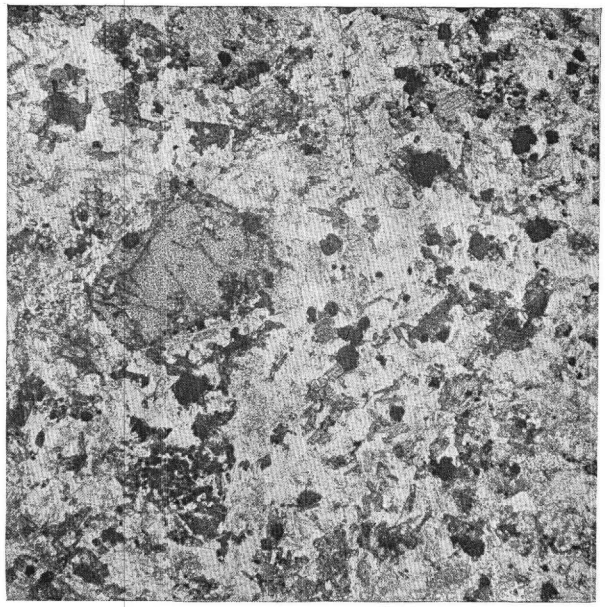
A



B



C



D

PHOTOMICROGRAPHS OF LATITE-PHONOLITE, SYENITE, AND TRACHYDOLERITE.

This calculation is based on the assumption, suggested by an examination of the thin sections, that the pyroxene is about double the amount of the hornblende. It also assumes that the ration of ægirine to augite is 1:10,[a] and that half the water given off above 100° represents primary water, and rests on the following arbitrary but more or less probable compositions assigned to the augite and hornblende:

Augite = CaO, MgO, $FeO(Al,Fe)_2O_3$, $3SiO_2$, the ratio of Al : Fe‴ being 4 : 1.

This is the same formula as that used for the phonolites (p. 67).

Hornblende = CaO, 2MgO, 2FeO, $3(Al,Fe)_2O_3$, $6SiO_2$, the ratio of Al : Fe‴ being 13 : 1.

Since the ægirine is united with the augite to form a single pyroxene mineral, and since the albite and anorthite form an intermediate plagioclase, oligoclase-albite, the following table expresses as accurately as possible the kind and relative amounts of the mineral components of these rocks:

Mineral composition of latite-phonolite.

Orthoclase[b]	29.75	Apatite	2.37
Oligoclase-albite (approximately Ab_5An_1)	29.18	Titanite	2.36
Sodalite	2.74	Magnetite	1.96
Nosean	3.53	Other minerals, hygroscopic water, water of hydration, etc	6.63
Analcite	4.60		
Soda-augite	11.25		100.00
Hornblende	5.63		

TRANSITIONS TO PHONOLITE.

In the course of the mapping and study of the Cripple Creek rocks, three varieties have been found which show, each in a somewhat different way, a mineralogical gradation of latite-phonolite into phonolite, or vice versa. This is what one would expect from the chemical relations just given. These three varieties will be briefly described, most emphasis being placed on the points which show the relation of the one group to the other.

On the upper southern slope of Bull Cliff occurs a fine-grained rock, holding an occasional small feldspar phenocryst and showing, by slight decomposition, the fluidal arrangement of its groundmass feldspars. It strongly resembles the phonolites in appearance and seems in the field to grade directly into that type. The microscope confirms this similarity, and shows a few narrow feldspar phenocrysts, many grains of ægirine, and small phenocrysts of ægirine-augite, a few decomposing nosean crystals, numerous minute grains of sodalite, but only an occasional small crystal of nepheline near or in the irregular analcite grains.

In a railroad cut on the east side of Battle Mountain, near the Rigi mine, is exposed a rock, a little of which is fairly fresh, which appears to be a contact facies, or rather marginal facies, of the large latite-phonolite area occurring east and southeast of the Portland mine. It is brownish gray, considerably mottled, nearly or

[a] It happens that the molecular weights of ægirine and of the augite chosen are identical.

[b] It is probable that a small amount of the soda calculated as plagioclase enters into the composition of orthoclase, leaving the plagioclase a little more calcic than Ab_5An_1.

quite aphanitic, and in appearance resembles rather the phonolites than the latite-phonolites. Microscopically it is characterized by a number of small lath-shaped feldspar phenocrysts, considerable ægirine, ægirine-augite, and blue amphibole, and irregular, interstitial masses of analcite, in a well-defined trachytic groundmass. Between the feldspar microlites occur numerous grains of sodalite. Nepheline, however, could not be identified with certainty, though a number of minute partially decomposed grains of higher index of refraction than the feldspar roughly correspond in outline to nepheline. The ægirine occurs in its usual tabular habit, but the ægirine-augite takes the more prismatic form of the ordinary pyroxenes. The habit of the pyroxene and the scarceness or entire absence of nepheline places this rock between the two main groups, but somewhat nearer to phonolite than to latite-phonolite.

The third variety occurs south of the main street of Altman, just west of the Deadwood mine. It forms part of a large area of latite-phonolite and appears to be identical with the finer grained varieties of that group. Besides numerous feldspar tablets and laths of good size, it contains large and small nosean crystals, clear little grains and ragged patches of pure ægirine, phenocrysts of ægirine-augite and augite, large grains of titanite, abundant sodalite microlites, and small shreds of the unknown mineral of high index and double refraction found in the phonolites, all contained in a comparatively coarse-grained trachytic groundmass. One or two rectangular sections of a partially decomposed mineral may be nepheline.

It is thus seen that though the phonolites are a particularly well-characterized group and the latite-phonolites are fairly well defined, a few intervening members reveal the close relation of the two and unite them all into one rock series.

SYENITE.

GENERAL DESCRIPTION.

Granular rocks closely resembling and connected by textural gradations with the latite-phonolites occur in various parts of the volcanic area. The larger masses were mapped by Cross and called by him nepheline syenite. In the recent study, however, no nepheline has been found. Cross's statement of the presence of this mineral is not very conclusive and seems to have been based mainly on the presence of decomposition products supposed to have been derived from nepheline.[a] These syenites are alkali-rich rocks and are most closely related to the alkali syenites of Rosenbusch; but because of too high lime and magnesia and rather low silica, they are in the following description classed broadly as syenites and confined to certain characteristics. They show certain affinities to the essexites, but differ in being decidedly lower in iron, magnesia, and lime; richer in alkalies, particularly potash; and somewhat higher in silica and alumina. They have lower bivalvent bases and higher alkalies than the monzonites. While a little more basic than their porphyritic equivalents, the latite-phonolites, exemplifying a common difference between the granular and the porphyritic rocks,[b] they nevertheless show certain close relationships not only to that rock type, but to the phonolites as well. On the other

[a] General geology of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 44.
[b] Cf. Rosenbusch, H., Elemente der Gesteinslehre, Stuttgart, 1901, p. 249.

hand, their divergencies from these two types are of such a character as to relate these syenites to the more basic rocks whose descriptions follow. They thus form another step in the increasingly basic series which begins with phonolite and ends with basic dike rocks.

In appearance they are medium to dark gray rocks, with prominent prismatic crystals of pyroxene in a feldspathic matrix. They are distinguished in the field with difficulty and not always with certainty from the coarser-grained types of latite-phonolite. Weathering or other alteration produces changes that are identical with those of the related porphyritic rocks, the resulting mass being usually of lighter color and more or less porous.

These granular rocks are not very liberally distributed. The Vindicator mine is near the center of the largest area, which is about 2,000 feet in diameter. Another mass of some size occurs near the Last Dollar mine, and smaller bodies are found near the Rose Nicol mine on the northeast side of Battle Mountain, west of the Logan mine on Bull Hill, and in the vicinity of the Pointer mine on Gold Hill. Granular rocks referable to this class are also encountered in masses which do not reach the surface in the Mollie Kathleen, Granite, and Portland mines and in the Ophelia tunnel.

The gradation to latite-phonolite is well shown on the surface both east and west of the Vindicator mine and near the Last Dollar mine and is strikingly seen in the underground workings of the Portland, Last Dollar, and Vindicator mines. Sometimes, however, there is a sharp contact of intrusion between the two, as shown in the Vindicator mine. The nature of the two groups of rocks and their manner of occurrence make it probable that only a slight difference in conditions, such as change of temperature or pressure, or minor variations in composition, were needed to cause the one or the other to crystallize from the magma. There is little or no evidence available to show that the granular rock is the deep-seated equivalent of the porphyritic. The transition from one to the other is apparently regardless of distance from the surface or from contacts. It is probable that these granular rocks have formed much nearer the surface than is believed usually to be the case, for erosion since the volcanic period does not appear to have been very great. It seems likely, in fact, that some of these rocks solidified within a few hundred feet of the surface. It is possible that the rocks into which they were intruded were then at a high temperature and that the cooling was consequently slower than it would otherwise have been.

MINERALOGICAL CHARACTER.

These syenites are in general made up of the same minerals as are the latite-phonolites. Analcite, however, is much less common, biotite is of more general distribution, and pyroxene and hornblende are on the whole more abundant, though in the case of the latter mineral the difference may be due to the fact that practically no resorption has taken place in these granular rocks. Nosean and sodalite are often present, but, as in the latite-phonolites, vary in amount and frequently can not be detected.

Orthoclase is the most abundant constituent. It is usually present in individuals of irregular outline, but occasionally gives a subporphyritic texture to the rock

by development in imperfect laths. Carlsbad twinning and visible traces of cleavage are less common than in the porphyries. Grains of microperthite are seen here and there. Plagioclase is rather abundant, and occurs like orthoclase. Polysynthetic twinning is often absent and the mineral must then be identified by its index, extinction, or double refraction. In composition it corresponds partly to albite and partly to oligoclase-albite, being thus a little more sodic than in the latite-phonolites.

Kaolin, epidote, and sericite result from various processes of alteration of the feldspars.

Nosean occurs as more or less automorphic grains up to 0.6 mm. in size. It sometimes shows the characteristic grills of inclusions, but is commonly decomposed into a rather low polarizing aggregate of zeolites.

Sodalite is often difficult of detection, but in a number of cases appears as minute grains between the other minerals, or more commonly included in the larger feldspars. In the neighborhood of mineral-bearing fissures sericite seems to form with particular ease from sodalite.

Nepheline, if present at all, is in very subordinate amount and in no case could it be identified with certainty.

Analcite has been found in a few instances as allotriomorphic grains along with the other constituents. In such cases it is undoubtedly primary.

Pyroxene is one of the important constituents, and, aside from its somewhat greater abundance and generally poorer crystallographic form, its occurrence corresponds to that in the latite-phonolites. It possesses on the whole the best form of all the important constituents of the syenites. It ranges from colorless, isochroic, to pale green, pleochroic, in the latter case indicating an admixture of a small amount of the ægirine molecule. Twinning parallel to the orthopinacoid is seen in a few instances. A common alteration is to calcite, chlorite, and quartz(?). Other decomposition products occasionally seen are epidote, the secondary green mica already described, sericite, and perhaps serpentine.

The hornblende is of similar nature to that in the latite-phonolites, but differs somewhat in color. The range in color is as follows: $\mathfrak{a}$, light greenish yellow; $\mathfrak{b}$, yellowish green; $\mathfrak{c}$, deep green in some varieties, to $\mathfrak{a}$, brownish yellow; $\mathfrak{b}$, strong brown; $\mathfrak{c}$, deep greenish brown in others. In all cases $\mathfrak{c}>\mathfrak{b}>\mathfrak{a}$. The angle $\mathfrak{c}:\mathfrak{c}$ reaches a maximum value of 27°. Hornblende frequently shows poikilitic intergrowth with pyroxene and at times completely surrounds individuals of that mineral. In a few instances it is possible that slight resorption has taken place. Chlorite is a common alteration product.

Biotite is rather common in irregular plates, usually of reddish-brown color, but sometimes greenish brown. Pleochroism is often intense. Like the mica of the porphyritic varieties, this mineral may be related to the iron-rich lepidomelane. It frequently occurs intergrown with hornblende and sometimes with pyroxene also. The most common decomposition product is aggregates of the secondary green mica.

Apatite is present as numerous small, sometimes corroded, crystals and occasionally holds inclusions of the kind previously described. Titanite, while less abundant than in the latite-phonolites, is still of unusual prominence as an accessory. Small irregular grains of magnetite are common.

As in the preceding rocks, pyrite replaces magnetite, and carbonates and fluorite are introduced by metasomatic action along veins.

The texture is in general typically granular, but occasionally becomes subporphyritic. The textural gradation to latite-phonolite has already been described.

CHEMICAL CHARACTER.

The analyses given below make clear the chemical nature of these rocks and their close relation to the latite-phonolites:

Analyses of syenites from Cripple Creek.

	I.	II.	III.	IV.
SiO_2	54.43	54.34	51.98	56.01
Al_2O_3	19.01	19.23	17.94	17.92
Fe_2O_3	2.85	3.19	3.85	4.20
FeO	1.93	2.11	3.37	2.52
MgO	.99	1.28	2.88	2.04
CaO	4.33	4.53	5.62	4.80
Na_2O	6.92	6.38	4.63	4.92
K_2O	5.07	5.14	4.50	4.21
H_2O-	.31	.14	.72	.31
H_2O+	1.68	1.17	2.09	1.10
TiO_2	.96	1.09	1.34	1.20
ZrO_2	.04	.07	.03	.02
CO_2	.14	.....	Trace.	None.
P_2O_5	.25	.27	.67	.55
SO_3	.42	.07	None.	None.
Cl	.22	.28	Trace.	Trace.
FeS_2	.07	.....	.41	.04
MnO	.08	.08	.08	.13
BaO	.21	.24	.19	.16
SrO	.21	.16	.11	.06
Li_2O	Trace.	Trace.	Trace.	.....
	100.07	99.77	100.32	100.19

I. Latite-phonolite, south slope of Bull Cliff (IV of table on p. 79).
II. Syenite, near Longfellow mine, west of Vindicator mine. See Cross, W., Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 45.
III. Syenite, Portland mine, 500-foot level.
IV. Latite-phonolite, Portland mine, 600-foot level (I of table on p. 79).
Analyses I–III by W. F. Hillebrand; IV by George Steiger.

II. This specimen is light gray and finely granular, with occasional larger grains of feldspar and numerous prisms of pyroxene showing a slight flow structure. In thin section the feldspars are found to be mostly orthoclase, with some microperthite, considerable albite, and a little which is perhaps more calcic. Sodalite occurs in good-sized grains, some of them well crystallized, others of irregular form; it is commonly decomposed. The analysis indicates that a little nosean is also present. Analcite is rather plentiful in clear grains of irregular outline commonly associated with feldspar. Extremely minute needles, perhaps of stilbite, penetrate these grains. The occurrence of the analcite is the same as in the latite-phonolites. No nepheline can be distinguished, though Mr. Cross thought that certain turbid areas represent it. The pyroxene has the colors and low extinction angle of ægirine-augite. It is often surrounded by a zone of greenish-brown hornblende, which

also occurs alone in good-sized individuals showing no resorption. Magnetite, apatite, and titanite are notable accessory constituents. This rock, called nepheline-syenite in the earlier report, is regarded by Rosenbusch as a member of an intermediate series, the nepheline-syenite-essexite series.[a] It occurs not far from the locality of the latite-phonolite (I), which is compared with it on page 85, and it is probable that the respective masses of which these are specimens are connected underground.

III. A rather light gray granular rock of moderately fine grain, holding well-formed prisms of pyroxene in a slightly pinkish aggregate of feldspar grains. Under the microscope the feldspar is found to range from orthoclase to oligoclase inclusive. A very little sodalite is present in tiny grains, and some larger areas, now converted into sericite, were possibly sodalite or nosean originally. The pyroxene is very pale green and is practically isochroic, with an extinction angle of about 40°. It is commonly accompanied by irregular grains of hornblende with pleochroism in light browns and greens, and by occasional small plates of strongly pleochroic biotite. Apatite is especially noticeable and is accompanied by magnetite and titanite. The texture is hypidiomorphic granular. This specimen and No. IV of the table on page 87 are from the Portland mine, and though from different masses are strikingly similar in chemical composition.

TRACHYDOLERITE (BULL CLIFF TYPE).

GENERAL DESCRIPTION.

The summit of Bull Cliff is made up of a dense, nearly aphanitic rock, almost black in color, which after partial weathering gives a peculiar rough fracture as if it were made up of polyhedrons. It was thought by Cross to grade into normal phonolite to the south and to be a peculiar local facies of that rock. While later field study has not been able to wholly establish its geological relations, there are certain facts which lead to a rather different view. The summit mass is on the whole very fresh, while most of the true phonolite to the south is much decomposed. The freshest of the near-by phonolite shows the fissility, the greasy luster, the tablets of feldspar, and the flow structure of the type, while the rock from the summit possesses none of these characteristics, but occasionally shows a very small glistening phenocryst of mica. There seems to be no gradation in appearance near the boundary between the two rocks and while talus and low scrubby bushes conceal the actual contact it is beyond question that an intrusive contact is present. The Bull Cliff mass overlies and is later than the breccia. On the west side of the hill the contact is nearly horizontal. On the east side it dips into the hill at something like 45°. Workings in the Isabella and Victor mines directly underneath the cliff do not encounter this rock, so far as known, but it is probable that it has issued from some small throat and spread out into the surrounding rocks as a laccolith-like mass. A rude vertical columnar jointing on the east side favors this view. The rock is younger than the latite-phonolite, for it is seen cutting off a dike-like body of that rock in the Pilgrim tunnel on the northwest slope of Bull Cliff. From such field evidence as can be obtained, which, it must be admitted, is not entirely convincing, it appears to be later than the phonolite.

[a] Elemente der Gesteinslehre, Stuttgart, 1901, pp. 177, 179.

Microscopical and chemical study shows that this rock belongs in Rosenbusch's family of trachydolerites, which are defined as containing in a fine-grained groundmass phenocrysts of generally calcic plagioclase and of pyroxene, and often accompanied by sanidine, a mineral of the sodalite group, hornblende, and olivine.

MINERALOGICAL CHARACTER.

The essential minerals of this rock are orthoclase, plagioclase, pyroxene, biotite, and analcite, with abundant black iron ore and many crystals of apatite as accessories, and here and there a little glass.

Phenocrysts of feldspar rarely exceed 0.5 mm. in greatest dimension and are always triclinic, belonging to the variaties oligoclase and andesine. Twinning is common and cleavage is particularly evident. Aside from prominent clinopinacoids, crystal faces are not well developed.

Feldspar of the second generation is about equally divided between orthoclase and plagioclase the latter including albite, oligoclase, and andesine. They are usually developed as laths, as in the trachytes, but are often of irregular form.

Pyroxene is very abundant, both as phenocrysts reaching 0.3 mm. in size, often anhedral, and as small lath-shaped microlites profusely scattered through the groundmass. The mineral is colorless or very pale yellowish-green and without noticeable pleochroism. The interference colors are moderate and the angle of extinction is large. The optical properties and the composition of the rock make it probable that this pyroxene is related to augite.

The manner of occurrence of biotite is rather unusual. It forms small ragged grains of brown color and intense pleochroism and is closely associated with grains of iron ore. Elongated individuals of larger size, sometimes 2 to 3 mm. in length, show what is probably an unusual kind of resorption. Small grains of black iron ore, pyroxene, and a colorless mineral—probably feldspar—mingle throughout the mass with residual particles of the biotite still retaining the original orientation. At times the pyroxene grains arrange themselves according to crystallographic directions, and then the pyroxene and biotite individuals possess the vertical axis in common. The pyroxene resulting from the magmatic alteration of biotite appears to be identical in composition with the original pyroxene.

Analcite occurs in variable amounts, as rounded patches 1 mm. or more in diameter, and more commonly as irregular interstitial grains between the other groundmass constituents. When in the larger patches, it holds abundant laths of pyroxene and feldspar arranged in the same parallel fluidal way as in the other parts of the rock. The mineral is uniformly colorless and clear, shows the low single refraction and characteristic rough surface, and is sensibly isotropic, though small areas of exceedingly faint polarization are occasionally seen. The possibility of this material being glass, as its occurrence suggests, is almost wholly excluded by its clearness and freshness in a rock which carries over 1 per cent of carbonate. No question can be raised, on the other hand, as to the primary character of the analcite.

Apatite is common in crystals which range in size from very minute up to 0.3 mm. They are nearly always crowded with the acicular inclusions described under the latite-phonolites, and consequently present a very striking pleochroism in brown and purple.

Black iron ore is very plentiful, and in the absence of sphene must be titaniferous to a considerable extent. (See analysis.)

Small interstitial particles of turbid appearance and brown color occur scattered sparingly through the groundmass. They possess weak single refraction and give aggregate polarization in low colors, and without doubt are devitrified portions of an original glass bases.

The texture of this rock is therefore hypocrystalline porphyritic. The holocrystalline portions are generally intermediate in character between the trachytic texture of the phonolites and latite-phonolites, and the intersertal texture of the basalts. Small portions of the groundmass are microgranular.

CHEMICAL CHARACTER.

The composition of this rock is shown in the analysis, by Hillebrand,[a] given below.

Analysis of trachydolerite from Bull Cliff.

SiO_2	49.84	ZrO_2	.03
Al_2O_3	17.78	CO_2	.52
Fe_2O_3	5.86	P_2O_5	.76
FeO	2.62	SO_3	None.
MgO	3.02	Cl	Trace.
CaO	7.35	MnO	.21
Na_2O	5.20	BaO	.22
K_2O	3.04	SrO	.18
H_2O-	.34	Li_2O	Trace.
H_2O+	2.02		
TiO_2	1.43		100.42

A comparison of this analysis with No. III on page 87 reveals the close chemical relation of the trachydolerite with the less alkalic of the syenites.

SUMMARY.

The occurrence of analcite as a groundmass constituent in a rôle similar to that of glass places this rock in Pirsson's "analcite group,"[b] along with the monchiquites which it somewhat resembles.[c]

From what has been said of its field occurrence and of its mineral and chemical composition, it appears probable that this trachydolerite is intermediate in age as well as in character between the latite-phonolites and syenites, on the one hand, and the latest products of eruption, the basic dike rocks, on the other.

BASIC DIKE ROCKS.

GENERAL DESCRIPTION.

Cutting all the other rocks of the district, and hence representing the final phase of eruptive activity, are certain dark intrusives which occur as dikes and sills from a few inches to several feet in thickness. They are most abundant in the

[a] Bull. U. S. Geol. Survey No. 228, 1904, p. 163.
[b] On the monchiquites or analcite group of igneous rocks: Jour. Geol., vol. 4, 1896, pp. 679–690.
[c] Cross, W., Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 37.

volcanic rocks, but occasionally cut the granites. As in the case of the phonolites, there is seen a tendency toward radiation from the center of the eruptive area. When fresh they are nearly or quite black rocks, with conchoidal fracture, and vary in granularity[a] from fine-grained porphyritic to aphanitic. Their mineralogical composition is such that they readily undergo alteration and with the exception of the northeasterly dike which outcrops in the main street of Altman they are not conspicuous at the surface. This decomposition is not limited to the vicinity of the surface, but frequently extends to depths of over 1,000 feet, changing the rock in extreme cases to a soft and clayey greenish-gray crumbling mass, while less decomposed portions vary from light to dark gray or greenish and are more or less porous through the removal of some of the constituents.

These rocks are locally known as basalts and have usually been mentioned as such in the literature. On the basis of partially decomposed material, Cross made two divisions which he called plagioclase basalt and nepheline basalt, respectively. To these Stevens added limburgite[b] and tephrite.[c] Careful examination of specimens collected from all parts of the district establishes three definite rock types which while outwardly resembling basalts are because of their notable content of alkalies really not basalts at all. They are trachydolerite, vogesite, and monchiquite. For various reasons it has been found impracticable to separate them on the map, where they appear as "basic dikes." In order to distinguish the first-named type from the rock of Bull Cliff, it will be designated as the Isabella trachydolerite.

TRACHYDOLERITE (ISABELLA TYPE).

This group is exemplified by the dike in the Isabella mine, which can be traced through the town of Altman nearly to the summit of Bull Hill and extends northward through the Block 8 mine to Grassy Creek. It is also represented by the Dolly Varden dike, by a dike crossing the Gold Bond property, one in the Ajax mine, and several in the Portland mine, and by an inclined dike in the Mary McKinney mine. Several dikes, such as those in the Blue Bird and Midget mines, though much decomposed, probably also belong to this type.

These rocks are distinctly phanerocrystalline, but of fine grain, and consist of plagioclase, pyroxene, and olivine, with smaller amounts of orthoclase and analcite, with or without a glass basis. As accessory or occasional constituents, occur apatite, magnetite, biotite, and hornblende. The plagioclase ranges from andesine to bytownite, inclusive, and though more than one species is sometimes contained in the same specimen, labradorite is most common. It occurs in tabular plates, but more frequently as laths, from over a millimeter in length down to minute microlites. It is seldom more than hypidiomorphic, but in a few cases attains almost perfect form. It occurs at times only as phenocrysts, at others both as phenocrysts and in the groundmass, while not infrequently it is confined wholly to the groundmass. Arrangement in zones of not very different composition may often be observed, and occasionally the phenocrysts are surrounded by a narrow, irregular, clear zone of

[a] Quantitative Classification of Igneous Rocks, Chicago, 1903, p. 154.
[b] Trans. Am. Inst. Min. Eng., vol. 30, 1901, pp. 759–764.
[c] Idem, vol. 33, 1903, p. 687.

orthoclase. Twinning, though not always present, usually follows the albite law and sometimes the Carlsbad law also. Pericline twinning is rarely seen. In some cases small patches of turbid glass are inclosed in zonal arrangement by the feldspar phenocrysts. Orthoclase is not very abundant, occurring, with the exception of the outer shell of the plagioclase phenocrysts, as small interstitial grains. Analcite is present in phenocrystic individuals which in thin section have an approach to square or hexagonal outline. It also occurs as rounded blebs, sometimes inclosing or penetrated by prisms of pyroxene, and as irregular interstitial grains. A common alteration is to radiating needles of stilbite. Augite occurs as phenocrysts, generally characterized by good crystallographic form, and also as more or less irregular grains in the groundmass. Cleavage is noticeably developed. Besides the usual prismatic cleavage, there is a prominent cleavage parallel to the clinopinacoid, and sometimes orthopinacoidal and negative orthodomal cleavage. The phenocrysts not infrequently show twinning parallel to the orthopinacoid and zonal structure is almost always present. Small particles of glass are sometimes included near the periphery of the larger individuals. In one rock, at least, that from a dike near the Gold Bond mine, corrosion and subsequent enlargement of the pyroxene individuals have taken place. The mineral is usually colorless or very light green. In one or two instances it shows a faint purple tint, indicative of the presence of titania, and then possesses a slight pleochroism. Olivine occurs as large and small phenocrysts, more or less idiomorphic, and sometimes as small grains in the groundmass. When fresh, it shows the usual irregular cracks along which alteration begins and in certain instances shows an imperfect cleavage also. Generally it is in an advanced stage of alteration, the more common and noticeable products being carbonates, serpentine, talc, and a material corresponding to what has been called iddingsite.[a] Biotite occurs rarely as phenocrysts, but is comparatively abundant in the groundmass as small grains, usually reddish brown, intensely pleochroic, and with high interference colors. It sometimes shows both corrosion and resorption. Hornblende occurs sparingly as irregular individuals of brown color. A dike in the Ajax mine contains a weakly pleochroic bluish-green amphibole. The apatite, which occurs in prisms as much as 2 mm. in cross section, is particularly free from inclusions.

In two of the rocks of this type a few grains of obviously secondary quartz are found. Epidote is rather plentiful in some of the partially decomposed specimens and carbonates are nearly always abundant.

These rocks possess a texture which is about midway between trachytic and intersertal. Most of them appear to be holocrystalline, but some undoubtedly contain small areas of brown, turbid glass.

A chemical analysis of material from the Isabella dike was made by W. T. Schaller, and serves to show the alkalic nature of the rock and its close relation to the trachydolerite of the Bull Cliff mass.

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[a] Lawson, A. C., Bull. Dept. Geol. Univ. California, vol. 1, p. 31.

Analysis of trachydolerite of the Isabella dike.

SiO_2	48.76	CO_2	0.22
Al_2O_3	17.04	P_2O_5	.79
Fe_2O_3	5.04	SO_3	Trace.
FeO	3.47	Cl	.01
MgO	4.57	FeS_2	.11
CaO	8.64	Cr_2O_3	Trace?
Na_2O	4.27	MnO	.08
K_2O	3.39	BaO	.15
H_2O-	.69	SrO	.07
H_2O+	1.84	Li_2O	Trace.
TiO_2	1.34		
ZrO_2	Trace.		100.48

A subtype of this group is represented in two dikes southeast of the Eagle mine on Bull Hill. They differ from the preceding rocks mainly in holding no olivine. On the other hand, their texture, which is intersertal, relates them more closely to the basalts. A decomposed rock occurring as a dike in the Ophelia tunnel probably belongs here.

VOGESITE.

The rocks of the vogesite group are phanerocrystalline, but are generally of fine grain. Small rounded grains of light-colored material (analcite) and flakes of dark mica are the characteristic minerals of the hand specimen. The rock of the Anna Lee dike in the Portland mine contains mica plates up to 1 cm. in diameter. Besides the Anna Lee dike, the dike in the Moose mine, one in the Jennie Sample mine, the Pinto dike, and perhaps some others are of this type.

The microscope shows the essential constituents to be orthoclase, hornblende, pyroxene, and biotite, with usually some analcite, frequently olivine, and at times a little plagioclase. The monoclinic feldspar is abundant as rather irregular laths of good size, usually untwinned. Plagioclase is only sparingly present and from its low, double refraction is probably albite. Analcite occurs in octagonal phenocrysts, also as rounded amygdule-like grains and as groundmass areas, as in the Bull Cliff rock. On decomposition it forms stilbite and is sometimes replaced by sericite. Brown hornblende is plentiful in long columns bounded by prism, clinopinacoid, and orthodome faces. It is often twinned. The pleochroism is not very strong. Augite is rather abundant in crystalline grains and a few larger phenocrysts. Numerous small foils of deep-brown mica are present. Olivine was present in considerable amount, but is now largely changed to serpentine and carbonates. Apatite is not common, but shows the same inclusions as in the Bull Cliff trachydolerite. Small particles of black iron ore are scattered here and there.

While the size of the individuals of the several constituents is not uniform and a porphyritic appearance sometimes thereby results, the rocks are essentially panidiomorphic granular in texture.

The analysis given below reveals the chemical similarity to the trachydolerites of the Isabella and Bull Cliff types. It shows that these rocks are somewhat deficient in ferromagnesian and rich in alkalic constituents for the typical vogesite, but the discrepancy is not very great and mineralogically they agree very closely.

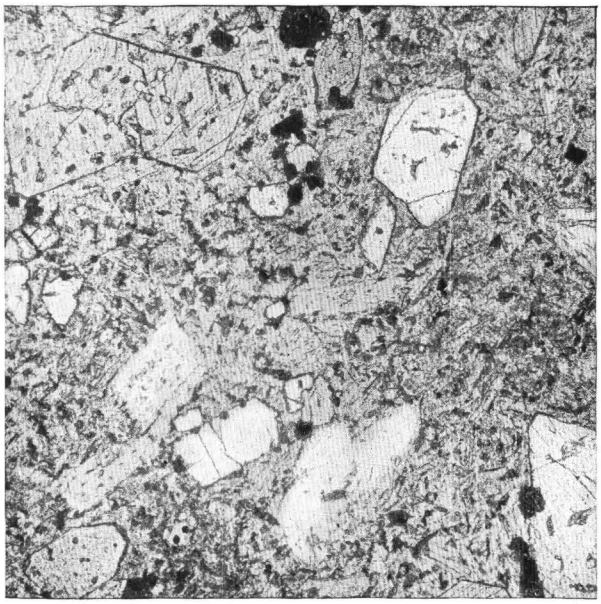
PLATE IX.

Photomicrographs of Rocks.

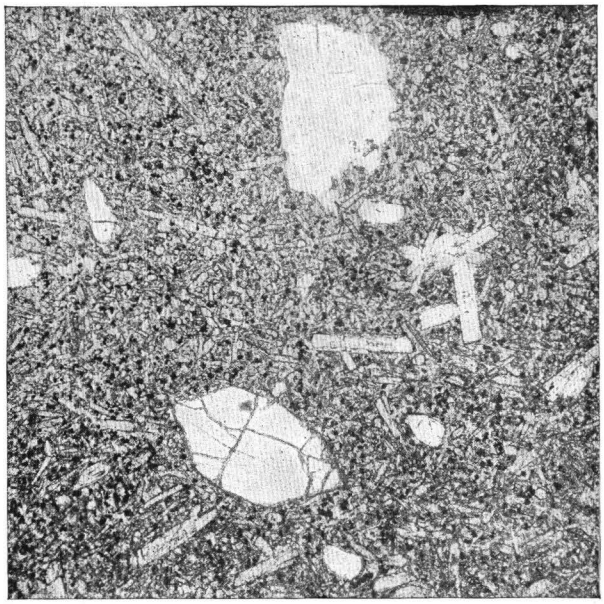
A, Trachydolerite (661 C. C.) from Isabella mine, level 10. Composed of orthoclase, plagioclase, analcite augite, olivine, and magnetite. Orthoclase and analcite are confined to the groundmass. Magnified 28 diameters.

B, Monchiquite (204 C. C.) from dump of Block 8 mine. Composed of analcite, augite, olivine, with a small amount of orthoclase. Analcite in phenocrysts and orthoclase in the groundmass. Magnified 28 diameters.

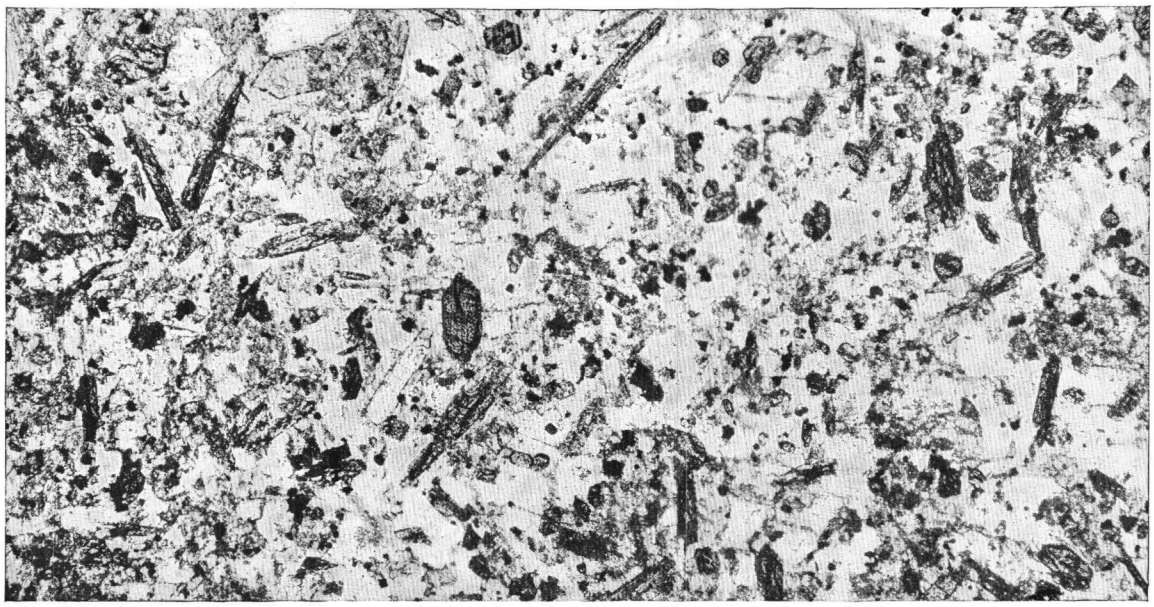
C, Vogesite (569 C. C.) from Jennie Sample mine, level 5. Composed of orthoclase, analcite, hornblende, and biotite. Magnified 35 diameters.



A



B



C

PHOTOMICROGRAPHS OF TRACHYDOLERITE, MONCHIQUITE, AND VOGESITE.

Analyses of vogesite.

	I.	II.		I.	II.
SiO_2	47.31	45.15	SO_3	0.05	.....
Al_2O_3	16.21	15.39	Cl	.05	.....
Fe_2O_3	5.05	2.76	FeS_2	.12	.....
FeO	2.90	5.64	Cr_2O_3	Trace.	.....
MgO	3.08	6.38	MnO	Trace.	.14
CaO	7.11	8.83	BaO	.17	.....
Na_2O	3.92	2.67	SrO	.02	.....
K_2O	3.73	2.77	Li_2O	Trace.	Trace.
H_2O-	.87	.....		100.29	100.21
H_2O+	2.17	2.85	Less O for Cl	.01	
TiO_2	1.64	2.80			
ZrO_2	.01	.....		100.28	
CO_2	4.98	4.27			
P_2O_5	.90	.56			

I. Vogesite, Jennie Sample mine, Cripple Creek. W. T. Schaller, analyst.
II. Vogesite, Castle Mountain. Bull. U. S. Geol. Survey No. 134, page 112.

MONCHIQUITE.

The monchiquites vary in granularity from aphanites to fine-grained porphyries holding phenocrysts of dark pyroxene, red olivine, and white amygdule-like grains of analcite. One specimen from a dike in the Gold Sovereign mine, has numerous flakes of dark biotite. Dikes referable to this group are known in many places, as in the Mollie Kathleen, Pointer, Gold Sovereign, Vindicator, Block 8, Ajax, Granite, Portland, and Strong mines, and in the Ophelia and Raven tunnels. A decomposed rock in the Ida May mine probably belongs here.

The characteristic of this group is the presence of abundant phenocrysts of pyroxene and olivine embedded in a matrix of analcite. Orthoclase is not uncommon as small grains in the groundmass, and albite occurs sparingly in a similar manner. Analcite occurs in round grains of a millimeter or two in size, penetrated by and inclosing crystalline grains of pyroxene. It often shows the characteristic cubic cleavage and faint shadowy birefringence. In a few instances these areas of analcite contain minute crystalline grains of a clear and colorless mineral of slightly higher refractive index than analcite and a double refraction of about 0.001 or 0.002. They appear to be made up of several hexagonal plates partially merged. It seems possible that the mineral is a zeolite, and if so it may be gmelinite, with which it corresponds closely. That it is leucite is remotely possible. Analcite also occurs very evenly distributed throughout the rock as a matrix for the other constituents, but relative to the amount of pyroxene and olivine it is not abundant. In this mode of occurrence it resembles the material in the larger areas, being clear and colorless, of so low index that the surface appears rough, and occasionally showing faint polarization. In both cases the material is easily decomposed to a somewhat turbid mineral, mostly developed in slender laths, which has properties corresponding to stilbite. Owing to the readiness with which analcite is dissolved, it is frequently partially replaced by dolomite. The pyroxene is probably augite and occurs in phenocrysts of two generations. The older individuals vary from

0.3 to 0.8 mm. in size, while the more abundant younger grains range from 0.2 mm. down. Practically no difference can be distinguished in the character of the two generations. Many of the olivine grains possess excellent form, but some are of irregular shape. They vary in size from 0.1 to 1 mm. Serpentine, carbonates, and iddingsite are the common alteration products. Biotite is of common occurrence in the groundmass. The biotite of the Gold Sovereign dike is yellowish red, pleochroic to nearly colorless, and gives brilliant interference colors. A few small crystals of apatite and many small grains of magnetite are present as accessories.

In texture these rocks are analogous to hypocrystalline porphyries in which analcite is present instead of glass.

Chemically they are richer in alkalies than many monchiquites, as an analysis shows. But, on the whole, they correspond very well with that group and better than with any other.

Analyses of monchiquites.

	I.	II.		I.	II.
SiO_2	44.08	43.74	Cl	0.04	Trace.
Al_2O_3	12.80	14.82	FeS_2	.26	.....
Fe_2O_3	4.58	2.40	S	.....	.10
FeO	3.72	7.52	Cr_2O_3	.05	.....
MgO	7.22	6.98	MnO	.14	.....
CaO	11.21	10.81	BaO	.13	.....
Na_2O	2.97	3.06	SrO	.06	.....
K_2O	3.31	2.90	Li_2O	Trace.	.....
H_2O-	.77	2.94		99.97	100.23
H_2O+	2.35		Less O for Cl	.01	
TiO_2	1.43	2.80			
CO_2	4.14	1.50		99.96	
P_2O_5	.70	.64			
SO_3	.01	.....			

I. Monchiquite, Block 8 mine, Cripple Creek. W. T. Schaller, analyst.
II. Monchiquite, Rio do Ouro, Brazil. Rosenbusch, Elemente der Gesteinslehre, Stuttgart, 1901, p. 244, analysis 8.

It was evidently this class of rocks which Stevens called limburgites. In his description it will be noted that Kemp, who made the determination, spoke of the phenocrysts as present in "a clear, colorless, isotropic base, either glass or analcite."[a] If the base were glass, the rocks would be limburgites, but since it is analcite they belong with the monchiquites of Pirsson.[b]

The dike from near the end of the Raven tunnel belongs to the same series of intrusions and is probably composed of a rock of similar character to that which Cross collected from the Appie Ellen shaft and which, from the analysis on page 50 of the 1894 report, he calls a nepheline basalt. He notes that the rock was considerably decomposed and that treatment with cold dilute hydrochloric acid dissolved nearly all of the soda. It seems quite probable that the soda was carried not by nepheline but by analcite and its decomposition products, like stilbite, especially since Cross's determination of nepheline by the microscope was not very positive.

[a] Trans. Am. Inst. Min. Eng., vol. 30, 1900, p. 763.

[b] Jour. Geol., vol. 4, 1896, pp. 679–690.

SUMMARY.

Nothing of very general application can be stated regarding the relative age of these three classes of dikes. In the Pinto mine the intersection of the Isabella and Pinto dikes is shown, and though, owing to the nature of the workings, a final opinion can not be reached, apparently the larger (Isabella) dike cuts and is therefore younger than the northward-trending Pinto dike. In the Block 8 mine a large dike which corresponds in every way to the Isabella dike cuts and faults the smaller monchiquite dike. Whether or not other dikes of the same respective classes are contemporaneous with these was not determined. On the assumption that they are, it may be said that the Isabella trachydolerite is younger than either the vogesite or the monchiquite, but no evidence has been found as to the relative age of the last two.

The foregoing descriptions make it plain that there are marked mineralogical and textural differences in these three groups of rocks. The analyses, on the other hand, show that the rocks are very closely related chemically and that they differ scarcely more from one another than they do from other rocks in the classificatory division in which they have been placed. For this reason the names assigned to them are not wholly satisfactory, but nevertheless seem to be the best now in use. It is possible that analyses of other specimens would show what is suggested by some of the thin sections—a still closer chemical relationship between the three groups and perhaps a complete gradation from one extreme to the other.

Finally, these basic dike rocks as a whole show close relationship to the type just preceding, the Bull Cliff trachydolerite, and through it are connected with all the foregoing Tertiary rocks. They complete, in the order recognized as normal, the series of eruptions from the Cripple Creek volcano.

BRECCIA.

The pyroclastic or fragmental volcanic rocks of the district have an extensive development. The largest area is a rude ellipse with the longer axis extending about 4 miles in a northwest direction from just north of the summit of Big Bull Mountain to the pass between Carbonate and Tenderfoot hills. The greatest width is about 2½ miles, reaching from the west side of Guyot Hill to Grassy Creek at Cameron. Masses of considerable size occur on Mineral Hill and Rhyolite Mountain, and smaller bodies are found on Copper Mountain, east of Galena Hill, on the summit of Big Bull Mountain, and on the upper part of Mount Pisgah just west of the area covered by the map.

The fragmental character of these rocks is generally discernible with readiness. They are, moreover, wholly fragmental, and do not consist, as is often the case, of numerous fragments held in a matrix which solidified about them from the molten state. They are made up of angular pieces which are, on the average, equidimensional and which vary in size from very minute grains to blocks over a meter in diameter. The name "breccia" is here applied to all these rocks, though "tuff" or "agglomerate" are in some cases more appropriate terms. There is usually no assortment of the material, and coarse and fine pieces occur together. The variety

most commonly met with consists of fragments whose maximum size is 2 to 3 cm., in a more finely granular matrix. In some cases all the grains are of small size, and then the true clastic nature of the rock is not always easily detected. Occasionally, however, a distinct banding is apparent, the material being well assorted into even layers a millimeter or less in thickness of extremely fine material, alternating with layers sometimes several centimeters thick of coarser yet still very small particles. Bedded tuff of this kind is seen on the slope north of Altman, at the southwestern base of Bull Cliff, and in the Lucky Guss No. 2 and Portland mines. In some cases the bedding is nearly or quite horizontal; in others it is much inclined. The appearance of some of this bedded tuff suggests that it is a deposit in quiet water.

All these rocks are considerably altered, even at the greatest depths attained in the mines. The freshest are soft, not very compact, of reddish, purplish, or bluish-gray color. Slight weathering changes them to brownish, probably by conversion of the iron into limonite. Most of the rock appearing at the surface has a light-yellowish color and is compact, owing to decomposition by atmospheric agencies. Hydrometamorphism, however, has been only one factor in the alteration of these rocks. Impregnation by dolomite and pyrite is a very common feature and may be attributed to the action of gases and solutions emanating from the seat of the Cripple Creek volcano. Small crystalline grains of pyrite or characteristic little cavities which result from its oxidation frequently serve to distinguish fine-grained, decomposed breccia from massive latite-phonolite. When rock thus heavily pyritized is exposed on a dump to the action of the atmosphere it frequently swels, cracks, and crumbles to a greenish-yellow powder.

Near the contact with granite and with schist the breccia generally contains a greater or less proportion of those rocks or of their constituent minerals. But the presence of these materials is uncommon in the great mass of the breccia. It appears, therefore, that the ancient crystalline rocks which occupied what is now the throat of the volcano were shattered and thrown out of the opening by violent explosions.

Cross, judging from specimens generally much decomposed, was of the opinion that the breccia is made up largely of andesitic rock. The extensive mine workings now give much additional information as to the character of these fragmental materials. In spite of the alteration which it has suffered, an examination of the breccia shows that it is made up chiefly of phonolite and latite-phonolite. The abundance of phonolite fragments in the breccia and the sharp contact of the massive phonolite with it prove that there took place at least two phonolite intrusions of considerable magnitude. But with the latite-phonolite the case appears to be different. Sharp contacts with the breccia do appear, it is true, as in the Trail tunnel, but in general the massive rock passes, by a gradual increase of shattering, into true breccia composed of various materials. In several places, as on the northeast knoll of Battle Mountain, the latite-phonolite is simply crushed and the fragments are only slightly dislocated. At increasing distance from the massive rock the disturbance becomes greater and the derangement of the grains finally admits the mingling of foreign fragments. In many places, particularly on the western slope of Bull Hill, an intermediate stage of this shattering has resulted

in a true breccia, composed, however, almost exclusively of fragments of latite-phonolite.

Granite (or schist or gneiss) brecciated in place in a similar manner occurs in narrow zones at several places along the contact, and in larger areas on the southern slopes of Carbonate and Mineral hills. The material is almost exclusively granite, with a rare fragment of volcanic rock. The grains are angular and appear to have suffered little dislocation. Only careful examination distinguishes this rock from massive granite, into which it grades. Its presence in considerable amounts at the northern edge of the main area seems to indicate that violent forces were at work at that place, but that they were not sufficient to wholly remove the shattered material, as was done in other places. This brecciated granite is not to be confounded with breccia, like that near the summit of Mineral Hill, composed largely of granite fragments which are not so strictly of local derivation. Granitic breccia of this kind is more or less loose and shows a sharp contact with the massive granite.

Fragments of vesicular, glassy rock have been found in some of the outlying breccia areas—for instance, in the small mass near the southwest corner of the area mapped and in one specimen from Copper Mountain. No material of this kind has been found in the main breccia mass, though the great decomposition which this fragmental rock has in many places undergone makes it impossible to speak with certainty on this matter.

On the dump of Stratton's Independence No. 2 shaft occur a few blocks of interesting material. It is a fine-grained, structureless tuff of light color, somewhat dolomitized, holding numerous small round pellets, nearly white, and varying from 1 to 6 or 8 mm. in diameter. Many of these have, instead of a single curved surface, a botryoidal or mammillary form, suggestive of concretions. When these are broken it is seen that a thin shell incloses material similar to that of the main portion of the rock. A thin section containing one of these pellets shows that the shell is made up of the same materials as occur both outside and inside of it, only of much finer grain. The interior of the globule seems to hold more carbonate than the material outside.

Whether these globules represent accumulations about drops of water,[a] and hence indicate the presence of surface conditions, or whether they have been formed by concretionary depositions from perhaps carbonated waters, and hence may have originated at a distance from the surface, it seems impossible to decide.

The microscope confirms the conclusions reached from an examination in the field. With the exception of the fragment of leucitophyre already described and the few occurrences of vesicular rock mentioned above, not a single mineral or particle of original material was seen in the scores of thin sections of breccia examined which is not represented in known areas of massive rock occurring in the district. The most prominent constituent is phonolite, usually in fragments which show only the trachytic groundmass, but occasionally phenocrysts are seen. But little less abundant are similar fragments of latite-phonolite. Next in abundance are broken phenocrysts of feldspar from these two rocks. Grains of magnetite from the latter are also common in some specimens. Broken grains of quartz,

[a] Cf. Howe, Ernest, Recent tuffs of the Soufrière, St. Vincent: Am. Jour. Sci., vol. 16, 1903, pp. 319-320.

microcline, and orthoclase are frequent and sometimes very plentiful, and locally fragments of schist are seen near the contact, but rarely in the midst of the breccia body. Sometimes the rock is evenly granular, but more commonly the larger grains are held in a finer-grained groundmass which is at times so comminuted that the highest powers of the microscope detect individual grains only with difficulty. The feldspars show some kaolinization, but are otherwise usually little changed. Dark silicates of all kinds are almost entirely removed through decomposition, and their place is frequently taken by either carbonate or pyrite, which also replace other minerals. Practically every specimen holds considerable dolomitic carbonate, and it proves to be this mineral which has accomplished most of the cementation and induration. A few grains of secondary quartz and chalcedony are sometimes observed, and little patches and microbotryoidal concentric coatings partially filling cavities are composed of opal. Silicification is, on the whole, however, surprisingly slight. The great majority of specimens hold crystalline grains of pyrite formed by replacement. Fluorite is found sparingly distributed throughout most of the breccia in small grains which have replaced other constituents. In the vicinity of mineral veins silica, carbonate, fluorite, and pyrite are apt to be more plentiful.

RHYOLITE.

Exposed in small isolated patches on the upper slopes of Grouse Hill is a volcanic rock readily determined as rhyolite. To the west of the Cripple Creek district the rock occurs in much larger areas which were doubtless originally connected and formed an extensive sheet. It is probable that this was largely a surface flow. It is considered by Cross to be of Miocene age. Where freshest the rock is of brownish-red color and composed of a compact, earthy groundmass, in which occur a few small crystals of sanidine and still less numerous grains of quartz and glistening flakes of biotite. None of the phenocrysts exceed a size of over 3 mm. In most places the rock is bleached to a light yellow and exhibits a noticeable vesicular structure which shows the direction of flow. In this weathered condition the rhyolite is easily mistaken for the fissile, bleached phonolite which occurs near by.

Quartz occurs in clear fragmental grains, frequently corroded and often holding embayed areas of the groundmass. Many of the phenocrysts of sanidine are well formed, and they commonly show Carlsbad twinning. Some of them are likewise corroded. A comparatively small amount of microcline is present. Biotite occurs in brownish foils, but is frequently decomposed and removed. The predominant groundmass is evidently a partially devitrified glass rich in silica. It shows the peculiar patterns of the felsophyric texture. In the more decomposed specimens the crystallization of the originally amorphous basis has reached such a stage that the groundmass may be called microgranular.

Cross considered that the rhyolite was older than the feldspathic grits of Grouse Hill and Straub Mountain, and on this conclusion based his arguments concerning the age of the Cripple Creek volcano. Later study has necessitated some modifications of this conclusion. It now seems probable that the grits have been invaded by the later rhyolite and indurated near the contact. The presence of rhyolite in them may be explained by brecciation at the time of intrusion. That brecciation of the rhyolite has actually occurred can be seen at one place. The contact of

rhyolite and grits is at nearly every place a sharp and close one. The rhyolite at the contact appears to be no more weathered than elsewhere, but it does show a narrow zone of finer, denser texture in immediate contact with the grits. The flow structure is parallel to this contact. In many places the upper part of the rhyolite is broken and cracked, and the fragments are angular. While the grits appear to have been in most places unconsolidated at the time of the intrusion and have fallen down into cracks and between fragments of the rhyolite, in a few cases the rhyolite seems to have broken across some of the mineral grains of the grits. There are indications just south of the boundary of the area shown in the map and also on the top of Grouse Hill that the grits partly underlie the rhyolite. Therefore, while final proof is perhaps lacking, it seems almost certain that the rhyolite is younger than the grits.

PETROLOGY OF THE DISTRICT.

In the foregoing pages of this chapter an endeavor has been made to present the distribution and the petrographic and chemical character of the various igneous and metamorphic rocks which occur within the Cripple Creek district. Short summaries have been given of the prominent features of the best-defined types, and in some cases a few words have been devoted to showing relations between certain of these types. It is the intention in the present section to view these rocks more broadly by considering them as products of crystallization from magmas. It will be the aim to hold closely to the facts as shown by the field occurrences and by the microscopic and chemical investigations and to avoid such considerations of the origin of the rocks, magmatic differentiation, and the like, as are purely theoretical.

For this purpose it will be advisable to disregard the gneisses and schists, in which metamorphism has been so intense that their origin is largely a matter of conjecture. The rhyolite, also, will not be considered, as it came from an extraneous source and is in no way essentially related to any of the other rocks of the district. The remaining rocks are igneous and may be divided on the grounds of magmatic relations into three groups, which, in order of age, are (1) the granites, (2) the olivine syenite with its related rocks, and (3) the rocks of the Cripple Creek volcano.

GRANITE GROUP.

Although there seems to be no very evident relationship between the several varieties of granite found in the district, Mathews has shown that when studied over a larger field, they present a marked uniformity in mineralogical and chemical composition. An average analysis which he has published[a] illustrates the character of this granitic type.

[a] Jour. Geol., vol. 8, 1900, p. 237.

Average analysis of Cripple Creek granite.

SiO_2	74.90	TiO_2	0.12
Al_2O_3	12.89	P_2O_5	.02
Fe_2O_3	.58	F	.31
FeO	.91	MnO	Trace.
MgO	.07	BaO	Trace.
CaO	.74	Li_2O	Trace.
Na_2O	3.10		100.26
K_2O	5.92	Less O for F	.13
H_2O-	.15		
H_2O+	.55		100.13

On comparison with analyses of typical granites of other localities, he found that these Colorado granites are (1) rich in silica, (2) deficient in the sum of iron, magnesium, and calcium oxides, (3) normal in regard to the amount of total alkalies, but rich in potash and hence correspondingly poor in soda, and (4) unusual because of their content of fluorine which is present as fluorite. To this the writer would add (5) that they are low in alumina.

OLIVINE-SYENITE GROUP.

The mineralogical evidence, as revealed by the microscope, makes it certain that an intimate genetic relationship exists between the pyroxene granite, pyroxene syenite with accessory olivine, olivine syenite, olivine gabbro and its doleritic contact facies, and the anorthosite dike of Iron Mountain, as well as nearly or quite all the diabase dikes of the district. Chemical investigations of these rocks have not been made, but it may be said that, in the order above given and excepting the anorthosite, they contain decreasing amounts of silica, alumina, and the alkalies, and increasing proportions of iron and lime. There is reason to believe that the content in magnesia reaches a limit in the olivine gabbro and is somewhat smaller in the contact facies of that rock and in the diabase. Even in the granite the amounts of silica, alumina, and alkalies are probably below the average for granite, while in the olivine gabbro and the diabase iron, magnesia, and lime are certainly high. Phosphoric acid is prominent in the olivine gabbro. The anorthosite, presumably the youngest rock of the group, probably contains rather low silica, high alumina and lime, and low soda.

This group, which is younger than the granite group, is thus characterized on the whole by low silica and alumina, high iron, magnesia, and lime, and probably a notable amount of alkalies.

ROCKS OF THE CRIPPLE CREEK VOLCANO.

For various reasons the rocks of the Cripple Creek volcanic group have been more thoroughly studied than those of the foregoing groups. Their distribution, being in general limited to the immediate vicinity of the volcanic center, has been conducive to obtaining a comprehensive and accurate idea of their mutual relations on the surface. The numerous mine workings, of which the majority are located in these volcanic rocks, add the great advantage of a third dimension to the geological relations seen on the surface and afford opportunity to collect fresh material which would not otherwise have been obtained. The interesting and comparatively unusual character of the individual rock types has led to more or less careful investigation of each.

MINERALOGICAL CHARACTERS.

As may have been inferred from a perusal of the description of these rocks, they have unquestionably been derived from some common source, or, as petrographers say, from the same magma. The calculation of all the analyses into percentages of constituent minerals would furnish a very valuable table for comparison of likenesses and differences throughout the series, but owing largely to the number of variable factors which would enter into such calculations it was found impracticable to do this. Since, with the exception of two varieties, the rocks are fine-grained porphyries it was likewise impossible to apply Rosiwal's[a] metric method at all easily or accurately. But the more important minerals may be tabulated to show the mineralogical similarities and differences throughout this rock group. The characteristic and distinctive mineral of the phonolites is nehpeline; olivine may be said to occupy an analogous position in the basic rocks. The ægirine of the former is balanced by the augite of the latter. The abundant alkali feldspar of the one class has a prominence which is occupied by calcic plagioclase and by hornblende and biotite in the other. Nosean and sodalite are noticeable constituents of the phonolites; the basic rocks contain considerable quantities of apatite. Intervening members of the series are in general characterized by none or by smaller amounts of these distinctive minerals, or by a combination of minerals from both extremes. They also contain minerals of an intermediate composition, like the sodic plagioclases and ægirine-augite. So much for the mineralogical differences. The points of similarity are not so numerous, but are perhaps more striking. The most notable is the fact that orthoclase and analcite occur in practically all members of the series. Another point of likeness is that the extreme members are linked together through the intermediate character of the middle members just outlined. These features can perhaps be better presented in a table.

Characteristic minerals in rocks of Cripple Creek volcano.

Phonolites.	Intermediate rocks.	Basic-dike rocks.
Nepheline.		
Soda orthoclase	Albite.	
Ægirine	Ægirine-augite.	
Sodalite, Nosean	Sodalite. Nosean.	
Orthoclase	Orthoclase	Orthoclase.
Analcite	Analcite	Analcite.
	Apatite	Apatite.
	Augite	Augite.
	Oligoclase, Biotite, Hornblende	Labradorite. Biotite. Hornblende.
		Olivine.

The conditions of cooling, as revealed by the texture of these rocks, apparently had but slight effect on the mineral composition. To be sure, the plutonic type, the syenite, often contains no analcite, but in other respects the mineral development is practically independent of texture.

[a] Verh. Wien. geol. Reichsanst., 1898, vol. 32, pp. 143 ff.

CHEMICAL CHARACTERS.

The foregoing relations, then, are almost wholly dependent on the chemical characters of the rocks, and are therefore expressed more exactly, although in a different light, in the following table of analyses. This is simply a compilation of the analyses appearing under each rock type, arranged approximately in the order of decreasing amounts of total alkalies, since these are the components which enter into orthoclase and analcite, the common minerals of the whole series, and which seem to constitute the most striking feature of the group. It is to be regretted that sufficient fresh material was not obtained for an analysis of the leucitophyre. It would probably correspond pretty closely with the phonolites, but would have an inverse ratio of potash to soda.

Analyses of rocks from the Cripple Creek volcano.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.
SiO_2	58.98	58.78	59.00	58.64	62.79	59.38	54.43	54.88	54.34	58.05	56.01	51.89	49.84	48.76	47.31	44.08
Al_2O_3	20.54	20.03	20.07	19.62	19.10	19.47	19.01	18.53	19.23	17.66	17.92	17.94	17.78	17.04	16.21	12.80
Fe_2O_3	1.65	1.87	1.58	2.17	2.29	1.60	2.85	2.93	3.19	3.51	4.20	3.85	5.86	5.04	5.05	4.58
FeO	.48	.49	.65	.42	.36	1.19	1.93	1.92	2.11	1.65	2.52	3.37	2.62	3.47	2.90	3.72
MgO	.11	.16	.10	.37	.40	.36	.99	1.26	1.28	1.55	2.04	2.88	3.02	4.57	3.08	7.22
CaO	.67	83	1.05	1.24	.87	1.96	4.33	4.15	4.53	4.48	4.80	5.62	7.35	8.64	7.11	11.21
Na_2O	9.95	9.36	8.34	8.39	6.23	7.80	6.92	6.65	6.38	5.80	4.92	4.63	5.20	4.27	3.92	2.97
K_2O	5.31	5.50	5.63	5.26	5.58	5.83	5.07	4.90	5.14	4.06	4.21	4.50	3.04	3.39	3.73	3.31
H_2O-	.19	.31	.24	.34	.25	.11	.31	.38	.14	.35	.31	.72	.34	.69	.87	.77
H_2O+	.97	1.57	2.03	2.40	.84	.69	1.68	1.75	1.17	.87	1.10	2.09	2.02	1.84	2.17	2.35
TiO_2	.24	.29	.29	.20	.71	.58	.96	.93	1.09	.91	1.20	1.34	1.43	1.34	1.64	1.43
ZrO_2	.20	.17	.20	.09	.02	.10	.04	.03	.07	.02	.02	.03	.03	Trace.	.01	None.
CO_2	.....	.....	.26	.23	Trace.	.....	.14	.13	.....	.....	.....	Trace.	.52	.22	4.98	4.14
P_2O_5	.04	.03	.05	.03	.12	.08	.25	.27	.27	.40	.55	.67	.76	.79	.90	.70
SO_3	.20	.12	.07	Trace.	None.	.37	.42	.36	.07	.04	None.	None.	None.	Trace.	.05	.01
Cl	.28	.58	.24	.14	Trace.	.22	.22	.14	.28	Trace.	Trace.	Trace.	Trace.	.01	.05	.04
FeS_2	.....	.....	.....	.....	.10	.....	.07	.10	.....	.....	.04	.41	.....	.11	.12	.26
Cr_2O_3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Trace?	Trace?	.05
MnO	.26	.15	.12	.20	.07	.15	.08	.25	.08	.13	.13	.08	.21	.08	Trace.	.14
BaO	None.	None.	Trace.	Trace.	.14	.13	.21	.18	.24	.19	.16	.19	.22	.15	.17	.13
SrO	None.	None.	None.	Trace.	.03	.03	.21	.11	.16	.08	.06	.11	.18	.07	.02	.06
Li_2O	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	.....	.....	Trace.	Trace.	Trace.	Trace.	Trace
	100.07	100.24	99.92	99.74	.....	100.05	100.12	99.85	99.77	.....	.....	.....	.....	.....	100.29	99.97
Less O for Cl	.07	.14	.06	.03	.....	.05	.05	0.3	.07	.....	.....	.....	.....	.....	.01	.01
	100.00	100.10	99.86	99.71	99.90	100.00	100.07	99.82	99.70	99.75	100.19	100.32	100.42	100.48	100.28	99.96

I.	Phonolite.	Miaskose.[a]	Mitre Peak.	IX.	Syenite.	Akerose.[d]	Longfellow mine.
II.	Phonolite.	Miaskose.	Straub Mountain.	X.	Latite-phonolite.	Akerose.	Anaconda mine.
III.	Phonolite.	Miaskose.	Big Bull Mountain.	XI.	Latite-phonolite.	Akerose.	Portland mine.
IV.	Phonolite.	Miaskose.	Rhyolite Mountain.	XII.	Syenite.	Monzonose.	Portland mine.
V.	Biotite trachyte.	Phlegrose.[b]	Portland mine.	XIII.	Bull Cliff trachydolerite.	Akerose.	Bull Cliff.
VI.	Latite-phonolite.	Miaskose.	Buff Cliff.	XIV.	Isabella trachydolerite.	Akerose.[e]	Isabella mine.
VII.	Latite-phonolite.	Essexose.	Bull Cliff.	XV.	Vogesite.	Monzonose.[c]	Jennie Sample mine.
VIII.	Latite-phonolite.	Essexose.[c]	Portland mine.	XVI.	Monchiquite.	Ourose.	Block 8 mine.

[a] According to the classification proposed by Cross, Iddings, Pirsson, and Washington, in "A Quantitative Classification of Igneous Rocks," Chicago, 1903.

[b] On line between phlegrose and nordmarkose.

[c] Near akerose.

[d] Near essexose.

[e] Near andose.

This table shows not only the close relation of each rock and each type of rock to those on either side of it, but it makes remarkably apparent a very gradual change from the Mitre Peak phonolite to the monchiquite. It expresses a considerable range in percentages of the essential oxides from one end of the series to the other as follows:

Range of percentages of essential oxides in rocks of Cripple Creek volcano.

SiO_2	62.80–44.00	CaO	11.20–0.70
Al_2O_3	20.50–12.80	Na_2O	10.00–3.00
Fe_2O_3	5.90– 1.60	K_2O	5.90–3.00
FeO	3.80– .40	H_2O	2.40– .70
MgO	7.30– .10		

But in spite of these wide limits, the analyses show a close chemical relationship or consanguinity, not only in these principal constituents, but in the less usual or less abundant ones like titania, zirconia, sulphuric anhydride, and chlorine. The last two components particularly are characteristic of this rock group. The noticeable percentage of combined water may be attributed mainly to analcite, but the fluid inclusions in apatite also account for an appreciable amount.

Certain features are brought out more clearly when these analyses are converted into molecular proportions, as has been done below. The "serial character"[a] of this rock group is thus very well shown.

Molecular ratios of essential oxides in rocks of Cripple Creek volcano.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.
SiO_2	0.983	0.980	0.983	0.979	1.046	0.990	0.907	0.915	0.906	0.967	0.933	0.865	0.831	0.813	0.788	0.734
Al_2O_3	.201	.196	.197	.192	.187	.191	.186	.181	.188	.174	.175	.175	.174	.167	.159	.126
Fe_2O_3	.010	.012	.010	.014	.014	.010	.018	.018	.020	.022	.026	.024	.037	.031	.031	.029
FeO	.007	.007	.009	.006	.005	.017	.027	.027	.029	.023	.035	.047	.036	.049	.040	.051
MgO	.003	.004	.003	.009	.010	.009	.025	.031	.032	.039	.051	.072	.075	.114	.077	.180
CaO	.012	.015	.019	.022	.016	.035	.077	.074	.080	.080	.086	.100	.131	.154	.127	.200
Na_2O	.161	.151	.134	.135	.100	.126	.111	.107	.103	.094	.079	.074	.084	.069	.063	.048
K_2O	.056	.059	.060	.056	.060	.062	.054	.052	.054	.044	.045	.048	.032	.036	.039	.035
H_2O+	.054	.087	.113	.133	.047	.038	.093	.097	.065	.048	.061	.117	.112	.102	.120	.131

From these figures certain other ratios may be obtained which also show the relations among the various rocks. Because of the definiteness and uniformity of composition of the phonolite group, the four phonolite analyses have been averaged and the resulting analysis designated by *P*. The other analyses are numbered according to the table on the facing page.

Ratios of potash to soda in rocks of Cripple Creek volcano.

I	1 : 2.87	IX	1 : 1.91
II	1 : 2.57	X	1 : 2.14
III	1 : 2.23	XI	1 : 1.76
IV	1 : 2.41	XII	1 : 1.54
P	1 : 2.54	XIII	1 : 2.62
V	1 : 1.67	XIV	1 : 1.92
VI	1 : 2.03	XV	1 : 1.61
VII	1 : 2.06	XVI	1 : 1.37
VIII	1 : 2.06		

[a] Washington, H. S., The igneous complex of Magnet Cove, Arkansas: Bull. Geol. Soc. America, vol. 11, p. 403.

As in the case of some similar computations,[a] the middle members of this rock series show an approach to a constant ratio of potash to soda, the ratio in this case being about 1:2, while the end members show greater variations, the ratio ranging, in round numbers, from 1:2.9 to 1:1.4. This is a rather smaller range than has been found in many petrographic provinces.[b] These ratios also show a general increase in the prominence of potash from the phonolite to the monchiquite end of the series, though there are several exceptions to this rule.

Without giving the figures for each rock, it may be stated that computation shows that the ratio of molecular proportions of total alkalies to the sum of Fe_2O_3, FeO MgO, and CaO ranges from 1:0.14 in the phonolites to 1:5.54 in the monchiquite, with fairly even gradation between these limits.

The ratio of molecular proportions of the sum of Fe_2O_3, FeO, MgO, and CaO to silica has a range of 1:33.8 in the phonolites to 1:1.6 in the monchiquite, illustrating the well-known tendency for these basic oxides to increase as silica falls.

The following table brings out the fact that, beginning with the phonolites, the alumina and silica decrease less rapidly than the total alkalies, and that the change is fairly uniform.

Ratios of total alkalies to alumina and silica in rocks of Cripple Creek volcano.

	K_2O+Na_2O.	Al_2O_3.	SiO_2.		K_2O+Na_2O.	Al_2O_3.	SiO_2.
P	1	0.98	4.86	XI	1	1.41	7.52
V	1	1.17	6.54	XII	1	1.43	7.09
VI	1	1.02	5.27	XIII	1	1.50	7.16
VII	1	1.13	5.50	XIV	1	1.59	7.74
VIII	1	1.14	5.77	XV	1	1.56	7.72
IX	1	1.20	5.77	XVI	1	1.51	8.85
X	1	1.26	7.01				

In the more alkalic rocks the close approach to unity of the ratio of alkalies to alumina is of interest when compared with the amount of minerals in those rocks which have this ratio—orthoclase, albite, nepheline, and analcite—together with the slight amount of alumina which enters into the pyroxenes in those rocks. In the phonolites soda orthoclase, nepheline, and analcite make up about 85 per cent of the rock. The excess of alkalies over alumina in this case is due to the soda in the ægirine and to the excess of soda over alumina in sodalite and nosean. In the more basic end of the series the predominance of alumina over alkalies, when taken in connection with the comparatively small importance of the anorthite molecule, is of interest in showing that the alumina must enter largely into the composition of the pyroxene, forming augite instead of diallage or diopside, the minerals which would naturally be expected in such rocks.

[a] Weed and Pirsson, Geology of the Castle Mountain mining district, Montana: Bull. U. S. Geol. Survey No. 139, 1896, pp. 137, 138.

[b] Weed and Pirsson, op. cit., p. 137. Washington, H. S., op. cit., p. 402. Iddings, J. P., The igneous rocks of Electric Peak and Sepulchre Mountain: Mon. U. S. Geol. Survey, vol. 32, 1899, p. 136. Adams, F. D., The Monteregian hills: Jour. Geol., vol. 11, 1903, pp. 265, 271. Pirsson, L. V., Igneous rocks of the Highwood Mountains, Montana: Bull. U. S. Geol. Survey No. 237, 1905, pp. 172, 173.

The above table shows a close relation between silica and alumina, which is better represented below:

Ratios of alumina to silica in rocks of Cripple Creek volcano.

P	1 : 4.98	XI	1 : 5.33
V	1 : 5.59	XII	1 : 4.94
VI	1 : 5.18	XIII	1 : 4.78
VII	1 : 4.82	XIV	1 : 4.87
VIII	1 : 5.06	XV	1 : 4.96
IX	1 : 4.82	XVI	[a]1 : 5.83
X	1 : 5.56		

This agreement throughout the series is really very striking and constitutes one of the best proofs that genetic relations exist between all these rocks. It almost wholly excludes the possibility of there having been more than one original source, or, conversely, it furnishes very strong proof that these rocks were derived from a common magma. It shows, furthermore, that although considerable differentiation[b] has taken place, as indicated by the range of percentages on page 104, the silica and alumina have nevertheless clung together during the processes which caused this result—whatever has affected the one has equally affected the other.

This is the only instance known to the writer in which an almost absolute chemical consanguinity (the sole fundamental factor) has been shown to exist between the various rock types of a petrographic province. The nearest approach to proof of definite chemical relationship which has been found in the literature is the exposition of the serial relations of the various rocks in certain areas, as in the Little Belt Mountains in Montana[c] and in the Magnet Cove laccolith in Arkansas.[d]

It is believed, moreover, that this practically constant ratio of alumina to silica, together with the intimate, gradually changing relationship of the other oxides throughout the series, constitutes the best evidence yet brought forward toward proving what has heretofore been only assumed[e]—that the common magma was originally homogeneous.

From a mineralogical point of view, this alumina-silica ratio, which is approximately 1:5, indicates a large proportion of molecules having the orthoclase-albite ratio, 1:6, combined with minerals like nepheline, analcite, the remaining plagioclases, and the pyroxenes, which in general have a ratio of alumina to silica lower than 1:5.

COMPOSITION OF THE ROCKS EXPRESSED BY DIAGRAMS.

Certain of these relations between these rocks are very well shown when the proportions of the essential oxides are represented graphically. For this purpose the general method adopted by Iddings[f] has been used, but a few modifications have been introduced. The individual diagrams, each representing one analysis, are constructed on four lines in the same plane, intersecting at a common point and

[a] The exceptional divergence in this case may be partially due to the decomposition which the rock has undergone.

[b] The term differentiation is here used in the same limited sense as employed by Pirsson. See Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 573; Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, pp. 566-567; and Bull. U. S. Geol. Survey, No. 237, 1905, p. 183.

[c] Pirsson, L. V., Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 571.

[d] Washington, H. S., Igneous complex of Magnet Cove, Arkansas: Bull. Geol. Soc. America, vol. 11, 1900, p. 403.

[e] Cf. Bull. U. S. Geol. Survey No. 139, 1896, p. 141.

[f] Prof. Paper U. S. Geol. Survey No. 18, 1903.

cutting the plane into sectors of 45° each. The accompanying chart (Pl. X) shows the disposition of the oxides, the length of the radii representing the relative amount of the respective constituents. The silica can not be feasibly shown in these diagrams because of its large amount. It seems desirable to separate the ferrous and ferric iron whenever possible, particularly in rocks of this kind where the ægirine molecule enters. It is a satisfaction to feel that such a separation is in this case perfectly warranted by the accuracy of the analyses made by the chemists of the Survey. Water is essential in these rocks and has been given a place in the diagram, while titanic oxide has been omitted, both because of the difficulty in representing it and because of its comparatively small importance in the composition of this group of rocks.

The center of each diagram is located with respect to a pair of coordinates, of which molecular proportions of silica are the abscissas and molecular proportions of total alkalies are the ordinates. This was the most practical manner of representing the silica, and as it is admittedly the most important constituent of igneous rocks it is perhaps not illogical to distinguish it from the other oxides. In the case of this particular rock series the total alkalies are of next importance and have been emphasized by being made the other determinant of the position of the diagram. No particular advantage could be seen in Iddings's method of using the ratio of total alkalies to silica as ordinates—at least for these rocks, where it seemed only to complicate and obscure the relations which it was desired to show.

To continue a simile which Iddings has used, likening these diagrams to ships moving away from the observer, it may be said that a large spread of sail indicates high alkalies and alumina; a large hull indicates high iron, magnesia, and lime; a high mast indicates much alumina; large draft points to high magnesia; upper sails out to starboard stand for soda and to port for potash; ferric iron is situated at the starboard rail and combined water at the port; ferrous iron and lime make up respectively the starboard and port sides of the hull; the farther to the right the diagram is situated on the chart, the more siliceous is the rock; the higher it is the more alkalic. The converse is of course true.

Because of the definiteness and uniformity of composition of the phonolite group, the four phonolite analyses have been averaged[a] and the resulting analysis represented by the diagram P. The other diagrams are numbered according to the table on page 104. To these thirteen diagrams is added, in its proper position, the diagram representing the average rock of the earth's crust (marked E) according to Clarke's latest computation.[b]

The position which the Cripple Creek rocks occupy with reference to this average rock shows at once that they are in general low-silica, high-alkali rocks; that, with the exception of the biotite trachyte (No. V), which in several respects diverges from the series, the most siliceous rock corresponds to the average rock in silica content, and the least alkalic corresponds to it in the proportion of alkalies.

A comparison of the individual diagrams with that of the average rock indicates also that on the whole the Cripple Creek rocks are alumina rich. Iron, magnesia, and lime are below the average in all but the last five members, in which they are above. Ferric iron is on the whole high, while ferrous iron is low. Magnesia

[a] See p. 66

[b] Bull. U. S. Geol. Survey No. 228, 1904, p. 19.

exceeds the average only in two rocks; but lime is about equal to or greater than the average in most of the types. Water is on the whole a little high.

The combination of high alkalies and alumina with moderate silica gives to this rock group the distinctive and rather uncommon feature of containing practically no quartz.

AVERAGE ROCK OF THE CRIPPLE CREEK VOLCANO.

Another and perhaps more valuable comparison might be made with the average rock of the earth's crust if some quantitative relation could be instituted between the Cripple Creek rocks and the composition of the average rock of the volcano thus be obtained.

By making certain assumptions, which are more or less supported by fact or probability, it is possible to obtain an approximate idea of the composition of the material extruded from the volcanic reservoir which must have underlain the Cripple Creek district.

It has been shown in a preceding chapter (p. 21) that the main breccia area practically occupies the throat of the volcano and that the walls of this conduit are very steep. If all the masses of eruptive rock which appear at the surface continue with uniform size in depth, then their volumes would bear to each other the same proportion as their areas. But it is certain that the size of these masses does vary at different depths. Mine workings which extend as deep as 1,500 feet, however, do not indicate any noticeable change in the relative abundance of the various rock types, with the exception of two cases that will be considered presently.

There is another fact also which tends to make a relation on the basis of area fairly representative. An uncertain but considerable amount of volcanic material has been removed by erosion. If, therefore, the contacts of a mass diverge downward, showing that the amount of material is greater below, they would in general have converged upward and have inclosed less of the rock than the present surface exposure indicates, and vice versa. Accordingly, while the surface area as now shown may not be an exact average cross section of the mass throughout its vertical extent, it nevertheless approaches such an average.

Furthermore, only a glance at the map is needed to show that phonolite, latite-phonolite, and breccia comprise by far the greater proportion of the volcanic rocks. The breccia is made up almost wholly of the two other rocks, in approximately equal amounts. The composition of the latite-phonolite does not vary greatly from that of phonolite. Finally, the amount of phonolite occurring within the limits of the area mapped is only about half as great as the amount which occurs outside those limits, but in the same general locality, and which must of course be included in the computation. It is therefore possible to predict, without further estimates, that the average rock will have a composition between phonolite and latite-phonolite, and that it will be nearer to phonolite. It is obvious, therefore, that any inaccuracies which may enter into the calculation of the relative amounts of the different rocks, be they theoretical or mechanical, will be very much minimized by this fact.

The two exceptions to the general rule that the igneous masses have on the average a nearly vertical contact are the Bull Cliff trachydolerite and some of the

bodies of latite-phonolite. The former certainly appears to decrease in amount with depth; but, as has been shown, its amount is so small relative to the total mass of eruptive rock that this error is practically insignificant. With the latite-phonolite the case is different. Large bodies are known to occur which are flat and ultimately give out in depth or diminish to comparatively narrow dikes; but, because of this flat shape, the actual horizontal extent of these bodies is in several known cases considerably greater than their area exposed on the surface. Moreover, flat bodies which do not appear at the surface have been encountered in some of the mine workings and this makes it fair to assume that still other buried masses of latite-phonolite exist at various depths. So, while the assumption that the present exposed area of this rock represents its relative volume is unfounded, still it does not seem at all improbable. But even if this assumption be wholly untrue the error which its use introduces is not so great as might at first appear. In all cases where the latite-phonolite has been found to give out in depth it has been underlain by breccia. But as has been shown, the breccia is composed of about half latite-phonolite; the other half, phonolite, is not very different in composition from latite-phonolite. Any error which may result from this assumption will therefore tend only to throw the computed composition of the average rock a little farther from phonolite than is actually the case.

On the whole, therefore, the first of the following assumptions seems warranted, as well as the remaining ones:

1. The volumetric proportion of the various rock types corresponds to their areal proportion on the present surface.
2. The same specific gravity (about 2.55) may be assigned to all the rocks except the breccia, which is given 0.8 of that value.
3. The breccia is composed of 5 per cent granite, gneiss, and schist; 50 per cent phonolite; and 45 per cent latite-phonolite.
4. The narrow phonolite dikes make up 1 per cent of the total massive phonolite.
5. The basic dikes have an average width of 4 feet, but because of their ready decomposition and consequent frequent escape of detection this width is increased to 6 feet.
6. Of the basic dikes, the Isabella trachydolerite comprises 50 per cent, vogesite 10 per cent, and monchiquite 40 per cent.

The areas of the rocks were accordingly measured on the map by means of planimeter and scale, and are shown in the table below:

Areas of the Cripple Creek volcano rocks.

Rock.	Actual area.[a]	Area corrected for breccia.	Rock.	Actual area.[a]	Area corrected for breccia.
	Sq. miles.	*Sq. miles.*		*Sq. miles.*	*Sq. miles.*
Phonolite	6.542	9.344	Isabella trachydolerite	0.005	0.005
Biotite trachyte	.130	.130	Vogesite	.001	.001
Latite-phonolite	.678	3.039	Monchiquite	.004	.004
Syenite	.143	.143	Breccia	6.636	.....
Bull Cliff trachydolerite	.046	.046			12.712

[a] Of this, 4.230 square miles of phonolite and 0.169 square mile of breccia are not included by the Cripple Creek map. See Pikes Peak folio: Geologic Atlas United States, folio 7, U. S. Geol. Survey, 1894.

When these areas are computed into percentages the following result is obtained:

Relative abundance of the Cripple Creek volcano rocks.

	Per cent.		Per cent.
Phonolite	73.505	Isabella trachydolerite	0.039
Latite-phonolite	23.907	Vogesite	.008
Biotite trachyte	1.023	Monchiquite	.031
Syenite	1.125		
Bull Cliff trachydolerite	.362		100.000

This shows the surprisingly small importance of the basic rocks, and though the figure for the Bull Cliff rock may be somewhat too high, it makes very little difference. The leucitophyre has, of course, been omitted, but the probably very small amount which was ever present would have little effect on the whole.

In order to obtain from these figures the composition of the average rock of the volcano, it is necessary to make another assumption, viz, that the analysis of each rock type in cases where only one analysis has been made and the average of the several analyses where several have been made represent truly the average composition of the respective rock types. It may be said in the first place that material for analysis was chosen particularly to typify the group to which it belonged. In the case of those rocks of which only one analysis has been made, their relative amount is so small that the possible error arising from an unrepresentative analysis will have little effect on the total composition. In each case where several analyses have been made, it is believed that the average of these is fairly typical of that rock division. In the phonolites, which, as above shown, make up nearly three-fourths of the total, the five analyses are so nearly identical that in that case certainly the average analysis is a fair representation of the composition of the phonolites.

By taking the above respective percentages of the average analyses of each rock type, an analysis is obtained which represents the average rock of the volcano.

Composition of average rock of the Cripple Creek volcano.

	I.	II.	III.		I.	II.	III.
SiO_2	58.23	58.50	0.975	SO_3	0.13	0.13	.....
Al_2O_3	19.65	19.75	.193	Cl	.26	.26	.....
Fe_2O_3	2.16	2.18	.014	FeS_2	.01	.....	.....
FeO	.86	.87	.012	Cr_2O_3	Trace.	Trace.	.....
MgO	.47	.47	.012	MnO	.17	.17	.....
CaO	1.74	1.76	.031	BaO	.05	.05	.....
Na_2O	8.29	8.34	.134	SrO	.02	.02	.....
K_2O	5.27	5.31	.056	Li_2O	Trace.	Trace.	.....
H_2O-	.27	.....	.....				
H_2O+	1.61	1.62	.090		99.99	100.06	.....
TiO_2	.43	.43	.....	Less O for Cl	.06	.06	.....
ZrO_2	.13	.13	.....				
CO_2	.10	.....	.....		99.93	100.00	.....
P_2O_5	.07	.07	.....				

I. Average rock computed from analyses.
II. Average rock with pyrite, carbon dioxide, and hygroscopic water excluded and recalculated to 100 per cent.
III. Molecular proportions of II.

By referring to the table on page 104, it is seen that, as was to be expected, this rock comes between the phonolites and latite-phonolites and agrees very closely with the most basic phonolite.

A few words may be added concerning the meaning and value of this analysis. In arriving at this result the assumptions made have been perhaps wholly incapable of conclusive demonstration; they have been more or less arbitrary, and largely dependent on the personal factor. It is believed, however, that the result given is an approximation to the truth and hence of value. This average rock is not proposed as representing the "originally homogeneous magma" from which the various types of rock have been derived by segregation, differentiation, liquation, fractional crystallization, or other means. Some petrologists are led by principles of physical chemistry to believe that the material which is extruded from the main reservoir is often not representative of the total material in the reservoir. But it is believed that this analysis gives an approximate idea of the composition of the material which has issued from this volcanic reservoir; that is, the average rock of the Cripple Creek volcano.

On comparing this analysis, which is represented on the chart (Pl. X) as C, with that of the average rock of the earth's crust, it is apparent that in silica content the difference is not great, but it is very much richer in alkalies and contains noticeably more alumina. Ferrous iron, magnesia, and lime are very low in the Cripple Creek rock, but ferric iron and water are about the same as in the average rock of Clarke.

The ratio of potash to soda in the average rock of the earth's crust is 1:1.75. The ratio of potash to soda in this average Cripple Creek rock is 1:2.39, a figure considerably higher than the apparent mean value of 1:2 in the table on page 105. It is believed that this illustrates the danger of placing too great confidence on deductions made from analyses without having regard to the quantitative relations of the rocks which the analyses represent.

The ratio of total alkalies to the sum of Fe_2O_3, FeO, MgO, and CaO is 1:0.36. The ratio of this sum to silica is 1:14.13. The predominance of ferric over ferrous iron accounts for the ægirine molecule in the phonolites.

The ratio of total alkalies to alumina and silica is 1:1.01 : 5.13, and of alumina to silica 1:5.05. These last two ratios emphasize the nearly unit ratio of alkalies to alumina and confirm the statements made on page 107 as to the constant relation of alumina to silica in these rocks.

The ratio of alkalies to alumina and silica is very nearly stoichiometric, but probably only by coincidence.

The appearance of orthoclase and analcite as final separations from the molten material and the constant relation of alumina and silica throughout the series may be some indication of an approach to the eutectic composition for the original magma.

Besides the essential oxides, high zirconia and chlorine and low phosphoric acid are characteristic of the Cripple Creek average when compared with the average rock of Clarke.

If lavenite is present in the phonolites, the rock contains original fluorine.

ORDER OF SUCCESSION OF THE ROCKS.

It is impossible to believe that near the beginning of eruptive activity effusive types were not more abundant than the few occurrences mentioned would indicate.[a] It is true, however, that by far the greater part of the rocks which now remain are intrusive. Latite-phonolite, together with syenite, was probably the first of these to be erupted. It was followed by phonolite, Bull Cliff trachydolerite, and the basic dike rocks in the order given. This sequence is a common one, beginning with a rock of intermediate composition, passing to one extreme, the phonolites, and thence finally to the other extreme, the basic dike rocks. These last do not appear to conform exactly to the general sequence, since the Isabella trachydolerite was probably erupted after the vogesite and monchiquite, but they are so similar in composition that they may best be considered as one group. In connection with the sequence, the radial grouping of the dikes is of interest.

SUMMARY.

The Tertiary volcanic rocks of the Cripple Creek district, except the rhyolite, afford an excellent illustration of a petrographic province, i. e., they have clearly been derived by differentiation from a single originally homogeneous magma. The average rock of the Cripple Creek volcano is characterized by very high soda, high potash, high alumina, noticeable sulphuric anhydride, chlorine, and zirconia, and low ferrous iron, magnesia, and lime. All the rocks have approximately the same ratio of alumina to silica.

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[a] Cf. p. 20.

CHAPTER IV.—GENERAL MINERALOGY OF THE DISTRICT.

LIST OF MINERALS.

For convenient reference, the names of the principal mineral species known to occur in the Cripple Creek district are assembled in the following list, which contains 68 established and 8 doubtful species:

List of minerals of the Cripple Creek district.

Gold.	Rutile.	Anorthite.
Copper.	Limonite.	Sodalite.
Tellurium?	Psilomelane.	Nosean.
Petzite?	Molybdite.	Nepheline.
Sylvanite.	Ilsemannite.	Analcite.
Krennerite.	Calcite.	Natrolite.
Calaverite.	Dolomite.	Stilbite.
Emmonsite.	Rhodochrosite.	Tourmaline.
Tellurite.	Barite.	Olivine.
Pyrite.	Celestite.	Augite.
Marcasite?	Alunite.	Diallage.
Molybdenite.	Gypsum.	Ægirine.
Stibnite.	Glockerite?	Hornblende.
Cinnabar?	Chalcanthite.	Arfvedsonite.
Galena.	Mirabilite.	Biotite.
Zinc blende.	Mallardite.	Muscovite.
Chalcopyrite.	Epsomite.	Roscoelite.
Tetrahedrite.	Apatite.	Chlorite.
Chalcocite?	Wavellite.	Serpentine.
Fluorite.	Titanite.	Kaolin.
Quartz.	Hübnerite.	Chrysocolla.
Chalcedony.	Orthoclase.	Morencite?
Opal.	Microcline.	Chloropal?
Magnetite.	Albite.	Coal.
Specularite.	Oligoclase.	
Zircon.	Labradorite.	

NOTES ON OCCURRENCE.

NATIVE ELEMENTS.

Gold.—Within the oxidized zone of the veins native gold is abundant, but it rarely exhibits its normal characteristics. It forms small particles, many of which are entirely invisible to the naked eye, or in a few cases larger grains, spongy masses, thin sheets, or plates. Occasionally elongated forms with grooved surfaces are found which more or less plainly show their character as pseudomorphs after calaverite or other tellurides. The color is dull brownish, not unlike that of limonite, but the true tint and luster is quickly shown upon slight pressure with a knife.

Its texture is spongy and brittle. In places it is covered by rusty films of a ferruginous compound containing tellurium (Penrose), and this coating often interferes with amalgamation. The gold of Cripple Creek is of great purity; sometimes, indeed, silver is present only in traces.

Free gold does not, as a rule, occur in the veins except where set free by oxidation. To this general statement there are, however, some exceptions. Bright gold of normal characteristics occurred on a seam with roscoelite in the El Paso mine and in tetrahedrite in the lower levels of the Doctor-Jackpot mine. Similar gold is reported to have occurred in the Laura Lee mine, on Mineral Hill. Examination of some telluride ores, supposedly free from oxidation, seems to indicate that a very small part of the gold is free; it is, however, very difficult to assert that no oxidation has taken place. The beginning of this process is indicated by a thin brown film on the telluride crystals.

The placer gold, chiefly won from the southwest slopes of Mineral Hill, has the same characteristics as that from the oxidized zone of the veins.

Pseudomorphs of this rusty and spongy gold after calaverite and other tellurides are common. They usually show the normal prismatic form of the calaverite and their faces are often warped and shrunken by loss of volume. Fine specimens of these pseudomorphs were seen from the Mercer and Zenobia veins. In the latter case their surface was covered by a film of opal.

Silver.—No native silver is reported from the district, although it might well form in places by the oxidation of tetrahedrite, some of which is very rich in this metal. Penrose reports a locality "on the hill above the Rosebud mill"[a] near the confluence of Cripple Creek and Arequa Gulch, where the gold contains 40 per cent of silver.

Copper.—Native copper was noted in a specimen from an altered basalt dike on the Hillside claim on Tenderfoot Hill. A seam containing partly crystallized copper is reported to have been found on Mineral Hill. The mineral might easily form by the oxidation of tetrahedrite.

Tellurium.—Tellurium has been reported from Raven Hill in crystallized form, but the find is not authenticated. Its general absence from the veins of the district is somewhat remarkable.

THE TELLURIDES.

As the principal ore minerals of Cripple Creek consist of tellurides, a brief review of the various compounds known in nature and belonging to this class may be of interest. The principal telluride of Cripple Creek is calaverite, although occurrences of sylvanite and petzite are also common.

The tellurides are minerals with metallic luster, usually soft, the hardness rarely exceeding 3; semisectile or brittle. The specific gravity is usually about 9; calaverite is the heaviest of the number and reaches 9.4.

Coloradoite.—Mercuric telluride (HgTe). Massive; iron black; not definitely known from Cripple Creek.

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[a] Penrose, R. A. F., jr., Mining geology of the Cripple Creek district: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 120.

"*Kalgoorlite.*"—Supposed telluride of gold, silver, and mercury ($HgAu_2Ag_6Te_6$). Probably a mixture of petzite and coloradoite.[a] Iron black; not known from Cripple Creek.

Melonite.—Nickel telluride (Ni_2Te_3). Reddish white; granular or foliated; not known from Cripple Creek.

Altaite.—Lead telluride (PbTe). Tin white, with yellowish tinge; massive, with cubic cleavage; not known from Cripple Creek.

Hessite.—Silver telluride (Ag_2Te; Te 36.7, Ag 63.3). Sometimes with up to 13 per cent gold. Isometric; lead gray or steel gray; not known from Cripple Creek.

Petzite.—Telluride of silver and gold $(Ag,Au)_2Te$. Ag:Au=3:1. Te 32.5, Ag 42, Au 25.5. Massive; steel gray to iron black; stated by T. A. Rickard to occur on the Geneva claim of the Gold King mine.

Tetradymite.—Sulphotelluride of bismuth ($Bi_2(Te,S)_3$). Steel gray; massive or small crystals. This is the most wide-spread tellurium mineral, but it is not known from Cripple Creek.

Nagyagite.—A sulphotelluride of gold and lead, with varying composition. Gold 6 to 13 per cent. Tabular crystals; blackish or lead gray; not known from Cripple Creek.

The tellurides which enter into the ores of Cripple Creek have the general formula $(Ag,Au)Te_2$ and comprise the three species calaverite, sylvanite, and krennerite.

Sylvanite.—Telluride of gold and silver [$(Au,Ag)Te_2$]. Au : Ag=1:1. Te 62.1, Ag 13.4, Au 24.5. Monoclinic; usually crystallized or in arborescent forms; twins frequent, specific gravity = 7.9 – 8.3; excellent cleavage; color pure steel gray or silver white, inclining to yellow. The name of sylvanite is derived from the province of Transylvania, Hungary, where it was first found. The presence of this mineral in Cripple Creek was first suggested by Mr. R. Pearce[b] on the basis of an analysis of ore from the Moose mine; but the mineral was finely divided and some silver ore like tetrahedrite might easily have been present. Since then the presence of typical crystallized sylvanite has been shown by Dr. Charles Palache,[c] the occurrences being at the Mabel M. and Little May mines, and from another doubtful locality, the material being obtained from Mr. F. M. Woods, of Victor. The small crystals are thin-tabular parallel to *b* (010) and are bordered by planes of the orthodome zone. T. A. Rickard[d] states that the mineral has been found at the Independence, Portland, Moon-Anchor, and Anchoria-Leland mines. During our investigation it was also identified from the Elkton and Blue Bird mines.

Krennerite.—Telluride of gold and silver [$(Au,Ag)\ Te_2$]. Composition variable. The original analysis of material from Nagyag, Transylvania, gave 19.44 per cent of silver. The analysis of Cripple Creek material gives Au 43.86, Ag 0.46, Te 55.68, or practically the same composition as calaverite. Orthorhombic; crystals normally developed; prismatic with striated prism combined with pinacoid and domes. Identified from the Independence mine.[e]

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[a] Spencer, L. J., Mineralogical notes on Western Australian tellurides; the nonexistence of "kalgoorlite" and "coolgardite as mineral species: Min. Mag., vol. 13, 1901–1903, pp. 268–290.

[b] Proc. Colorado Sci. Soc., vol. 5, 1894–1896, p. 15.

[c] Zeitschr. f. Krystall. u. Min., vol. 34, 1901, p. 539. Also Am. Jour. Sci., 4th ser., vol. 10, 1900, pp. 419–422.

[d] The Cripple Creek gold field: Inst. Min. and Met., London, vol. 8, 1899.

[e] Myers, W. S., and Penfield, S. L., Am. Jour. Sci., 4th ser., vol. 5, 1898, p. 376.

Calaverite.—Telluride of gold and silver [(Au,Ag) Te_2]. This mineral, previously known from Boulder County, Colo., and from Calaveras County, Cal., was first identified from Cripple Creek by F. C. Knight[a] in 1894. About the same time it was found at three separate localities in the district by Doctor Hillebrand.[b] Elaborate studies of its crystallography were made in 1901 and 1902 by S. L. Penfield and W. E. Ford[c] in the United States and by G. F. Herbert Smith and G. T. Prior,[d] in England.

Some of the calaverite from Cripple Creek differs from that of other localities in having an exceptionally small percentage of silver. Most of the following analyses were made of well-crystallized material.

Analyses of calaverite from Cripple Creek.

	1.	2.	3.	4.	5.[a]	6.[b]	7.	8.
Te	56.22	57.60	57.40	57.30	(57.25)	(56.75)	57.87	56.93
Au	40.14	39.17	40.83	41.80	40.99	42.77	41.66	41.90
Ag	3.63	3.23	1.77	.90	1.74	.40	.77	.79
	99.99	100	100	100	99.98	99.92	100.30	99.62

[a] Plus gangue 0.02 per cent; tellurium by difference. [b] Plus gangue 0.08 per cent; tellurium by difference.

1. F. C. Knight, Cripple Creek.
2. W. F. Hillebrand, Prince Albert mine. } Specific gravity, 9.0, impurities subtracted.
3. W. F. Hillebrand, Raven mine. } Specific gravity, 9.0, impurities subtracted.
4. W. F. Hillebrand, C. O. D. mine. } Specific gravity, 9.0, impurities subtracted.
5. Penfield and Ford, Monument mine. Specific gravity, 9.328.
6. Penfield and Ford, Cripple Creek. Specific gravity, 9.388.
7. Smith and Prior, Raven Hill. Specific gravity, 9.155.
8. Smith and Prior, Cripple Creek. Monoclinic.

The calaverite occurs commonly in slender, deeply striated prisms, elongated in axis of symmetry. Ordinarily they are very small, but sometimes reach 1.5 cm. in length. The faces have very high indices and do not fall in zones. On the whole the development is extremely unusual and presents some features difficult to explain. The axial ratio and angles resemble those of sylvanite. Smith and Prior[d] attempt to account for this puzzling crystallographical development by assuming triclinic symmetry accompanied by complicated twinning—of which, however, there is little external evidence—and believe that the crystals consist of an "intermingling of different structures, indicating that the crystals are really not homogeneous." Massive calaverite occurs more rarely, but was noted from the Blue Bird mine; it has here a more bronzy-yellow color. There is no cleavage, a notable distinction from sylvanite. Brittle; hardness, 2.5; color, silver white, with a yellowish tinge. The calaverite from the original localities, as well as that from Kalgoorlie, Western Australia, has a pale, bronze-yellow color, usually absent in the Cripple Creek mineral, which in small particles is rather difficult to distinguish from pyrite. Calaverite occurs massive only in certain granitic and phonolitic

[a] Proc. Colorado Sci. Soc., vol. 5, 1894–1896, pp. 66–71.
[b] Geology and mining industries of Cripple Creek district: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 133–135.
[c] Am. Jour. Sci., 4th ser., vol. 12, 1901, pp. 225–246.
[d] Min. Mag., vol. 13, 1902, pp. 122–150.

replacement ores. It is usually in the form of ill-defined crystals on quartz crusts, more rarely on fluorite or dolomite crusts. Fine crystals were obtained from the Conundrum mine, where they occur in vugs with fluorite in gneiss. Silver-white, thin, and bladed crystals, often showing radial arrangement, were found on joint cracks in the breccia of the Captain stopes of the Portland mine. Sometimes the crystals are contained in crystalline comb quartz (El Paso, C. K. & N., and Gold Dollar mines), or in chalcedony (Last Dollar mine).

OXIDIZED TELLURIUM COMPOUNDS.

The presence of oxidized compounds containing tellurium was first proved by Dr. R. Pearce.[a] In the same year F. C. Knight analyzed a light-brown, brittle substance, with bright-yellow streak occurring mixed with a metallic telluride, and found that, subtracting the telluride, it gave the composition under I and II.

Analysis of tellurium compound from Cripple Creek.

	I.	II.	III.
Fe_2O_3	30.27	35.44	32.72
TeO_2	68.05	62.79	65.45
H_2O	1.68	1.77	1.83
	100.00	100.00	100.00

This would correspond to a ratio $Fe_2O_3 : TeO_2 : H_2O = 2 : 4 : 1$ and to the formula $2(Fe_2O_3, 2TeO_2) + H_2O$, requiring the composition given under III. No name was given to this compound, the homogeneity of which is, indeed, somewhat doubtful.

Mr. Knight reports the presence of about a third of 1 per cent of selenium, but this element has not been discovered in any subsequent analyses of Cripple Creek ores.

Two other tellurites have been described. The first is emmonsite, discovered by Hillebrand in a specimen from near Tombstone, Ariz., and also essentially a hydrated ferric tellurite. The second is durdenite, found by Dana and Wells in specimens from Honduras. This is a greenish-yellow, massive substance containing TeO_2 67.1, Fe_2O_3 27.7, H_2O 10.2. Ferrotellurite and magnolite (Genth) from Boulder County, Colo., have, probably, the compositions $FeTeO_4$ and Hg_2TeO_4, but neither species is satisfactorily established.

Emmonsite.—A small quantity of a yellowish green tellurite was collected at the W. P. H. mine, Cripple Creek, where it occurred in a very rich pocket of ore, together with native gold and partly oxidized calaverite. The vein cuts granite and schist near the contact with volcanic breccia, and the pocket occurred at a depth of 245 feet. A similar substance occurred with rusty gold in the Moose mine and is reported from the Deadwood mine. It is probably generally present in the rich, partly oxidized ore, though it has usually escaped detection. Dr. W. F. Hillebrand has examined this substance carefully, with the results in the quotation below.[b]

[a] Proc. Colorado Sci. Soc., vol. 5, 1894–1896, pp. 66–71.

[b] Hillebrand, W. F., Emmonsite (?) from a new locality: Am. Jour. Sci., 4th ser., vol. 18, December, 1904, pp. 433–434.

The mineral occurs as irregular small masses of yellowish green color, which often assume mammillary forms, the largest observed being about the size of a pea. Doctor Hillebrand says:

In its optical properties, so far as they were determinable, there is no positive disagreement with those reported for emmonsite. Mr. W. T. Schaller reports as follows:

"There are two cleavages, one parallel to *b* (010) and another parallel to a form in the orthozone. Axial plane parallel to *b* (010). Bx_a perpendicular to a cleavage face in the orthozone. The extinction on the clinopinacoid is inclined 25° to 30° to the vertical axis. 2E is approximately 40°. Double refraction medium, and the mineral is nonpleochroic."

* * * * * * *

Like emmonsite, the mineral melts at a low heat to a red-brown liquid, but, unlike it, gives on stronger heating only tellurous oxide, with no trace of selenium or selenious oxide. Analysis confirmed the absence of selenium. Its density, too, differs from that of emmonsite, if the determinations in both cases on scanty material are to be depended on. After allowance for gangue the original emmonsite was judged to have a density of at least 5, while that of the present mineral is but little above 4.53, after allowing for 24.44 per cent of gangue, consisting mainly of quartz and to which the specific gravity of quartz was assigned.

In its appearance the present mineral would seem to resemble durdenite more than emmonsite, but the marked difference in water content differentiates it sharply from that mineral, durdenite yielding over 10 per cent.

After deducting 22.44 per cent of gangue, containing over 90 per cent of silica, three portions of from 0.15 to 0.20 gram net weight each gave the following results:

Analysis of emmonsite (?) from Cripple Creek.

	1.	2.	3.	Mean.	Ratios.
TeO_2	70.83	71.80	70.20	70.71	3.16
Fe_2O_3	22.67	22.81	22.79	22.76	1.00
H_2O-	4.68	4.82	.21	.21	
H_2O+			.....	4.54	1.77
P_2O_5	.34	.....	.....	.34	
Al_2O_3	.....	.58	.54	.56	
SiO_2, etc. [a]	.....	.....	.....	.88	
				100.00	

[a] Includes alkalies, traces of MgO and of gold, and a small amount of a metal or metals precipitable by hydrogen sulphide, whose identity could not be established.

Allowing the alumina to offset the P_2O_5, though it may belong to a soluble silicate or to the tellurite and a small portion of iron be demanded for the P_2O_5, the ratios given in the final column result. They are as unsatisfactory as those afforded by the original emmonsite, which were for $Fe_2O_3 : TeO_2$, 1 : 3.65 in the original description and 1 : 3.75 : 1.82 for $Fe_2O_3 : TeO_2 : H_2O$ if the supplementary determinations in this journal, xl, 81, 1899 are accepted. The presence of tellurite in association with the green mineral suggests a possible explanation of the failure to obtain a simple ratio, though such contamination was not noted in the material analyzed nor on the neighboring gangue. If this explanation is correct, however, the variation from the original emmonsite ratio becomes still more marked. Provisionally the mineral may be regarded as emmonsite.

The above results are given in some detail, notwithstanding their inconclusiveness, because of the importance of accumulating data regarding the as yet small but interesting group of ferric tellurites and of inciting collectors and mining men to careful search for and preservation of material for more extended study.

Thus far emmonsite, durdenite, and an unnamed mineral from Cripple Creek, described by Knight in the Proc. Colorado Sci. Soc., v, 66, and affording likewise unsatisfactory ratios, comprise the list of natural ferric tellurites, the formula of no one of which can be regarded as established beyond question.

Tellurite.—The pure tellurium dioxide, TeO_2, forms slender orthorhombic prismatic crystals and small spherical masses. It is a soft white or yellowish-white mineral of adamantine luster, with excellent cleavage. It has been identified by Doctor Hillebrand from the W. P. H. mine at Cripple Creek and occurs also at the Gold Sovereign and Blue Bird mines. It is confined to the oxidized zone.

SULPHIDES AND SULPHANTIMONITES.

Pyrite.—This mineral is the most common sulphide in the district. It occurs disseminated in the altered breccia and other volcanic rocks, but is most abundant in or near the veins. Disseminated in the rocks, it is usually crystallized, showing pyritohedral forms; the small crystals coating quartz crusts in the veins show the same form, occasionally also simple octahedrons or combination of cube and octahedron. At the Galena and C. K. & N. mines it forms thin reniform coatings on quartz and has a radial fibrous structure. It commonly occurs in massive form, in veinlets, or occasionally in large, irregular masses. It was thus observed in the granite ores of the Portland, Ajax, and Elkton mines, in the cross veins of the Last Dollar mine, and near Vindicator shaft No. 2 on level 3, near the Hull City line. Well-formed crystals one-half inch in diameter occur in the Lost Anna vein. The pyrite is usually very poor in gold, but sometimes cupriferous, as shown by copper stains on the 1,000-foot level of the Portland mine. Two pure crystallized specimens examined by Hillebrand proved to be without even a trace of gold.[a] At the localities just given the pyrite is also nearly barren. It is believed that in most cases the gold contents of the pyritic ores of Cripple Creek are due to admixed tellurides.

Marcasite.—Crystal growths doubtfully referred to marcasite occur in Stratton's Independence mine on crusts of dolomitic carbonates.

Molybdenite.—The molybdenum disulphide frequently appears in the ores as soft lead-gray scales, particles, and smaller masses, more rarely covering slickensides, and is on the whole very inconspicuous. As seen under the microscope it forms flocculent aggregates, and is very commonly intergrown with pyrite and zinc blende. It has generally been overlooked, but without doubt is a very characteristic part of the vein matter. It occurs at all depths below the oxidized zone and has been identified from the Vindicator, Findley, Last Dollar, Mary McKinney, Moose, Portland, and several other mines.

The mixed ores analyzed at the chlorination mills of the United States Reduction and Refining Company at Colorado City contain about 0.04 per cent molybdenum.

A little molybdenite was also found in a quartz veinlet 1 mile southwest of Cripple Creek, in gneiss. This veinlet is probably older than the gold veins of Cripple Creek.

Stibnite.—The sulphide of antimony is of common occurrence in the Cripple Creek district in association with rich gold ores. In the usual groups and bunches of brilliant, steel-gray, striated prismatic crystals it is found in the C. K. & N. and El Paso veins, in the former in masses weighing up to 50 pounds. Other occurrences are in the Mary McKinney, Puzzle, Katinka, Blue Bird, and Stratton's Independence

[a] Penrose, R. A. F., jr., Mining geology of the Cripple Creek district: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 122.

mines, and it is probably entirely absent from few of the prominent veins of the district. The stibnite is frequently rich in gold, but this seems to be due to an admixture of calaverite, as was chemically proved in the case of rich stibnite from the C. K. & N. mine.

Cinnabar (with native mercury).—According to Mr. Brown, an assayer at Cripple Creek, a little cinnabar, with some native mercury, was found in the Moon-Anchor vein. This is the only reported occurrence of this mineral in the district. The mineral was identified in the specimen.

Galena.—In very small quantities this mineral is probably almost universally distributed in the ores. It is not always, however, perceptible to the naked eye. It has been observed with telluride ore in the Emerson and Bobtail veins of Stratton's Independence mine, in the Buena Vista vein of the Isabella mine, in the Vindicator vein, in the Gold Coin, Dillon, Theresa, Blue Bird, Portland, Lost Anna, Anna Lee, Last Dollar, and Blue Bell veins; also in the rich pocket of the W. P. H. vein. Apparently it is rather more abundant in the western part of the district and occurs here in places in considerable quantity in small veins, some of which are not notably auriferous. Other occurrences are near the Fluorine mine on Copper Mountain, at several places along Spring Creek, at the Deerhorn, Ironclad, and Abe Lincoln mines (here coarsely crystalline), Chicago and Cripple Creek tunnel, Puzzle, Pointer, Midget, Conundrum, Moon-Anchor, Moose, C. K. & N., and El Paso mines. The mineral occurs at all depths, but within the oxidized zone is partly altered to cerussite and anglesite (Penrose). The galena, while containing some silver, is not often strongly auriferous.

Zinc blende (*sphalerite*).—Next to pyrite, zinc blende is the most common metallic mineral accompanying the gold tellurides. It is probably present in every important vein. The mineral is usually of a reddish-brown color and occurs as small masses intergrown with pyrite, galena, and fluorite. It is not known to form distinct crystals. In fairly large quantities it was observed in the ores of the Blue Bell and Puzzle veins, associated with galena and covered by quartz and telluride; also in the Bonanza King vein of the Midget, in the Pointer, and in the lead vein of the Moon-Anchor. The Portland ore contains about 1 per cent of zinc blende. The mineral occurs at all depths, but in the oxidized zone it is usually converted to soluble sulphate. The dark-brown zinc blende from the Last Dollar mine contains, according to Hillebrand, a considerable amount of cadmium.

Chalcopyrite.—This mineral, elsewhere so common, occurs very rarely in the district. It has been noted as a thin coating on tetrahedrite from Blue Bird mine. The few oxidized copper ores seem to be derived from tetrahedrite.

Tetrahedrite.—This mineral, a sulphantimonite of copper, usually referred to as "gray copper," is practically the only primary copper ore of the district. It generally occurs in dark steel-gray masses with a reddish-brown streak, sometimes so red as to suggest specular iron ore. It is occasionally crystallized in tetrahedrons (Abe Lincoln and Doctor-Jackpot mines). It always contains silver, sometimes in large amounts, and most of the ore rich in silver which is shipped from the district carries a considerable amount of tetrahedrite. It occurs in the veins throughout the district and at all levels. The statement has sometimes been made that this mineral begins to be more abundant at a certain depth supposed to mark the

beginning of a zone of secondary sulphide enrichment, but this is erroneous. Occurrences noted are as follows:

Yellow Bird claim (Ellen McGregor group), near surface.
Vindicator mine, 1,200-foot level.
C. O. D. mine, level 10.
Wilson claim, Bull Hill, surface.
Prospect, 2,000 feet north of Hoosier mine.
Ironclad mine, level 6.
Puzzle vein, 60 feet above Ophelia tunnel.
Isabella mine, Buena Vista vein, many levels, especially level 4.
Isabella mine, Empire No. 2 vein, level 11.
Isabella mine, Cheyenne vein, level 11.
Mountain Monarch mine (near Doctor-Jackpot), level 2.
Trachyte mine, 110-foot level (with 800 ounces silver per ton).
Pointer mine, probably in all levels.
Accident mine, probably in all levels.
Anaconda mine, adit level.
Last Dollar mine, levels 5, 10, and 12.
Blue Bird mine, on 1,350-foot level; oxidized zone above was rich in silver.
Dolly Varden mine.
Sunset-Eclipse mine, 50 feet below surface.
Hull City mine, in Shaft vein for 300 feet between levels 8 and 11.
Doctor-Jackpot mine, 550 to 700 feet, Morning Glory levels.
Moose mine, level 15.
El Paso mine, level 1 (old workings).
Portland mine, Lost Anna vein, level 10.

Chalcocite(?).—A sulphide of copper, probably chalcocite, has been found in the Uncle Sam mine.

Arsenopyrite.—We have not observed this mineral, which certainly is rare in the district. Mr. Edward W. Brooks, formerly chemist of the Ajax mine, states that it occurs occasionally with finely divided pyrite.

OXIDES, CARBONATES, SULPHATES, SILICATES, ETC.

Fluorite.—As a primary constituent of granite, fluorite occurs on Pikes Peak and probably also in the small area of Spring Creek granite in the northwestern part of the Cripple Creek district. It has not been found in any other granites or fresh igneous rocks within the district. As a vein-forming mineral fluorite is very abundant, occurring in smaller or greater quantities in almost every vein. It is ordinarily of a purple color of varying intensity, often very dark and rarely pale or colorless. The tendency toward crystallization is very marked, though the crystals rarely exceed 5 mm. in diameter. The universal form is the cube, in which form the mineral, together with quartz and dolomite, often coats the vugs and crevices in the rocks. Even when forming a solid vein filling the apparently granular mass consists of minute cubes cemented by quartz. To a limited extent the fluorite also appears as a product of replacement in all the various rocks in which the veins occur, especially in the so-called "granite ore."

Just outside the boundaries of the area represented on the map on both sides of Cripple Creek Canyon, purple and light-green fluorite occurs in narrow veins in granite. Whether these belong to the same period of vein-forming activity as the principal veins is doubtful.

Quartz.—Quartz is an important constituent of the older rocks, including granites, schists, and gneisses, but is generally absent from the younger volcanic rocks. It is one of the principal vein minerals occurring in every mine, chiefly forming crusts and combs, granular masses, or mammillary forms in the little fissures, and, to a minor degree, replacing the constituents of the adjoining rock. It has the usual forms of prism and pyramid, but the crystals are commonly small. Many of them appear rounded as if corroded. It is frequently intergrown with calaverite. In some places a late silicification has taken place, the quartz replacing earlier vein minerals, in part celestite. Smoky quartz with distinct dichroism of carmine brown and pure brown occurs on crusts in the Ironclad mine.

Chalcedony.—This mineral occurs sparingly as a filling between quartz crystals and is rather common as an incrustation lining small vugs in the veins.

Opal.—The hydrated amorphous silica is not uncommon in Cripple Creek, but generally represents the last phases of vein-forming action, and forms also during the process of oxidation. It is especially abundant in the Zenobia mine as yellow masses, often like tangled wires or rods. It is sometimes found in vugs at considerable depth, as on the 1,000-foot level of the Gold Coin vein. Hyalite, a colorless opal, occurs in cracks of the Anaconda dike.[a] In the Victor and Buena Vista veins is found a brilliant-red siliceous mineral consisting essentially of 72 per cent silica, 18 per cent ferric oxide, 1 per cent potash, and 3 per cent water.[a]

Magnetite (with ilmenite and titanomagnetite).—These are minor constituents of schist, diabase, latite-phonolite, basalt, and other rocks. Magnetite also occurs in a pegmatite dike in the town of Cripple Creek.

Specularite.—This has been observed only once as a vein-forming mineral inclosed in quartz. It has also been reported to occur in a pegmatite dike on Rhyolite Mountain. In the form of hematite it is probably present in a finely divided state in the oxidized rocks.

Zircon.—Occurs in microscopic form as an accessory constituent in most of the rocks. When the roasted ore is concentrated on Wilfley tables in the chlorination and cyanide mills, a small quantity of white, heavy concentrate is separated, which proves to be zircon and doubtless is derived from the rocks in which the ore is contained.

Rutile.—Occurs in microscopic form as a product of alteration of titanite, due to vein formation.

Limonite.—Abundant, in finely divided form, within the oxidized zone; it results from the decomposition of both rocks and vein material.

Psilomelane and wad.—Black manganese minerals are generally distributed in the oxidized zone as stains or filling of small cracks and fissures. Occasionally they form irregular masses or nodules (Summit and Pharmacist mines, Penrose). They are usually soft and sooty, more rarely hard and massive. These minerals undoubtedly result from the oxidation of carbonates containing a small percentage of manganese, which occur very abundantly in the veins.

Molybdite and ilsemannite.—In a prospect on the north side of Battle Mountain, near the Comanche Plume tunnel, a bright canary-yellow mineral occurs in the

[a] Penrose, Mining geology of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 127.

rusty cracks and joints of weathered latite-phonolite. The mineral forms microscopic capillary crystals, which extinguish parallel with the prism axis and have very strong double refraction, the minute hair-like crystals giving interference colors of the third or fourth order. Chemical tests by Doctor Hillebrand show that the material is chiefly oxide of molybdenum and that the mineral is probably molybdite.

A short distance east of the Howard flat vein the Ophelia tunnel crosses a small vein parallel to this and located on the Anaconda property. It consists of coarse quartz, with comb structure, growing on a black, fine-grained mixture of pyrite, molybdenite, and zinc blende with a very small amount of galena and traces of copper and tellurium (Hillebrand). Upon exposure to the sun and air the quartz turns yellow or green and finally a deep prussian-blue color. Specimens soon color the paper of the label to a similar blue. This energetic oxidation is also shown by little tufts of yellow material on the specimens and occasional coatings of a dark-blue mammillary substance. The yellowish material is believed to be molybdite or MoO_3. The blue substance, which dissolves in water and is associated with some ferrous sulphate, also contains a large amount of molybdenum and probably is the rare mineral ilsemannite (MoO_2, $4MoO_3$), which thus far has only been found at Bleiberg, Carinthia, as a product of decomposition of wulfenite, while it here appears as a direct product of oxidation of molybdenite.

Calcite.—Calcium carbonate is fairly common in the district, usually as a product of alteration in basalts or other rocks containing much lime. Microscopic pseudomorphs of calcite after titanite are often seen in the latite-phonolites. In the veins it is, on the whole, uncommon.

Dolomite.—A dolomitic carbonate of probably variable composition is common both as crusts in the veins and as the product of alteration in adjoining rock. It has in some cases the form of the primary rhombohedron and is often slightly greenish in color, probably due to copper. Qualitative analyses of specimens from the Last Dollar mine, where the mineral is especially abundant, showed lime, magnesia, iron, and manganese. Dolomite crystals, replaced by opal forming hollow pseudomorphs, were noted from the Orpha May mine.

Rhodochrosite.—A pink carbonate, crystallizing in rhombic forms, from the Fluorine mine contains an abundance of manganese and is probably rhodochrosite. The same mineral is abundant in the Pointer vein in veinlets up to 3 or 4 inches in width, crystallized with fluorite, pyrite, galena, and sphalerite. It occurs also in similar association in the Lead vein of the Moon-Anchor mine.

Barite.—Massive barite in considerable amounts has been reported from several mines on Globe Hill. The only occurrence of supposed barite in this vicinity which could be examined proved to be celestite, and much of the so-called barite is probably celestite. Barite is, however, definitely identified from some of the El Paso veins, and barium (probably as sulphate) has been determined by analyses in the Portland ores. A small vein containing green and purple fluorite with tabular barite crystals occurs in granite about 4 miles south-southwest of Cripple Creek, near the western brink of Cripple Creek Canyon.

Celestite.—Our attention was first called to this mineral, which is a sulphate of strontium, by Mr. R. H. Burrows, who stated that it occurred in a vein crossing

the Josie S. shaft near the Humboldt prospect, at the head of Squaw Gulch. Later the mineral was also identified from the Wild Horse lode. Doctor Hillebrand states that it does not seem to be wholly anhydrous. At both places the mineral occurs in the oxidized zone and forms small white, bluish, or yellowish prisms and groups of crystals. It is directly associated with limonite and kaolin and evidently deposited during the process of oxidation. There is, however, a second mode of occurrence of celestite in Cripple Creek. In slender needles it coats the open vugs in the vein fissures far below the line of oxidation, and here it certainly seems to be one of the primary vein minerals.

The needles are combinations of the dome (011) and the pyramid (144), the curved sides of the prisms being due to the oscillatory growth of these two crystal forms. The crystals resemble in habit the pseudomorphs of calcite after celestite found at Obersdorf, near Sangerhausen, Thuringia, and the celestite crystals of Mineral County, W. Va. It was identified from the C. K. & N. mine. In most cases these delicate needles and prisms have been transformed into acicular pseudomorphs of fine-grained quartz, or are coated by quartz crystals, while the original substance has been dissolved. These are found more or less abundantly in the majority of veins in the district, but are especially plentiful in the Howard flat vein in the Ophelia tunnel, where they line a large cavity 2 or 3 feet in width. The pseudomorphs are found in some collections labeled quartz after stibnite, which of course is erroneous.

A third mode of occurrence is as principal gangue in a vein on the 660-foot level of the Ironclad mine. The mineral is granular and partly crystallized, white or yellowish, and is associated with some oxidized lead ore. Here, too, celestite is doubtless a primary gangue mineral.

Alunite.—This mineral was identified from level 5 of the Last Dollar mine; it follows the vein fissure as a rather hard and compact, fine-grained, white substance, looking very much like kaolin. It was also noted from the adjoining Modoc mine and probably occurs at many other places. It seems to be confined to the oxidized zone.

Gypsum.—Occurs in large masses in the Deerhorn shaft, associated with flourite and pyrite, and seems also to be fairly common in decomposed vein matter.

Glockerite ($2Fe_2O_3SO_3+6H_2O$).—This mineral was identified with considerable certainty by R. Pearce[a] in an oxidized ore from the Modoc mine. The same or similar ferric sulphates are probably of common occurrence in the upper levels of the mines.

In the Ophelia tunnel a brown, sticky substance drips from the back and forms rosinlike crusts on the floor. It accumulates only during the winter. According to Hillebrand, it consists of a mixture of hydrous sulphates of ferric iron, alumina, zinc, and perhaps a little of the alkali metals. It also contains some phosphates, but no lime or magnesia. While essentially a mixture, it probably contains glockerite.

Basic hydrous strontium sulphate.—This new mineral occurs as an impalpable white powder covering granular celestite in a vein on level 7 of the Ironclad mine, described on page 286. Under the microscope it proves to consist of short and

[a] Further notes on Cripple Creek ores: Proc. Colorado Sci. Soc., vol. 5, 1894-1896, p. 13.

extremely delicate white fibers of very feeble, double refraction and an extinction which is probably parallel to the principal sections of the nicols. An analysis by W. T. Schaller of a very small quantity gave:

Analysis of basic strontium sulphate.

SrO	25.1	H_2O (107° C.)	None.
CaO	15.1	H_2O (red heat)	24.1
Al_2O_3	13.9		
MgO	2.5		94.6
SO_3	13.9		

At 260°, 1.49 per cent H_2O was driven off, while the rest remained until red heat. Repeated determinations gave the same result. The analyzed material was homogeneous. The composition is that of hydrous basic sulphate, corresponding perhaps roughly to CaO, SrO, Al_2O_3, SO_3, 5 H_2O. This is the first hydrous strontium mineral known to mineralogy, and as soon as its composition is satisfactorily ascertained it will be established as a new mineral species.

Chalcanthite.—Occurs very sparingly in the oxidized zone of the veins. Penrose mentions it from the Gold King mine in Poverty Gulch. It also occurs in the Lone Jack vein, Ophelia tunnel, and at several places in the Chicago and Cripple Creek tunnel.

Mirabilite.—Delicate efflorescences of hydrated sodic sulphate are very common in old drifts within the oxidized zone. Usually a little potassic sulphate is also present. It has been identified from the Anaconda-Raven tunnel and from the Last Dollar mine.

Mallardite.—Efflorescences of this mineral, which is a sulphate of manganese with 7 molecules of water, were collected from the Moon-Anchor mine and determined by Hillebrand. It contains also 2.55 per cent MgO and a very small amount of nickel.

Epsomite.—Hydrated magnesium sulphate was identified from the 1,000-foot level of the Portland mine, but mixed with it are also some sulphates of manganese and alkalies.

Other sulphates.—In the drift on the Lone Jack vein in the Ophelia tunnel, a narrow vein in granite, the walls are coated by a white, silky, fibrous substance, which was determined by Hillebrand to be a mixture of hydrous sulphates of aluminum, zinc, ferrous iron, and magnesium. It contains no lime. Coatings of a somewhat similar but more massive substance of pink color proved to contain in addition a notable amount of cobalt sulphate, to which the color of the mineral is doubtless due.

Apatite.—Occurs commonly in the latite-phonolites as stout prisms up to 4 mm. long and showing prism, basal plane, and pyramid. Regarding its inclusions see page 74. It is also abundant as a secondary mineral in slender microscopic prisms with adularia in the Elkton mine.

Wavellite.—A white phosphate in spherical masses of radial structure, probably wavellite, is mentioned by Penrose from the veins of the Raven and Bertha B. mines. The same mineral was found in the May mine, Arequa Gulch, and at a prospect one-eighth of a mile northeast of Midway station. Small amounts of phosphates mixed in the sulphates and various ferric silicates have been noted by Hillebrand in oxidized products from the Vindicator and Portland mines.

Hübnerite.—The only occurrence of a tungsten mineral noted in the Cripple Creek district is in the Puzzle vein on the level of Ophelia tunnel. Hübnerite, a tungstate of manganese and iron, appears here in a small vein associated with the zinc blende and galena and intergrown with quartz. It forms radial dark-brown to dark-green aggregates; the mineral is monoclinic, with excellent cleavage parallel to clinopinacoid; the striated prisms have partings parallel to an orthodome (102); extinctions are usually parallel to prisms, but occasionally oblique extinctions up to 17° are obtained. Its color in transmitted light ranges from almost opaque reddish brown to olive green, a single crystal sometimes showing several different colors. It is not pleochroic. The double refraction is medium strong, probably about 0.025.

Titanite.—In microscopic, lozenge-shaped yellowish-brown crystals this mineral is common in many of the rocks of the district, notably in the latite-phonolite.

Orthoclase.—Occurs as an important constituent in all of the rocks in the district, except the diabases and some basaltic dikes. It is also common as a mineral of the vein-forming period and has then the crystal form and composition of adularia. It is most abundant in the "granite ore" formed by partial replacement of Pikes Peak granite, but is also found in veins contained in breccia, latite-phonolite, or phonolite. In the granite it appears as crystalline coatings and as a true replacement. Where formed by deposition in open space it usually takes the wedge-shaped form characteristic of the variety of adularia called valencianite and is entirely similar to that mineral as described from Silver City, Idaho.[a] The prevalent combination is the prism (110) and the unit dome (101). Between crossed nicols the crystals sometimes show optical anomalies consisting in a peculiar arrangement of sectors, similar to the phenomena observed in certain kinds of vein quartz.

Microcline.—Common in Pikes Peak granite.

Albite.—Occurs as constituents of the granites and often intergrown with orthoclase as microperthite. Not known in the district as a vein mineral.

Oligoclase, labradorite, and anorthite.—These feldspars occur as constituents of many rocks of the district, but are much less abundant than orthoclase, microcline, and albite. Labradorite forms the principal mass of an anorthosite dike near the Galena mine.

Nepheline.—Occurs as an important constituent of the phonolite.

Sodalite and nosean.—Occur as important constituents of phonolite and latite-phonolite.

Analcite.—Occurs in phonolite, trachytic phonolite, and basaltic dikes, partly as an original constituent of the rocks, partly due to subsequent decomposition.

Stilbite and natrolite.—Both these minerals occasionally form during the decomposition of phonolitic rocks.

Tourmaline.—The only occurrence of tourmaline reported from the district is in a pegmatite dike said to occur near Rhyolite Mountain in granite. It contains large and well-developed crystals of this mineral, contained in quartz.

Olivine.—Found as constituent of some of the basaltic dikes and the gabbros near Iron Mountain.

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[a] Twentieth Ann. Rept. U. S. Geol. Survey, pt. 3, 1900, p. 167.

Amphibole.—Hornblende occurs as a constituent of gneiss, latite-phonolite, and syenite; also in some basalts. It is usually of dark-brown color; a blue amphibole of doubtful relationship has been observed in the phonolite.

Pyroxene.—Occurs as augite abundantly in diabase, olivine syenite, phonolite, latite-phonolite, syenite, and various basic dikes. Ægirine and ægirine-pyroxene are found in the phonolites.

Muscovite.—This mineral occurs in the granites, gneisses, and schists of the district. It is found as large foils in some pegmatite dikes in Pikes Peak granite, here occasionally of possible economic value; also as large foils in some of the schists. As a secondary mineral formed by the action of the vein solutions on feldspars, nepheline, and many other minerals, it is fairly abundant in the volcanic rocks, near the veins. It here takes the form of sericite, but has nowhere been developed on the extensive scale seen in many mining districts.

Biotite.—Occurs as a constituent of the gneisses and granites; it is less abundant in the volcanic rocks. A dark-brown biotite was found as a vein mineral, associated with pyrite, in the Dolly Varden vein, Ophelia tunnel. Possibly this is the same occurrence mentioned by Penrose from the Ocean Wave claim, which we have been unable to locate. A green micaceous mineral allied to biotite is found as a product of rock alteration, probably by vein-forming solutions of pyroxene in many volcanic rocks.

Roscoelite.—This light-green vanadium mica, which frequently accompanies rich gold ores, occurs in massive form with quartz, fluorite, and calaverite in the Mary McKinney mine and probably in small quantities at many other places. It is also believed to be present in the Lost Anna vein of the Portland mine, as well as in the Ajax and Stratton's Independence mines. In similar association it is known from California gold-quartz mines, from eastern Oregon near Sumpter, and from the Kalgoorlie mines in Western Australia.

Chlorite.—Chloritic minerals form rather abundantly during the alteration of the volcanic rocks, seemingly both by ordinary decomposition without oxidation and by vein-forming waters.

Serpentine.—This mineral in no place forms large masses, but is noted as a product of decomposition of augite and olivine in the volcanic rocks.

Kaolin.—Regarding this mineral Penrose says:[a]

> A large quantity of soft argillaceous material is found in the ore bodies in both the granite and the eruptive rocks throughout the district, and has evidently been derived largely from the decay of feldspar and other aluminum compounds. Sometimes it is stained brown by iron or black by manganese, but very often it is pure white. It occurs throughout the mass of many of the rocks, but is most abundant along lines of fissuring, sometimes simply filling cracks, at other times in irregular masses, often a foot or several feet in diameter and intermixed with the quartz and other vein minerals. Analyses of this material show it to have a very similar composition whether derived from the granite or from the eruptive rocks, and in all cases it is essentially a kaolin.

Three analyses of occurrences in various rocks are given to substantiate this statement; in one of them, from the Albany tunnel, on the west side of Bull Hill, a small percentage of barite is mixed with the kaolin. A specimen from the Bobtail vein, Portland mine, analyzed by Hillebrand also gave almost the exact

[a] Geology and mining industries of Cripple Creek district: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 127.

composition of kaolin. Contrary to the opinion of Penrose, the kaolin appears to be strictly confined to the zone of oxidation, and is probably formed by the action of sulphuric acid on aluminous minerals.

Chrysocolla.—Occurs as a product of oxidation of tetrahedrite on level 7 of the Ironclad mine and may probably be found in small quantities at many other places.

Morencite (?), chloropal (?).—Within the oxidized zone a soft dark-green to black substance is of fairly common occurrence as the filling of seams and narrow veins. Upon being dried it assumes a light yellowish-brown color and proves to be chiefly a hydrous ferric silicate, possibly corresponding in part to chloropal and in part to the newly established species morencite.[a] It was first observed by Penrose [b] from the Ida May mine, and has been noted by us from the Portland, Vindicator, and Deadwood mines. Hillebrand found the mineral from the Ida May mine to consist of 41.80 per cent SiO_2, 37.20 per cent Fe_2O_3, 19.90 per cent H_2O, and 1.10 per cent CaO, etc. Smaller amounts of carbonates and phosphates are often present.

HYDROCARBONS.

Coal.—At several places the breccia contains inclusions of coaly material, evidently formed by carbonization of vegetable remains carried down from the surface at the time of the volcanic eruptions. The character and significance of these occurrences have been discussed on page 31.

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[a] Lindgren, W., and Hillebrand, W. F., Minerals from the Clifton-Morenci district, Arizona: Am. Jour. Sci., vol. 18, December, 1904, p. 455.

[b] Op. cit., p. 122.

CHAPTER V.—HISTORY AND TECHNOLOGY OF THE GOLD DEPOSITS.

HISTORY OF MINING DEVELOPMENT.

The story of the discovery of gold at Cripple Creek has been well summarized by Penrose,[a] and has been related in picturesque detail by Rickard.[b] The latter interesting account leaves, indeed, little to be added, and were it more accessible to most readers of this report the following sketch of the development of the district might begin where Rickard ends.

The historic rush of prospectors to Pikes Peak in 1859 resulted in no important discoveries and is significant rather as the first determined attack upon the wilderness than from any direct connection with the history of Cripple Creek. It was not until 1874 that the region adjacent to Cripple Creek began to attract the attention of prospectors. The report that H. T. Wood, while connected with the Hayden Survey, had found gold ore near Mount Pisgah drew a number of men to that locality. A few loose fragments of ore were found on the surface and the Mount Pisgah mining district was organized. But no valuable deposits were uncovered, though in 1878 Henry Cocking is said to have driven a tunnel in Poverty Gulch near the point where the Gold King and C. O. D. mines were afterwards developed, and openings were made by B. F. Requa and others in what is now the productive part of the district.

The district was then gradually deserted. There was a brief renewal of activity in 1884, caused by the reported discovery of rich placer deposits near Mount Pisgah. The alleged discovery, however, appears to have been fraudulent, and the grassy hills of the Cripple Creek region, now thoroughly discredited in the eyes of mining men, were given over to the grazing of cattle. Traces of the pastoral period remain in the names of many of the hills, while in the southern part of the town of Cripple Creek there yet stands the log house of Bennett & Myers's Broken Box ranch, long the only habitation in the region.

The events that were destined to transform a lonely cattle ranch into one of the greatest gold districts in the world have been so vividly related by Rickard as to be best given in his own words:

> Among the earliest of the gold seekers was Robert Womack, who once owned a small ranch in the district. He sold it to Bennett & Myers, the proprietors at that time of the cattle range, which covered a large part of the area now forming the environs of the town of Cripple Creek. For many years, between 1880 and 1890, Bob Womack lived in the district, doing occasional work for Bennett & Myers and spending his spare time in prospecting. He had previously had some experience in Gilpin County and knew gold ore when he saw it. In the course of desultory diggings he found several veins, and when he would turn up at

[a] Cross, W., and Penrose, R. A. F., jr., The geology and mining industries of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 113–115.

[b] Rickard, T. A., The Cripple Creek gold field: Trans. Inst. Min. and Metallurgy (London), vol. 8, 1899, pp. 49–55.

intervals, at Colorado Springs, he exhibited pieces of float (surface ore) as evidence of his discoveries; but having a reputation for honesty rather than shrewdness, his statements made little impression. For many years he worked on a hole in Poverty Gulch without staking a claim in proper form. There seemed no need to do so; no one came to disturb him; the whole hill country was at that time fenced in so as to serve as a summer range for cattle. The cowboys and herdsmen looked good-naturedly at Bob's digging, but did not consider it of any moment. In December, 1890, E. M. De la Vergne and F. F. Frisbee came up from Colorado Springs to prospect. George Carr, who was in charge of the ranch belonging to Bennett & Myers, showed them around the district. The hills were under snow, and only a few bare spots permitted of any prospecting. On Guyot Hill, in Eclipse and Poverty gulches, they found evidences of gold veins, and samples were taken away. These averaged about 2 ounces of gold per ton. Encouraged by their first visit, De la Vergne and Frisbee returned early in February, 1891. They found Bob Womack at work in Poverty Gulch. He had sunk a shaft to a depth of 48 feet, and encountered good ore. The claim he had pegged out was called the "Chance," and a number of stakes indicated that he had relocated it six years in succession without recording the fact or complying with the conditions of the mining law in regard to the amount of assessment work required annually. When he found the newcomers were making inquiries he relocated the claim as the "El Paso," and De la Vergne, finding another lode, heavy in iron pyrites, to the west of Womack's vein, located a claim which he called the "El Dorado." It was recorded a few days later, and in the certificate the district was called for the first time by the name which it still bears, Cripple Creek. Although these locations had been made, little actual mining was done upon them for some time afterwards. Womack absented himself. Frisbee saw that there was a good deal of surface ore which could easily be removed, so while Womack was away, he sent 1,100 pounds by wagon to the Pueblo Smelting and Refining Company, who gave returns at the rate of $200 per ton. This was in August, 1891. Frisbee induced Womack to give him a bond and option on the El Paso for $5,000. Shortly afterwards it was transferred to Messrs. Lennox and Giddings, who still own it, as a part of a very successful mine, the Gold King.

In May Frisbee and De la Vergne happened to be at Colorado Springs and met W. S. Stratton, to whom they showed certain assays of ores brought down by them from Cripple Creek. Stratton was a house builder and carpenter by trade, but in the intervals of his regular occupation he had been prospecting for fully twenty years previous to this date. He had learned the use of the blowpipe and was familiar with the outlines of mineralogy and geology—in fact, an energetic, well-informed man, thoroughly equipped for prospecting work of any kind. At that time he had been searching for cryolite, a mineral from which the metal aluminum is obtained, and had a camp on the Little Beaver, on the Cripple Creek side of Pikes Peak. After the meeting with De la Vergne and Frisbee he went to Cripple Creek and camped there. Stratton met Bob Womack and went around seeing the little work done by the latter and his associates. Among those who were prospecting in the vicinity was Dick Houghton, an old mountaineer, prospector, and specimen hunter whose labors have enriched many museums. One day Houghton brought down a piece of rock from the Lone Star claim on Gold Hill, and, meeting Stratton in Poverty Gulch, he told him he had found some galena (the sulphide of lead). Stratton examined it with his magnifying glass and expressed doubts as to its being galena, and in looking at the ore he saw little cubes of rusty gold, one of which had been scratched by being carried in Houghton's pocket so as to expose a bright surface. They went down to Stratton's tent, and he pulled out his blowpipe and made a test which proved that it was gold. Neither of these men knew at the time that the bright silvery mineral, which Houghton thought to be galena, was sylvanite—the telluride of gold and silver. Stratton went up and located the claim adjacent to Houghton's; it was named the Gold King, and is now a part of the Gold and Globe property. On the 5th of June Stratton, accompanied by Fred Troutman, went to the ridge above Battle Mountain, and, seeing the willows at the head of Wilson Creek (where now the town of Goldfield is situated), they inferred the presence of water. They descended the hill and got a drink; then climbing the hill behind the spring, they found loose pieces of rock, one of which was broken open and found to be smothered in gold. The owner of the Independence says that this was the only time he got really excited. Camp was moved from Cripple Creek next day and pitched close to the spring. A search was begun for the lode which had shed so goodly a float. Trenches were dug; but Stratton had an idea at this time that veins with a north and south direction were the ones which carried rich ores, and so his trenches were dug at right angles to this course, with the result that they paralleled the veins actually existing there, and since developed into the Legal Tender, Lillie, and Vindicator mines. They found nothing. An old ranchman, Billy Fernay, came along about this time and brought some float which he had found on the hill below, now called Battle Mountain. Stratton liked the look of it, so Fernay located it for Stratton, Troutman, and himself, calling it the Black Diamond. It is now one of the claims included within the territory of the Portland mine. Next

day Stratton went down to see the vein and tried to make the course of it accord with the line of the ridge. This led him down the hill to a big outcrop of granite. It was the Independence vein, which had already been seen by many, including nearly all of those whose names have been mentioned. The path from one ranch to another went close by, and all the cattlemen who had any idea of prospecting had looked at it. Every one had condemned it as worthless granite. Fernay pointed it out to Stratton, but he also did as the others had done. On examining the outcrop he remarked the absence of any metallic mineral and of vein quartz such as he had been accustomed to in the San Juan region, and therefore concluded that it was an unlikely looking rock. And so it really was, for it was granite without the ordinary gold-bearing minerals visible in it, differing indeed from the granite of the dome of Pikes Peak in being less fresh in appearance, brown instead of pink, and marked by dark spots where the mica had been decomposed. Some of it yet remains in place, inviting the observation of those who may wonder why the great lode was so long disregarded. Stratton overlooked it, but not irretrievably. Two days later John R. McKinnie, who was one of the first prospectors in the district, came to their camp, and so did Charlie Love, a ranchman from Beaver Park, who had pointed out the big outcrop to many of the prospectors. The latter asked McKinnie if he had seen it, but the matter was allowed to drop. Stratton remembered the incident when, on the morning of the Fourth of July, he was at Colorado Springs, whither he had gone with five samples for assay. The assays gave only $3 or $4 per ton at the best, notwithstanding that he had obtained good results by panning. It suddenly occurred to him that the granite outcrop must be *the* lode. He had found gold in the loose fragments of porphyry lying upon the south face of Battle Mountain near the granite outcrop, but he had been unable to trace its source to any vein in the porphyry formation. Acting on the impulse, he took a horse immediately, and on arrival found Troutman ready to leave in order to celebrate the Fourth at Colorado Springs. Stratton made two locations, the Washington and the Independence. I doubt if any man ever celebrated the Fourth of July to better advantage. Some pieces of the outcrop of granite ore were broken, and Troutman took them to be assayed at the Springs, while Stratton awaited the result. Troutman returned on horseback next day with the assay certificate, proving the ore to be worth $380 per ton. The rest of the story is simple. It records the steady development of one of the richest mines ever uncovered by the miner's pick.

The development of the district, notwithstanding the fact that many mining men of capital and experience looked askance at what they regarded as another Cripple Creek bubble, was extraordinarily rapid. Before the opening of spring in 1892 the hills swarmed with prospectors, and on February 26 the town of Cripple Creek was incorporated. Adjoining it on the southwest sprang up the town of Fremont, afterwards absorbed by Cripple Creek. The main route into the district at this time was by wagon road from Florissant.

In October the Anaconda, Arequa, Blue Bell, Buena Vista, Deerhorn, Eclipse, Gold King, Matoa, Mountain Boy, Ophir, Pharmacist, Plymouth, Strong, Summit, Sweet, Victor, and Work mines were shipping ore, and railroads were under construction from Canyon on the south and from Divide on the north.

In the autumn of 1893 the list of producing mines had become a long one and included the Blue Bird, C. O. D., Dead Pine, Doctor, Eclipse, Elkton, Gold Dollar, Granite, Ingham, Logan, Mary McKinney, Moose, Morning Glory, Portland, Raven, Stratton's Independence, Strong, Tornado, Zenobia, and many other well-known properties.

The Midland Terminal Railroad, connecting Cripple Creek with Colorado Springs by way of Divide, was completed December 16, 1893, and the Florence and Cripple Creek Railroad was opened to traffic July 2 of the following year.

The year 1894 is memorable on account of a strike during which the miners resorted to arms, property was destroyed, and lives were lost. A large force of deputy sheriffs was finally enrolled to restore order, but at this stage the governor of Colorado called out the militia and put a stop to what threatened to become

a miniature war. The mine owners, by the "Waite agreement," consented to the establishment of a minimum wage, to the eight-hour day, and to the avoidance of all discrimination between union and nonunion men. In spite of these disturbances the development of tne district made notable strides and the Independence mine in particular revealed bodies of ore that were the marvel of the camp. The mine at this time was only 70 feet deep and was worked with a horse whim. It shipped in August 800 tons, of which the poorest carload averaged 3½ ounces of gold per ton. The Portland mine at this time was shipping about 60 tons of smelting ore daily. About 100 men were employed and the mine produced more ore than any other property in the district. It was in the latter part of this year that Cross and Penrose investigated the district for the United States Geological Survey.

In 1895 the Portland mine had reached a depth of 600 feet and the Independence 470 feet. The latter was the most profitable mine in the district, and Stratton, now a rich man, began the purchase of outlying property. The Logan and American Eagle mines were bought by him this year and were consolidated as the American Eagle group. He acquired a number of other mines in succeeding years. The Vindicator, 60 feet deep; the Mary McKinney, 146 feet deep; the Anna Lee, 760 feet deep; and the Elkton, Pharmacist, Isabella, Victor, Last Dollar, Strong, Anchoria-Leland, Abe Lincoln, C. O. D., and Gold King were all shipping ore in this year, and considerable excitement was caused by the remarkably rich ore shoots in the Moose, Raven, and Doctor mines on Raven Hill. Several of the mines encountered water about this time and had to begin pumping.

During the next few years the number of producing mines continued to increase, and in 1900 the maximum output of $18,000,000 was obtained. Beacon Hill attracted much attention in consequence of rich ore found in the Prince Albert and adjacent mines. The Victor and Isabella mines were highly productive up to 1898 and 1900, respectively, and shipped large quantities of very rich ore. Four long tunnels, the Chicago, Good Will, Ophelia, and Standard, were begun about this time. In 1899 the Standard tunnel encountered a flow of water 2,800 feet from the portal, which compelled a suspension of operations. Teller County, with Cripple Creek as its county seat, was formed from a portion of El Paso County. Another notable event of the year was the sale of Stratton's Independence, the most famous and profitable mine in the district, to the Venture Corporation (Limited), of London, for $10,000,000.

In 1901 the Colorado Springs and Cripple Creek District Railway was completed into the district. About this time many of the larger mines, having worked down to the water surface determined by the outflow through the Standard tunnel, were again compelled to face the question of deeper drainage. A drainage commission was formed, subscriptions were collected, and the El Paso tunnel was begun in 1903. Connection was made with the El Paso mine, under Beacon Hill, in the autumn of the same year.

The year 1902 is noteworthy chiefly on account of the discovery of remarkably rich ore in the recently opened C. K. & N. mine on Beacon Hill and the coming into prominence of the El Paso and Golden Cycle mines as large producers.

Early in 1903 a strike was ordered by the Western Federation of Miners in all mines shipping ore to certain reduction works in Colorado City. The difficulty was

adjusted for the time, but after some months of agitation and uncertainty another strike was called on August 10, which resulted in the closing of nearly all the mines in the district except the Portland. The mine owners organized and took active steps to reopen the mines with nonunion labor. Work was first resumed at the El Paso under strong guard, and some of the other mines were soon afterwards reopened under similar conditions. It soon became evident, however, that any general attempt on the part of the mine owners to work the mines would be the signal for violence. Governor Peabody accordingly ordered the militia into the district, and under their protection all of the mines gradually resumed operations with nonunion miners. A number of dastardly outrages, such as the murder of the superintendent of the Vindicator mine and the blowing up of a station platform at Independence at a time when it was crowded with nonunion miners, were perpetrated about this time, and, being generally charged to the union men, led to coercion and deportations.

The general depression caused by the labor difficulties of 1903 and 1904 was partially relieved by a number of discoveries of new pay shoots, particularly of a body of remarkably rich ore in the W. P. H. claim, on Ironclad Hill. Ore of very high grade was found also in the El Paso mine and new pay shoots opened in the Gold Coin and Granite mines. In the Portland mine a number of new ore bodies were discovered, indicating that the ore reserves on several of the levels were larger than had been generally supposed.

At the present time there are probably not more than ten of the really large mines that are operated by their owners. The Isabella, one of the most extensive mines in the district, is doing very little, and the great Stratton's Independence is now worked by lessees. The number of small mines in active operation is, however, comparatively large, and it is to be noted that some of these small mines, such as the Strong, have been nearly as profitable as their larger neighbors. Leasing or tributing is extensively practiced, several mines of moderate size and a large number of the smaller properties being worked on this plan. The extensive holdings of the Stratton estate, which have lain idle for the past few years, have recently been opened to lessees and may be expected to add materially to the production of the district.

PRODUCTION.

Though situated close to the centers of population in Colorado and in an easily accessible region, the gold deposits of Cripple Creek were not discovered until 1891. To a great extent the lateness of the discovery was due to the extremely inconspicuous character of the vein croppings and to the equally inconspicuous appearance of the dark-brown, powdery gold set free by the oxidation of tellurides. As soon as the true character of the veins was ascertained the development of the district proceeded rapidly. In 1894, when the first survey was made, the production was a little less than $3,000,000, but the next year this amount was more than doubled, and in 1900 the maximum production of a little over $18,000,000 was attained. In 1901 and 1902 the production declined slowly, and dropped the next year to $13,000,000. The sudden decrease in 1903 was to some extent brought about by the impoverishment of several mines, but the labor troubles of that year had also

much to do with it. From August, 1903, to the summer of 1904 many mines experienced more or less difficulty from this cause.

Production of the Cripple Creek district according to the reports of the Director of the Mint.[a]

Year.	Gold.	Silver.	Year.	Gold.	Silver.
		Fine oz.			*Fine oz.*
1891	$449	.....	1900	$18,073,539	80,166
1892	583,010	.....	1901	17,261,579	90,884
1893	2,010,367	5,019	1902	16,912,783	62,690
1894	2,908,702	25,900	1903	12,967,338	42,210
1895	6,879,137	70,448	1904	14,499,529	55,790
1896	7,512,911	60,864	1905	15,724,344	35,643
1897	10,139,709	57,297			
1898	13,507,244	68,195	Total	154,638,895	737,626
1899	15,658,254	82,520			

[a] The figures given in the mint reports are considerably lower than those usually quoted in mining journals and popular descriptions of the district.

The total dividends can not be ascertained on account of the many individuals and small companies operating in the district. The dividends of the larger companies, it is stated, amounted to $32,752,000 to the end of 1903. In that year it is reported that $1,716,000 was paid by fourteen mines, the Portland, Strong, and Stratton's Independence leading, with $360,000, $300,000, and $250,000, respectively.

The annual tonnage of the camp has probably not exceeded 700,000 short tons of ore. For the year 1904 it was nearly 600,000 tons. Of this, the Portland mine produced about one-sixth.

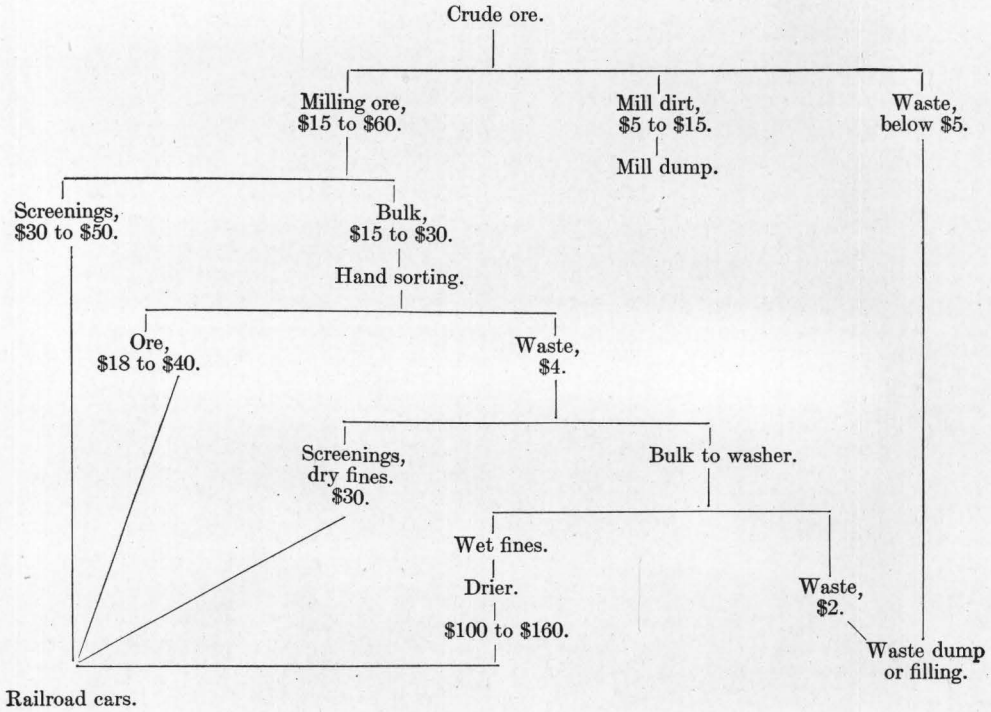
The distribution of the total tonnage of ore over the several parts of the district varies, of course, from time to time. An investigation made in 1903 for the Cripple Creek Times shows that 42.7 per cent came from the Battle Mountain mines, 30 per cent from Bull Hill, including the Vindicator lode system, 7.4 per cent from Raven Hill, 5.8 per cent from Beacon Hill, 7.8 per cent from Gold Hill, and 4.9 per cent from Guyot Hill (including the Mary McKinney mine). Since that time the output from Beacon Hill has increased considerably and that from Bull Hill is probably somewhat less.

MINING.

The methods of mining employed at Cripple Creek are not materially different from those in use in other districts where metalliferous veins are exploited. Overhand stoping with slightly differing variations is used. In narrow veins short stulls comprise about the only timbering used and required, but when the stopes become over 12 feet wide square sets become desirable. The rock is usually so hard that stopes will stand unsupported for a remarkable height and width. Examples of stopes up to 200 feet high and 30 feet wide standing without any support may be seen at the Vindicator and Prince Albert mines. Still in many places the calcite seams cause a dangerous scaling off on the walls, and partial filling must be resorted to in conjunction with the square sets. In the big stopes up to 50 feet wide, as in the Portland mine, from 30 to 40 per cent of the total amount broken can be left in the mine as filling.

A favorite method of stoping is to break down the whole of the ore in place between two levels, leaving the loose rock to be drawn off through shoots as rapidly or slowly as may be required. This leaves the empty stope entirely unsupported. Sometimes the walls are partly secured by stulls while the ore is being drawn off. The ordinary half or three-fourths ton cars are used. The El Paso is the only mine in which 1-ton cars have been introduced and hoisted on cages. Buckets are also employed very extensively in the shafts and sometimes used to a depth of even 1,000 feet, a practice which is not to be recommended. Practically all of the shafts are perpendicular. The hoisting is generally effected by steam; electric power is used in winzes and small shafts. The Portland is the only mine which has installed self-dumping 3-ton skips into which the contents of the cars are directly charged at the various levels. At this mine the waste is disposed of into side-dumping cars taken to the dump by rope haulage.

In treatment and sorting of the ore at the mines various plans have been adopted. The general occurrence of friable tellurides in cracks and fissures forms the principle upon which the sorting and separation is based. The fines are invariably much richer than the coarse stuff, and the separation of the two classes becomes of importance. The ore is usually broken on plank floors with canvas underneath to avoid loss of the fine material. A rough preliminary sorting is effected in the mine—at least in places where wide stopes are being operated. The further treatment varies in the different mines. Very rich ore containing from 4 ounces upward is usually sacked and sent to the smelters. At the Portland mine the following process is adopted, the scheme being outlined in the eighth annual report of the company by Mr. Charles J. Moore, formerly its consulting engineer, as follows:



The ore from the various stopes is not separated but dumped in two bins after passing over 1-inch grizzlies. The hand sorting is done at six tables with four men at each. The waste from the sorting slides down over an inclined 15- by 4-foot sheet-iron plate perforated with half-inch holes and is continually sprayed in order to wash off the fines. Before going to the dump the waste from the washer is finally picked over on a belt conveyor.

At the Mary McKinney mine the ore from the stopes is shoveled into a Crane washer, a local invention composed of a 46-inch by 15-foot trommel with three-fourths inch holes, separating out the dry fines. The coarse is discharged into a smaller strongly inclined and perforated trommel about 15 feet long, the near end partly submerged in a tank of water. By this device the ore is washed, the fines falling into the tank and the coarse being carried up by means of an endless screw and discharged at the higher end of the trommel on a conveyor belt 50 feet long and 20 inches wide, on which the ore is sorted by five men. The capacity is said to be 100 tons per eight hours.

At the El Paso mine ten bins are used and the ores from various stopes are kept apart. The classification is effected by two or three parallel screens under a protecting 3- by 15-foot grizzly, with bars 4 inches apart. The first screen has 1-inch perforation, the second three-fourths inch. The dry fines below three-fourths inch average $75 per ton, those between 1 inch and three-fourths inch $25. From each bin the ore slides down on a sorting table, while sprays wash off the remaining fines, which are collected in tanks. These fines are of very high value. Ten sorters are employed. The present output (March, 1904) is 50 tons per day.

In former years the sorting of the ore was much neglected, as evidenced by the numerous rich dumps in the camp. Even now the arrangement at many mines is imperfect.

The cost of mining is, as a rule, very high, though few accurate data are available on this subject. Mr. J. R. Finlay,[a] the former manager of the Portland mine, makes the following statement, which is well worth quoting:

> A study of the situation shows that these high costs result from the amount and character of the waste that must be handled with the ore. As is well known, the largest ore bodies of Cripple Creek are not solid masses of uniformly valuable mineral, but contain volumes of rock into which the gold-bearing solutions have penetrated along multitudes of crevices. The problem of getting the best results in such veins is essentially one of concentrating the values. The peculiar character of the ore renders concentration difficult, if not impossible, by any method other than hand sorting. Ordinarily the concentration of ores may be effected cheaply by mechanical means, depending on the difference in specific gravity between the valuable and the worthless minerals. In the case of Cripple Creek ores this difference can not be depended upon. When the rock is blasted, a large part of the valuable material in the seams is reduced to an extremely fine powder, practically the lightest part of the mass; another part of the values will adhere to the rocks, while another small part is probably heavier than the average.

The total cost of mining, including sorting and development work, is probably nowhere in the district—in the deep mines—less than $8 per ton and in many cases it may be considerably higher. The actual stoping cost in the Portland mine averaged about $3 per ton in 1902, and for 1903 is reported as averaging $2.19.

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[a] Ninth Ann. Rept. Portland Gold Mining Company, p. 16. See also Finlay, J. R., Mining costs at Cripple Creek: Eng. and Min. Jour., November 21, 1903.

SAMPLING.

The sampler, in the western mining regions, is the recognized middleman between mine and reduction works. His services have been found particularly acceptable at Cripple Creek on account of the richness of the ore and the corresponding difficulty of obtaining an agreement between smelter and miner. The leasing system in vogue has also helped the sampling works by multiplying small parcels of ore which must be separately handled. A modern sampling mill is quite a complicated affair, especially where rich ores render extra care necessary, and it is sometimes arranged to run almost automatically. Even large mines use the services of samplers, the Portland and the Woods Investment Company being the only ones possessing mills of this kind for their own exclusive use. The charges, not including freight, run from 60 cents to $1 per ton. The principal sampling mills working at present in the district are the Cripple Creek, the Rio Grande, the Eagle, and the Taylor & Brunton.

The last, situated in the gap between Bull Cliff and Big Bull Mountain, is the most modern plant and a brief description of its process may be of interest. The ore is shoveled from the car into a bin from which it goes to crusher and coarse rolls (42 inches). An automatic elevator carries it to the top of the building to 36-inch rolls, below which an automatic sampling machine, by alternately deflecting the stream of crushed rock, cuts out 20 per cent of the total material. This 20 per cent goes to 27-inch rolls, below which a second sampling machine cuts out 20 per cent, the operation being repeated underneath the third (20-inch) rolls. All of the rolls have automatic feeders. The total sample now amounts to 1 per cent of the total amount and has been crushed to about one-sixteenth of an inch in average size. If necessary, in large lots of ore comprising several cars, this is further reduced by hand, with the implement known as a "split shovel," to about 0.08 per cent of the original lot of ore. The sample, which now weighs from 20 to 50 pounds, is dried and crushed fine in a rotary grinder and further reduced by means of the "split box" to about 30 ounces. The final pulverizing is accomplished by means of the bucking board and a 110-mesh screen. A smaller splitter divides it into four parts which make the final samples. One of these is assayed at the sampling works, another is sent to the shipper, while two are held in reserve in case of disagreement between the sampler and the smelter.

PROCESSES OF REDUCTION.

The history of the development of the present processes of reduction for the Cripple Creek gold ores is in many respects of great interest.[a] Stamp milling, long the recognized mode of treatment of gold quartz, was first tried. During 1892 and 1893 ten stamp mills of the Gilpin County type with slow drop and light stamps were erected, aggregating 270 stamps, the largest being the Rosebud and the Gold and Globe mills, having, respectively, 60 and 40 stamps, both situated along Cripple Creek below the town. A short trial sufficed to demonstrate their inefficiency to deal with the free gold, on account of difficulties of amalgamation due to a tarnish supposed to be tellurite of iron. Percussion tables and blankets were introduced

[a] For a full account of the early attempts to reduce the ores see Rickard, T. A., The Cripple Creek gold field: Trans. Inst. Min. and Metallurgy, vol. 8, London, 1899.

to improve the gold saving, but even then the extraction was lamentably low. The matter was made worse by the appearance of unoxidized tellurides and in a few years this process was entirely abandoned.

Smelting was early recognized as a proper method of treatment for rich ores, and an increasing amount of such material soon found its way to the smelting works at Denver and Pueblo. At the present time probably one-sixth of the tonnage—roughly 100,000 tons—is thus disposed of; but as ores below 4 ounces of gold per ton rarely go to the smelters it follows that their production is a very considerable part of the total output of the district. The smelting charges range from $6.50 upward, but vary somewhat from time to time.

The first chlorination plant was erected by Edward Holden in 1893, and by January, 1895, the first well-designed mill, of 50 tons daily capacity was completed at Gillett, a few miles northeast of Cripple Creek. The process employed was the barrel chlorination used in South Carolina and the Black Hills.

About the same time experiments were made with the cyanide process, the first mill being erected at Brodie in 1892. In 1895 the Metallic Extraction Company's mill was built near Florence and gradually enlarged to a capacity of 170 tons per day. At that time began the struggle for supremacy between the chlorination and cyanide processes, from which the former appears to be emerging victorious.

Another change soon began to be apparent. With the advent of improved railroad facilities the lower valleys were found to be better adapted for the location of great reduction works, Colorado Springs and Florence being the most favorable points selected. In 1899 there were still four plants in operation at Cripple Creek, but in 1903 only one mill was active, aside from two smaller plants, for direct cyanide work.

In 1904 the different plants were located as follows:

	Tons capacity.
Cripple Creek:	
Economic mill (chlorination)	300
Homestake mill (direct cyanide)	200
Sioux Falls mill (direct cyanide)	100
Colorado Springs:	
Portland mill (chlorination)	300
Telluride mill, General Metals Company (chlorination)	300
Standard mill, United States Reduction and Refining Company (chlorination)	450
Florence:	
Dorcas mill (cyanide)	150
United States Reduction and Refining Company (chlorination)	400

This makes a total capacity of over 2,200 tons, or about 800,000 tons per year, which considerably exceeds the greatest tonnage yet produced in the district.

The charges of the cyanide and chlorination mills vary with the tenor of the ore. The cheapest schedule issued in 1904 ranged from $5.50 per ton for half-ounce ore to $9 per ton for 3- to 5-ounce ore, the freight charges from mine to mill being included. Recently, however, it is understood that these prices have been raised. The schedule in 1903 varied from $7.50 for half-ounce ore to $13.50 for 5-ounce ore.

The cost of treatment is somewhat difficult to arrive at, as few figures are published. The Portland mill places the cost of chlorination at about $3.70 per ton. Mr. T. A. Rickard states that in one of the large mills the cost reaches $3.46, which will probably be increased to $4 per ton with charges for depreciation and general expenses added. Roasting alone costs from 45 to 60 cents per ton (Rickard). In the opinion of some able metallurgists the cyanide process is much better adapted to the ores and will eventually displace chlorination; they claim that the cost should not exceed $2.50 per ton, including amortization of capital invested.[a]

Cyaniding without roasting is practiced in two mills at Cripple Creek which handle low-grade and entirely oxidized ores. In this case mining costs are low and ore containing $5 per ton should yield a fair profit. The extent of these ore bodies, chiefly located on Globe and Ironclad hills and at Copper Mountain, is as yet more or less problematical. The breccia is thoroughly oxidized on Globe Hill, in places to a depth of over 800 feet, and it is not impossible that good-sized ore bodies of low grade may be encountered in this vicinity. Up to date the fairly extensive exploration has not been rewarded by corresponding development.[b]

TECHNICAL DETAILS.

At present the Dorcas mill, at Florence, is the only cyanide plant treating the ordinary telluride ores. Much of the ore is of remarkably high grade, averaging 4 ounces per ton; it is largely obtained from the C. K. & N. mine. After passing through rock breaker, three sets of rolls, and a drier the ore is roasted in a Holthoff automatic oil-burning furnace, from which it is conveyed to bins. There are twelve 140-ton steel leaching tanks about 30 feet in diameter. The solution used is naturally strong, the different grades ranging from 0.6 to 0.8 per cent. The percolating gold solution is precipitated in boxes with zinc shavings. Tailings are passed over Wilfley tables, on which a considerable amount of coarse gold is saved.

The different chlorination plants use practically identical processes.

A type is the Standard plant of the United States Reduction and Refining Company at Colorado City, which treats Cripple Creek ores exclusively, has a capacity of 450 tons per day. All the ore received goes to the sampler. The ore is there crushed to three-fourths inch mesh and one twenty-fifth of it taken out for finer crushing and quartering for the assay and analysis sample. Belt conveyors take the ore from the sampler to the bedding room, where it is loaded from hoppers into cars and thence dumped in heaps on the bedding floor below. With ore of ordinary grade sufficient homogeneity of the mixture is secured by dumping alternately on different heaps small carloads from different shipments. But high-grade ores are mixed more carefully with those of lower value.

From the bedding floor the ore is taken by belt conveyors to the driers—long tables where the ore is moved by mechanical rakes and heated only sufficiently to drive off mositure. It is next trammed to hoppers, whence it goes to the rolls to

[a] Argall, Philip, Chlorination *v.* cyanidation: Eng. and Min. Jour., November 24, 1904. For further contributions to the same subject see Greenawalt, W. E., Eng. and Min. Jour., October 27, 1904; and Doveton, G. D., The metallurgy of Cripple Creek, Colo.: Min. Jour. (London), December 23, 1905.

[b] At the end of 1905 five small plants with individual capacities up to 150 tons were in operation.

be crushed to about 20-mesh size and then fed into the roasters. These are of the Holthoff-Wethey type, have a capacity of 100 tons per day each, and employ an average temperature of about 1,600° F. The roasted ore is cooled in its journey back underneath the furnaces, and is then conveyed on an inclined belt to the barrel house, where it is loaded into hopper cars and finally charged into the chlorination barrels.

The 10 barrels, of a capacity of 10 tons, are about 20 feet long and 5 feet in diameter. The exact composition of the lixiviating solution is not made public, but it consists essentially of a solution of electrolytically generated chlorine in water. The strength of the solution used is determined not so much by the value of the ore as by the composition of the gangue. About 100 gallons of the solution are used for each ton of ore, and this amount contains 1 to 2½ pounds of chlorine.

When the barrels have been charged with ore and solution, they are sealed and rotated for two or three hours, at the end of which time a valve at the bottom of the barrel is opened and one at the top is connected with water pressure. The solution is thus made to pass through an interior filter of the Sloan type, and the pulp is washed for two to four hours. About 100 gallons of water per ton of ore are added during the washing, making the total bulk of gold-bearing solution about 200 gallons for each ton of ore. After the pulp is sufficiently washed the manhead is removed from the barrel, the barrel is rotated, and the pulp emptied into a launder by which it is conveyed to Wilfley tables on a floor beneath. There are 20 of these concentrators, arranged in batteries of 5. The headings from four of the five pass to the fifth, and the concentrates from this table, which represent about one two hundred and fiftieths of the total pulp, are saved and sent to the smelters. They have a value of $20 to $30 per ton. For the presence of the greater part of the gold in them the following explanation is offered: When the ore is roasted, pyrite is oxidized and converted partly into magnetite (Fe_3O_4), which is only slightly attacked by the chlorine solution. Any gold which may have been inclosed in the pyrite is thus protected from the action of the solvent, and without concentration would be lost. Besides magnetite other iron oxides and barite are noticeable constituents of the final concentrates, and a molybdenum mineral is said to be present at times. Finely divided free gold is occasionally seen on the last table.

After passing through the filters the lixiviating solutions together with the wash water pass to the sand boxes where the coarser sediment which has escaped the filter quickly falls and is returned to the barrels; then to the settling tanks, where they remain for eight hours and allow practically all the material in suspension to separate out. During this time a gelatinous precipitate, said to be a basic aluminum silicate, forms and falls to the bottom. On account of the difficulty of washing this precipitate thoroughly, a small loss of gold may take place.

From the settling tanks the solution is drawn into lead-lined monte-jus, and thence forced by air pressure into precipitating tanks. Into these the precipitating agent, hydrogen sulphide, is introduced direct from the generator. Precipitation is continued until tests show no more gold in solution, the time required being thirty to forty minutes. After the precipitate settles the supernatant liquor is drawn off and run through filter presses, and before leaving the building is passed through a sand filter to counteract possible leakage or breakage of these presses.

When sufficient precipitate has collected at the bottom of the precipitation tanks, it is drawn into a small monte-jus, and forced through the filter presses, of which there are six. Finally the presses are cleaned and the precipitate is dried, roasted, melted with flux, and cast into bricks. On ores of average grade an extraction of about 95 per cent is obtained, but since the actual loss approaches a constant amount, the percentage of recovery is higher for rich ores.

Chlorine for the solution of the gold is generated electrolytically at the plant. A hot saturated solution of salt is treated in McDonald cells, the chlorine being piped away and the concentrated caustic-soda solution collected as a by-product.

Among the principal mines from which this mill treats ores are the Abe Lincoln, American Eagle, Elkton, El Paso, Findley, Golden Cycle, Shurtloff, Strong, Theresa, and Vindicator. In April, 1904, the plant was handling about 250 tons daily.

At the Florence plant of the same company the practice is similar, except that six Pearce turret furnaces are used instead of the Holthoff type.

In the Telluride mill of 300 tons daily capacity Holthoff furnaces are used. The chlorine is generated by calcium oxychloride and sulphuric acid. The liquor from the filter presses passes through a box of finely divided charcoal and a further saving of 0.005 ounce of gold per ton of solution is thus effected. The chlorinated pulp is not concentrated at this plant. Among the mines which ship ore to the Telluride mill are the Ajax, Dillon, Mary McKinney, and Old Gold.

The Economic mill at Victor, with a capacity of 300 tons, roasts after crushing in seven Argall furnaces and one Pearce furnace, both burning crude Florence oil. The chlorination takes place in seven 20-ton lead-lined revolving barrels, 17½ by 8 feet. Chlorine is generated by sulphuric acid and calcium oxychloride. The agitation occupies three hours. The filtrate goes to settling tanks and thence to five steel precipitating tanks 8 by 16 feet. Hydrogen sulphide is the precipitant used. After passing through filter presses the cakes of gold sulphide are roasted in shallow iron pans, mixed with flux, melted in a wind furnace in large graphite crucibles, and the gold finally poured out in 700-ounce bricks.

The latest mill to be built is that of the Portland mine at Colorado Springs. This includes a sampling department with adequate dust collectors. Ore beds are made up of 3,000 tons capacity, the ore being reduced to three-quarters of an inch in size. There are three Pearce and one Holthoff roasting furnaces, originally built for oil burning, but now preferably heated by producer gas. Otherwise the practice corresponds to that already described.

LABOR CONDITIONS.

The minimum wages for ordinary miners are $3 a day of eight hours, and machine men receive ordinarily $4 to $5 a day. The total number of men employed by the mines and samplers was about 5,500 in 1903, and more than this were probably employed in 1900 and 1901. The aggregate monthly pay roll of the camp amounts to $600,000. By far the greater number of men, probably about 3,000, are working on Battle Mountain and Bull Hill. The miners are chiefly Americans, comparatively few foreigners being employed.

With fair wages, a healthful climate, and comparatively cheap living expenses there would seem to be no reason for such labor troubles as have twice afflicted the

district, in both cases originating in questions relating to labor unions. The big strike of 1894 ended in a compromise establishing the present scale of wages and hours of labor. The second great strike of 1903 and 1904, begun by the Western Federation of Miners on the basis of seemingly irrelevant issues, was unfortunately, like the first, accompanied by much bloodshed and violence and ended in the defeat of that organization.

FINANCIAL CONDITIONS.

Most of the mines of Cripple Creek were located by prospectors and working miners. Extensive consolidations have since taken place, but the camp still largely remains an aggregate of many small mines. Most of the mines paid for their own development almost from the grass roots. The total number of working companies is probably not far from 250, while the number of mines recorded on the map accompanying this report is 324. The owners of individual claims have usually developed their property themselves if they proved payable from the start. If not, a company was organized with the financial aid of some local man of means and, if necessary, some stock sold until the mine was put on a paying basis. If success did not attend the efforts, promising parts of the claim were leased to working miners or to small companies of men who were able to work more economically than a larger organization. A vast amount of "wild-catting," or organization of companies based upon some probably worthless piece of ground, has also been practiced, chiefly by a class of promoters who are always to be found in newly discovered and rich mining camps and to whom the gullibility of the distant public offers attractive vistas of illegitimate profits. Some companies consolidated to larger corporations or were sold to foreign capitalists, but the list of foreign-owned mines is a small one. The leasing system built up as a result of all these conditions has perpetuated itself and is still in extensive practice. The leases run from six months to two years and the royalties are usually 15 to 35 per cent of the net return, that is, of the sum obtained from the sale of the ore after subtracting transportation and reduction charges. Occasionally several lessees will work in one mine, each having a separate level or vein to work on. In one case 14 sets of lessees were at work on one small property of two claims. While this system may have some advantage, its drawbacks are considerable; it is, as Mr. T. A. Rickard says, "the last resort of a perplexed mine owner, and is a confession of inability to work one's own property."[a] Moreover, the expiration of the lease usually leaves the mine in a very unsatisfactory condition. The leasing system at Cripple Creek has recently been discussed by Mr. J. W. Finch,[b] who concludes that under certain conditions which prevail in Cripple Creek it is of considerable advantage.

In organizing the mining companies of Cripple Creek a very large nominal capital is the rule, regardless of the size or the character of the property. In general it is $1,000,000 or $1,500,000, divided into shares of the par value of $1. If the property is a small one the value of each share is of course only a few cents; indeed, if it is a mere prospect the shares may be quoted as low as $1 per thousand. Practically all of the stock is nonassessable and this is one of the reasons for the excessive capitalization practiced. A large amount is usually held as treasury stock and sold

[a] The Cripple Creek gold field: Proc. Inst. Min. and Metallurgy, London, 1899, p. 39.
[b] Mining Mag., vol. 12, No. 6.

for what it may bring in case more money for development is needed. Another motive for overcapitalization is that every prospecting company feels that it may some day by rich discoveries attain the dignity of a mine, and that it will then be ready to do business on a great scale without reorganization. A further advantage from the stock-market point of view is likewise apparent; but when all is said the fact remains that this mode of financiering is objectionable, chiefly because of the false impressions created. A worthless prospect may easily be given, in the eyes of persons not familiar with such devices, a semblance of importance which it is far from possessing.

The official manual of the Cripple Creek district, published by Mr. Fred Hills in 1900, contains a very complete record of the mining companies organized to work properties in the district. It describes the properties of 500 companies, about 100 of which have a production of over $2,000 to their credit. Among the few companies with a reasonable capitalization is the Strong, with 500,000 shares at $1 and a heavy production, while the highest capitalization is that of the Colamokas Gold Mining Company, with 5,000,000 shares at $1, the production apparently being nil; also the Greater Gold Belt Mining Company, with the same capitalization and a very small output, and the Stratton's Independence (Limited) with the same capitalization, a production of $7,500,000, and dividends of $4,000,000. The average capitalization is $1,250,000, most companies being organized with at least $1,000,000. Very few mines have yielded the amount of their capitalization in dividends. It is readily seen that few mines will be able to pay adequate dividends on this excessive capitalization. Fortunately the capitalization is imaginary, not real, and thus it happens that many of the gold mines of Cripple Creek are in a healthy condition and decidedly remunerative.

The value of a mine is measured by the price of the stock. Here again the tendency to booming and exaggeration incidental to excessive capitalization has made itself felt in higher prices for stock than were warranted. Since 1900, however, the prices have receded and now probably more nearly approach the true value, based on ore in sight plus an amount varying with the probable prospects of the mine. From the present share prices ($1.70) the Portland mine is now worth $5,000,000, whereas a few years ago the valuation reached $9,000,000. Stratton's Independence at present prices (1905) is valued at $620,000, whereas in 1899 it sold for about $11,000,000. The Elkton at present prices would be worth $1,250,000.

It might seem that a high production would justify a very large valuation. Many people, however, lose sight of the fact that the majority of gold mines have a limited life and that a large interest is necessary to recover the capital, together with an adequate return from the venture.

To illustrate the manner in which many of the mines have grown, the Portland may again serve as an example, though few properties have been as successful as this. The Portland was located as a small claim in 1892 by three prospectors. A year later some rich ore was stoped. The development continued on a small scale, and in 1894 the present company was organized with a capital of $3,000,000. Rich ore was found, and in the next few years the proceeds were diverted to the purchase of adjoining claims, until in 1899 the whole present area of 200 acres had been acquired. Meanwhile the mine also paid for the erection of plants and all other necessary

expenses, including a large mill built in 1902. The mine is now in an enviable position. It is said that not one share of treasury stock was sold for purposes of mine development or equipment.

The English companies which have ventured into the Cripple Creek field have been notably unfortunate. The Lillie Gold Mining Company (Limited) was capitalized at $1,125,000 and had yielded $360,000 in dividends when it was found that the shoot pitched into the adjoining ground. On the basis of the moderate capitalization which the small area of only 7 acres would have justified, this should have been a successful undertaking. The Stratton's Independence (Limited) was bought, with $5,000,000 profits in sight, for $11,000,000 and capitalized for £1,000,000 in £1 shares, the value per share at the time of flotation being about $10; from 1899 to 1904, inclusive, $7,500,000 have been produced and $4,000,000 paid in dividends. The Moon-Anchor Consolidated Gold Mine (Limited) has also an unsuccessful record.

It can not be said that any record-breaking results have been achieved in Cripple Creek in the way of economic treatment of the ores. In fact, compared with that in many other districts, both in the United States and in foreign countries, the expense of mining and milling seems extraordinarily high. The combined cost of mining and milling in the large mines ranges from $15 to $25 per ton. At Kalgoorlie, Western Australia, where similar ores and conditions prevail, the total cost had several years ago been reduced to $10 per ton and is now still further reduced to about $7.50 per ton.

There are several factors entering into this problem. One relates to imperfect sorting and washing of ore, now less in evidence than formerly. The many rich dumps of supposed waste, profitably washed over again, testify abundantly to neglect in this direction. On the other hand, careful hand sorting will materially increase the cost of mining, though at the same time it may result in greater profits.[a] There has undoubtedly been great carelessness in mining, as is shown by the profits made by tributers in old stopes. The Cripple Creek ores are much more friable than those of Kalgoorlie and loss by fines is much more apt to take place. Free gold is present in the Western Australia ores in varying amounts, while almost wholly lacking in Cripple Creek. The Diehl process used at Kalgoorlie includes a preliminary concentration on Wilfley tables, roasting and cyaniding of concentrates, and agitation with bromocyanide of the tailings from the tables. This does not seem to be directly applicable to Cripple Creek ores. But of even greater importance are the heavy charges for ore reduction, which, for very commonly occurring ores of $40 per ton, amount to from $8 to $13 per ton, inclusive of freight. To a great extent this is caused by the presence of many small operators, who can not afford to build reduction works themselves and who naturally avail themselves of the advantages of the custom mill. The large mines mostly followed the example of the smaller contingent. The rich ores were there in sight awaiting extraction; the stockholders were awaiting their dividends. Why bother about a few dollars per ton when a custom mill was available? This seems to have been the line of reasoning of many large companies who doubtless would have made much more money by waiting a little while and building their own reduction works, not necessarily on a very large scale. There is no doubt

[a] Finlay, J. R., Eng. and Min. Jour., November 21, 1903.

that it is of advantage to "rip" the ore out of a mine as rapidly as possible, short of "robbing the mine," but there is also such a thing as dividing profits a little too liberally with reduction works and railroads.

EXTENT OF PRODUCTIVE TERRITORY.

There is nothing in the history of the district since 1894 warranting any extension of the bounds of the productive territory as then known. Now, as then, a circle of 3 miles radius described from the summit of Gold Hill would include all deposits of known or prospective value, while the really important mines would be embraced by a circle of about half that radius, with its center near the summit of Raven Hill. That scattered deposits of greater or less value may be found in outlying portions of the district is by no means improbable. But the close dependence of the typical Cripple Creek ores upon the main volcanic center and the consequent remarkable compactness of the gold-bearing area are features highly characteristic of the district and are likely always to remain so.

The greater part of the ore has undoubtedly come from the central area of breccia, particularly from that part of this area in which the breccia extends to great depth. Very productive ore bodies have been found, however, in the granitic rocks, usually within 1,000 feet of the steep contact limiting the breccia on the southwest. The important Beacon Hill mines, with ore bodies nearly three-fourths of a mile from this contact, are exceptional, and are probably genetically connected with the intrusive mass of phonolite forming the core of the hill.

CHAPTER VI.—PRELIMINARY REVIEW OF THE MINING INDUSTRY.

EARLIER WORK IN MINING GEOLOGY.

To the excellent work of R. A. F. Penrose, jr., apply statements similar to those made in the discussion of the purely geological branch of the subject. Few shafts had then attained a depth of 400 feet, and most of the exposures were marked by surface oxidation. It would be surprising, in view of the facilities created by the later development of hundreds of mines, if a subsequent investigation should not bring out some slight modifications of earlier results.

DISTRIBUTION OF MINES.

The productive district, as previously stated, is practically covered by the area of a circle 3½ miles in diameter. The center of this circle would be located halfway between Raven Hill and Bull Hill, and the towns of Cripple Creek, Victor, and Cameron would be situated on its periphery. A very few mines—notably the Galena and the Fluorine—and many prospects lie outside of this area.

The culminating points of the district are found in a ridge of high and bare hills that extends in a northwest-southeast direction and divides the waters flowing into Cripple Creek and Wilson Creek on the southwest from those joining Spring Creek and Grassy Creek on the north. From northwest to southeast the following hills mark this divide: Mineral Hill, Carbonate Hill, and Tenderfoot Hill, north or northeast of Cripple Creek; Globe Hill, Ironclad Hill, and Bull Hill, the latter being near the center of the district and equidistant from Cripple Creek and Victor. The ridge is continued by Bull Cliff and Big Bull Mountain, the latter, really outside of the productive area, being the highest point in this dividing range of hills. Its elevation is 10,826 feet. Three long spurs project to the southwest from the dividing range separating the deep trenches of Cripple Creek, Squaw Gulch, Arequa Gulch, and Wilson Creek; the first, called Gold Hill, rises directly east of Cripple Creek; the second is Raven Hill, being continued to the southwest by the lower spur of Guyot and Beacon hills; the third is Battle Mountain, continued by the almost equally high salient of Squaw Mountain.

The important mines are situated in this region of sharply accentuated topography. As has been several times emphasized, the volcanic area practically coincides with the hills and ridges just described and is surrounded on all sides by granitic rocks.

Globe and Ironclad hills and Gold and Raven hills consist chiefly of heavy masses of breccia, and were scenes of great activity during the early years of the district. Near Poverty Gulch, just northeast of Cripple Creek, is the Abe Lincoln, not a large mine, but still actively worked with satisfactory results. Higher up are

the Gold King, with dividend records of $150,000, and the C. O. D., with a reported production of $600,000 and dividends of $150,000. Both were idle in 1904 and have attained their eighth or ninth levels.

On the summit of Globe Hill are the Stratton properties of Plymouth Rock and Globe mines, in which extensive low-grade mineralization without many sharply defined veins seems to be the rule. Adjoining is the property of the Homestake Company, including the Ironclad mine, where direct cyaniding of oxidized surface ores is now carried on in a mill erected on the property.

Gold Hill is crowned by the Anchoria-Leland mine, with a production of over $1,000,000 and dividends of $198,000. The shaft is 1,100 feet deep. The adjoining Moon-Anchor has paid dividends of $261,000, and the Half Moon (Matoa Gold Mining Company) has a gross production of $650,000 to its credit, but is reported to have paid only a small amount in dividends. None of these mines is being worked at present, except on a small scale by lessees.

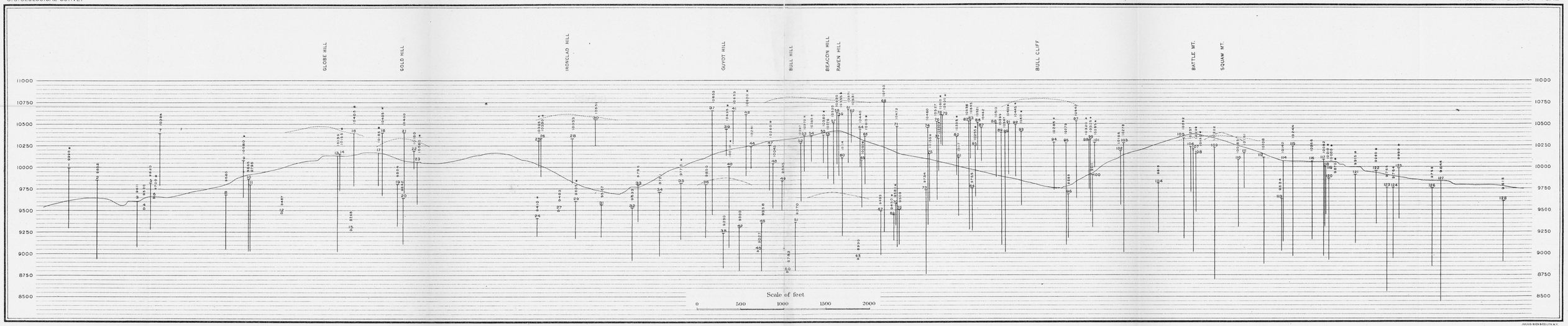
On the western slope is the Midget mine, actively worked at present, with a depth of 800 feet, a total production of $662,000, and dividends of $195,000. The Conundrum, in the same vicinity, is likewise worked with good results to a depth of 600 feet. The Midget, like the mines described above, follows a vein in breccia, while the Conundrum is mining on a "basalt" dike in granite, close to the contact of the breccia.

In the deep gulch between Gold Hill and Raven Hill are situated the Anaconda, Doctor-Jackpot, and Mary McKinney mines, all working on sheeted zones forming lodes in the breccia. The Anaconda produced about $1,000,000, chiefly from upper levels, and is now being worked by lessees. The Mary McKinney is one of the most successful mines worked at present in the district. Its depth is 600 feet. The Doctor-Jackpot has $4,000,000 to its credit and likewise a handsome dividend record. The shaft is only 700 feet deep, water having until now prohibited deeper sinking.

The breccia-granite contact is found on Guyot Hill a short distance south of the Mary McKinney. The extreme spur of Raven Hill, called Beacon Hill, is formed of an intrusion of phonolite in granite, and about this outlying volcanic center cluster a group of veins of great production and promise. On the eastern side of the hill are located the Prince Albert, Gold Dollar, and others, which are worked on a small scale by lessees. On the western side lie the El Paso, C. K. & N., and Old Gold mines, with their narrow but extremely rich fissure veins in granite, now actively and successfully worked.

A great number of smaller mines have been worked on veins cutting the breccia of Raven Hill. The famous Elkton mine is situated in the deep hollow between Raven Hill and Battle Mountain. It has been working on an exceptionally long vein, partly contained in breccia, partly in granite, and generally following a "basalt" dike. The production approaches $6,000,000, and the depth attained is about 900 feet, excessive water having formed a serious obstacle to deeper sinking. Dividends amount to $1,200,000. The Moose mine, situated higher up on the slope of Raven Hill, had a good ore shoot, from which $500,000 was obtained.

Continuing northwest, we soon attain the summit of Bull Hill, which affords a magnificent panorama, not only of the whole camp, but of a large part of the State

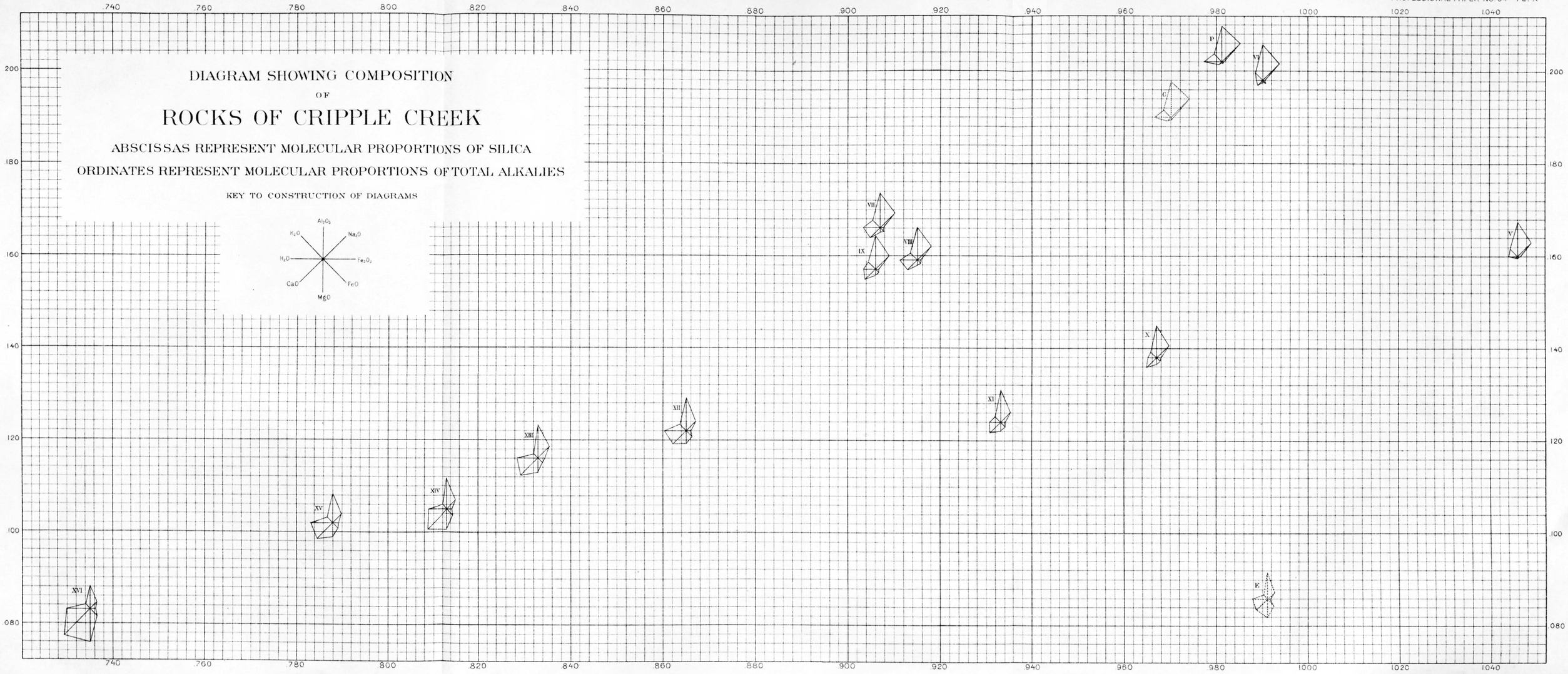


SECTION ACROSS THE CRIPPLE CREEK DISTRICT FROM THE ABE LINCOLN MINE TO STRATTON'S INDEPENDENCE MINE, SHOWING BY SECTION AND PROJECTION THE RELATIVE VERTICAL POSITIONS OF THE PRINCIPAL SHAFTS, LOOKING NORTHEAST.

SHAFT AND TUNNEL NAMES, CRIPPLE CREEK DISTRICT, WITH ELEVATIONS OF COLLARS AND PORTALS

1 Mollie Kathleen....9,990*
2 El Paso Gold King..9,852
3 Abe Lincoln.....9,611
4 Cripple Creek and Gold Hill tunnel....9,500
5 C. O. D.....9,820
6 Chicago tunnel.....9,700*
7 Hoosier.....10,394
8 Conundrum.....9,680
9 Gold Pass.....10,080*
10 Moon Anchor.....9,865
11 Midget.....9,796
12 Good Will tunnel...9,467
13 Anchoria Leland...10,139
14 Half Moon.....10,155*
15 Ophelia tunnel.....9,268
16 Deerhorn.....10,405*
17 Lexington.....10,185*
18 Plymouth Rock No. 1.....10,435*
19 Mint.....9,804
20 Pointer.....9,642
21 Ironclad.....10,400
22 Sunshine.....10,180
23 E. Porter Gold King.....10,080*
24 Caledonia.....9,410*
25 W. P. H.....10,305*
26 Jerry Johnson....10,330*
27 Anaconda tunnel...9,493
28 Damon.....10,333
29 Howard.....9,605*
30 Londonderry.....10,551
31 Peggy.....9,567
32 Mary McKinney....9,533
33 Dolly Varden.....9,795
34 Morning Glory.....9,721
35 Jackpot.....9,770*
36 Katinka.....9,800
37 Gleason.....10,653
38 Old Gold.....9,230
39 Sheriff.....10,435*
40 Doctor.....10,010*
41 Wild Horse.....10,653
42 C. K. & N.....9,300
43 Kalamazoo.....10,620*
44 Ingham.....10,241
45 Standard tunnel...9,027
46 El Paso, new shaft..9,358
47 Pinnacle.....10,260*
48 Jennie Sample....10,043
49 Ophir.....9,845
50 El Paso drainage tunnel.....8,783
51 El Paso, old shaft...9,370
52 Gregory.....10,287
53 Ida May, new shaft..10,370*
54 Ida May, old shaft..10,365*
55 New Haven.....10,380*
56 Joe Dandy.....10,376
57 Empire State, Orphan shaft.....10,520
58 Pharmacist.....10,630
59 Wrockloff.....10,555*
60 Tornado.....10,114
61 Zenobia.....10,671
62 Burns.....10,631
63 Newell tunnel.....8,930
64 Buena Vista.....10,440
65 Block 8.....10,080*
66 Pinto.....10,615*
67 Mabel M.....9,493
68 American Eagle...10,750
69 Zoe.....9,450*
70 Prince Albert.....9,580*
71 Logan.....10,472
72 Gold Dollar.....9,509
73 Elkton.....9,734
74 Lee.....10,460
75 Gold Sovereign, Jackson shaft....10,155*
76 Shurloff No. 2.....10,527
77 Gold Sovereign, Whisper shaft.....10,330*
78 Free Coinage, Mercer shaft.....10,610*
79 Free Coinage, Murphy shaft.....10,600*
80 Dante.....10,355*
81 Moose.....10,117
82 Orpha May.....10,538
83 Deadwood No. 1...10,545
84 Thompson.....9,755
85 Trilby.....10,258*
86 Smuggler.....10,521
87 Trachyte.....10,462
88 Lucky Guss No. 1.10,510*
89 Findley.....10,399
90 Blue Bird.....10,397
91 Lucky Guss No. 2..10,420*
92 Delmonico.....10,445*
93 Deadwood No. 2...10,410*
94 Dexter.....10,285*
95 Hill City.....10,279
96 Eclipse.....9,689
97 Victor.....10,540
98 Los Angeles.....10,320*
99 Rubie.....10,325*
100 Carbonate Queen...9,911
101 Colorado City.....10,285*
102 Vindicator No. 2...10,186
103 Last Dollar.....10,278
104 May B.....9,813
105 Portland No. 3....10,332
106 Coriolanus.....10,237
107 Vindicator No. 1...10,209
108 Modoc No. 2.....10,150*
109 Lillie.....10,222
110 Clyde.....10,085
111 Christmas.....10,161
112 Ajax.....10,108
113 Santa Rita.....9,634
114 Granite.....10,140
115 Portland No. 2....10,244
116 Golden Cycle.....10,066
117 Portland No. 1....10,082
118 Theresa.....10,010*
119 Monument.....10,000*
120 Dead Pine.....9,870*
121 Dillon.....9,915*
122 Stratton's Ind. No. 2. 9,960*
123 Gold Coin.....9,765
124 Mary Cashen.....9,764
125 Gold Knob.....9,990*
126 Strong.....9,756
127 Stratton's Ind. No. 1. 9,844
128 St. Patrick.....9,615

* ELEVATION APPROXIMATE



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of Colorado. Toward the east, and 5,000 feet lower, spread the great plains at the foot of the Rocky Mountains; westward the Sangre de Cristo, Collegiate, and Mosquito ranges—a snowy and jagged line of ramparts—define the distant horizon.

A multitude of small mines occupy the southwestern slope of Bull Hill. On the northwestern side an area of brecciated granite appears among the volcanic rocks, and in this formation is situated the Wild Horse mine. This lode, which has been worked to a depth of 1,250 feet, has produced over $1,000,000, but is now operated only by lessees. A number of smaller producers may be found on the northern slope, toward Cameron, among them the Damon, Jerry Johnson, W. P. H., and Pinnacle.

Those who have followed this description on a map will have noticed that the mines are chiefly situated on the periphery of a circular area, the central part of which, comprising the upper part of Squaw Gulch, has thus far yielded very little. Few strong veins have been met with in this part of the breccia, but, on the other hand, the developments in depth are not extensive.

On the east and southeast sides of Bull Hill begins that most important belt of lodes which extends southward to Victor and includes the richest group of producers in the camp. A characteristic feature of this belt is the intrusion into the breccia of thick masses of latite-phonolite and syenitic rocks.

With few exceptions the veins of this belt strike north-northwest. We may begin the description with the system of linked veins, 3,000 feet long, covered by the Isabella and Victor mines. The last-named mine, on the southern end of the system, is situated just below the western slope of Bull Cliff. It has been worked to a depth of over 1,000 feet, has produced about $2,200,000, and has paid dividends amounting to $1,150,000. The Isabella has attained a depth of 1,127 feet, produced $3,200,000, and paid dividends of $600,000. Both mines lost their pay shoot in depth, but are still worked by lessees.

The small but rich cross veins of the Empire State, Burns, Pharmacist, and Zenobia connect this vein system with that of the Stratton mines on Bull Hill. South of the Burns begins the great Vindicator vein system, traced southeastward for a mile through the Findley, Hull City, Vindicator, Lillie, and Golden Cycle mines. The Hull City and the Lillie have each produced over $1,000,000, the Vindicator and Golden Cycle over $2,000,000 each, all with corresponding dividend records. The Lillie is deepest, having attained 1,500 feet. Next in depth is the Vindicator, 1,200 feet. All of them, except the Lillie, are still actively worked. In the whole system water has been and still is a source of trouble. The deepest mine evidently drains all the others in this vicinity.

The Stratton properties on Bull Hill, with the Logan, Orpha May, and Pikes Peak veins, on which maximum depths of 1,200 and 1,500 feet have been attained, are now worked only to a slight extent, whereas in the early days of the camp they were highly productive.

This vein system is continued southward in the Last Dollar mine, now working at a depth of 1,270 feet. The production exceeds $1,000,000. South of the Last Dollar the veins enter the Modoc ground, a mine worked for a long time with gratifying success. The Blue Bird, an old-time producer, is situated a short distance west of the Last Dollar.

South of the Modoc is the Battle Mountain vein system, crossing from the granite into the breccia, with general northerly or north-northwesterly directions, and distinguished by heavy production and ore bodies of imposing size. None of the veins is of great length, and the whole system extends scarcely a mile along the strike of the veins. The veins can not be directly connected with others already described, though, in its general trend, the system heads toward the Dexter, Blue Bird, and Moose veins.

Beginning on the southwestern side, we first come to the Gold Coin mine, the veins of which are in granite; one of them is successfully worked at present at a depth of 1,200 feet. The total production approaches $6,000,000; the dividends paid exceed $1,000,000. North of the Gold Coin is the Ajax, working partly in the veins, partly in large, irregular ore bodies in the granite. The total production is very considerable. The depth attained is 1,200 feet.

Between this and the Portland vein system, almost within the town of Victor, are the Granite, Dillon, and Dead Pine veins. They are worked at present at depths of 800 to 1,000 feet.

The Portland vein system begins on the south at the Strong mine, now worked at a maximum depth of 900 feet, on a vein in granite that follows a "basalt" dike, which is in places accompanied by a phonolite dike. The mine is an unusually regular and profitable producer, the total dividends since 1892 amounting to $2,500,000.

The veins of Stratton's Independence run about parallel to those of the Strong, a few hundred feet eastward. They extend from the granite into the breccia, following for some distance a phonolite dike. The production of this mine amounts to over $11,000,000, with a dividend record of $4,000,000 since 1899. At present the company is leasing the various levels to tributers. From the two properties last described the vein systems continue into the Portland mine, but in the northern part of that great property are replaced by another and still richer aggregate of veins, the Captain system. The Portland is, beyond question, the most prominent mine of the Cripple Creek district. Its total production from 1894 to the end of 1903 amounted to $18,000,000, derived from 466,000 tons of ore (both in round figures), from which $4,600,000 has been paid in dividends, the remainder going to acquirement of territory, extensive milling and mining plants, and operating expenses.

Outside mining properties.—The area outside of the principal volcanic area contains very few productive properties, but it is by no means barren. A great deal of money has been spent here, usually with unsatisfactory results. Although there are many properties of merit and although much honest effort has been made in this part of the district, it has long been the favorite camping ground of concerns more or less lacking in stability.

The granite hills west and south of the city of Cripple Creek contain few prospects; phonolite dikes occur in places, but usually show little value. Along Gold Run and Arequa Gulch prospects with a little ore have been found, down to the junction with Cripple Creek, and even at isolated places below this locality. Grouse Hill, with its phonolite cap, shows many prospects from which occasional good assays have been obtained, but neither here nor on Straub and Brind mountains has anything of permanent value been developed thus far. It is claimed that ore bodies of low grade, containing a few dollars per ton, exist.

The breccia caps of Mineral, Carbonate, and Tenderfoot hills are dotted with prospect dumps and even shafts several hundred feet deep. Nothing of permanent value is recorded from Mineral Hill, though fairly productive placers have been worked at its southwestern base, almost in the town of Cripple Creek.

On Carbonate Hill the Elkhorn has been a small producer; on Tenderfoot Hill the Friday, Hoosier, Black Diamond, and Mollie Kathleen contribute to the production. Two miles north-northwest of Cripple Creek is the Galena mine, the vein of which follows, for a part of its course, a phonolite dike in granite and has a small output to its credit. About the same distance north of the city is the small volcanic center of Copper and Rhyolite mountains. At the former the Fluorine mine has produced $160,000, and low-grade ore is now being cyanided. Prospects are found on Rhyolite Mountain, and in fact all over the flat, granite country between it and Trachyte Mountain. The Lincoln mine, near Gillett, and several other prospects farther south, along a belt of phonolite dikes, have produced a little ore. It is claimed that there are low-grade veins on both sides of Bernard Creek, northwest of Gillett, in a region of granite with occasional dikes and masses of phonolite. Trachyte Mountain, southeast of Gillett, is covered by phonolite, and a little ore is occasionally found in veins at its southern foot. Some work has also been done on Cow Mountain, about 4 miles northeast of Bull Hill.

The eastern margin of the central volcanic area, east of Victor Pass and extending southward across Big Bull Mountain to Brind Mountain, has thus far failed to produce anything of importance, though well covered by prospects. A survey of these outlying parts of the district serves to emphasize strongly the remarkable concentration of deposits within the narrow limits of the central volcanic area.

EXTENT OF UNDERGROUND DEVELOPMENT.

At the time of the earlier survey the deepest shafts, those of the Moose, Pharmacist, and Anna Lee mines, were down only about 400 feet, while few of the other mines were over 200 feet in depth. Many subsequently prominent mines were then mere prospects or had not been located.

The deepest shaft at present is the Lillie, which is over 1,500 feet deep, although the Stratton's Independence shaft, 1,400 feet deep, has the lowest sump in the district. The American Eagle shaft is nearly as deep as the Lillie, while there are about 20 other shafts over 1,000 feet in depth, and at least 100 shafts deeper than the deepest workings existing in 1894. As regards absolute elevations, the Gold Hill shafts are down to a level of scarcely 9,000 feet above sea; the Elkton, El Paso, and Lillie shafts descend to 8,750 feet; Stratton's Independence reaches the lowest level at 8,450 feet; while the Gold Coin shaft, at 8,550 feet, is of interest from the fact that the deepest ore shoot in the district is now being stoped from its twelfth level.

The amount of drifting and cross cutting accomplished since the earlier survey is more than commensurate with the increased number and depth of the shafts, and the district is further intersected in various directions and at different levels by two long tunnels run for drainage purposes and by a dozen or more extensive adits, many of which have their portals in the granitic rocks and extend well into the central part of the breccia area.

PLACERS.

Owing to the light, powdery, or spongy form of the gold set free by the oxidation of the tellurides, placer deposits have been formed only to a very subordinate extent. Penrose states that limited areas of placer ground have been worked at Hull City, along Beaver Creek, in Squaw Gulch, Arequa Gulch, and on Wilson Creek. The principal placers were found in the northern part of the town of Cripple Creek, on the southerly slopes of Mineral and Carbonate hills, particularly in the broad hollow on the southwest side of Mineral Hill. A fair amount of gold was taken out from this shallow ground in the early days by sluice, rocker, or dry washer; in many cases the pay dirt was extracted by drifting from little pits or shafts. A certain amount of payable ground is said to remain here, and, were water available, a considerable area could probably be washed with profit. The gold appears to have been derived from veins in the breccia directly southwest of the summit of Mineral Hill; extensive prospecting has, however, thus far failed to reveal any primary deposits of value.

CHAPTER VII.—STRUCTURE OF THE GOLD DEPOSITS.

PRINCIPAL TYPES OF DEPOSITS.

With few exceptions the ore bodies, of whatever shape, are causally connected with fissures. The most important types of auriferous ore bodies occurring in the district are:

(1) Tabular in form and strictly following simple fissures or sheeted zones. A subtype comprises lodes in which the sheeted zone follows "basalt" or phonolite dikes.

(2) Irregular bodies adjacent to fissures and formed by replacement and recrystallization of the country rock, usually granite.

These types are not always sharply distinct, but may be connected by deposits of intermediate character.

All the ore bodies, of whatever type, exhibit certain common features which serve to distinguish the deposits of Cripple Creek from those of most other mining districts. In the first place, the actual openings in the rocks available for the deposition of ore are, as a rule, remarkably narrow. In the second place, the amount of material carried in the mineralizing solutions and deposited as gangue and ore minerals was comparatively small. In consequence of these two conditions, the district contains no such massive veins, solidly filled with quartz or other vein minerals, as are characteristic of the San Juan region in Colorado or the Mother Lode region in California. Even the small fissures of the Cripple Creek district are seldom completely filled, but have a characteristic open or vuggy structure. Where the fractures are unusually wide, or where the rocks are extensively shattered, as in the Midget and Moose mines, the small volume of available vein matter is particularly noticeable. The walls of such fractures and the fragments of the shattered rock are often merely coated with a thin deposit of quartz, fluorite, and other minerals. As the rich tellurides were usually among the minerals last to form, and are particularly abundant on the walls of the vugs, it is probable that had quartz, fluorite, or other gangue minerals been more abundantly deposited, the ores would have been of much lower grade.

LODE FISSURES.

DISTRIBUTION.

As elements of geological structure, the lode fissures of Cripple Creek are exceedingly inconspicuous. They are marked neither by bold outcrops of quartz nor by superficial bands of ferruginous gossan. They seldom fault perceptibly the structures which they traverse and they are not sufficiently different from the mass of the rocks, as regards resistance to erosion, to have perceptibly influenced the topographic development of the district. It is this obscurity that, as already

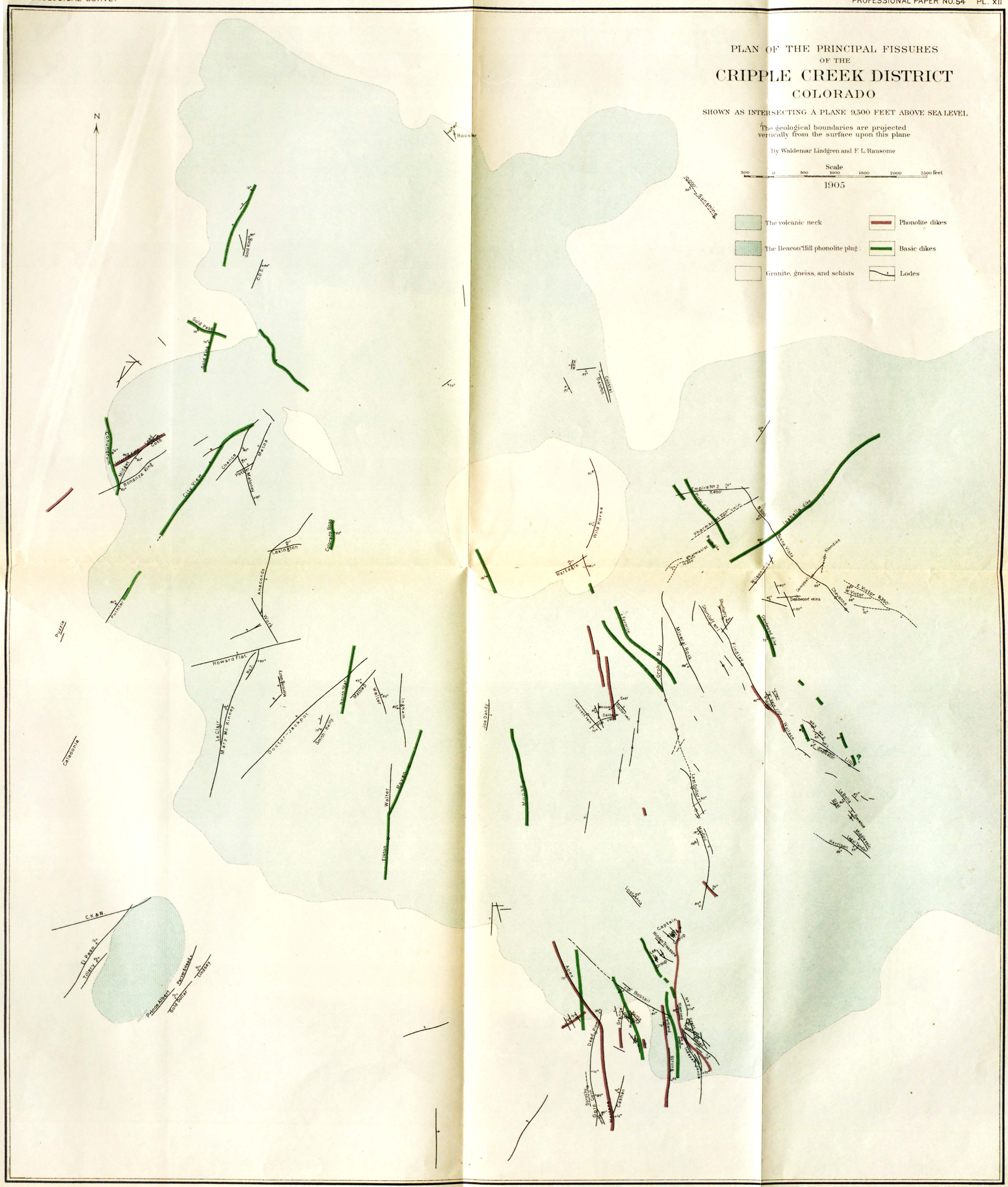
related, retarded the discovery of the ore deposits, and that to-day renders it impossible to follow the veins over the surface without first stripping off the soil and loose rock or sinking test pits. In the early stages of mining development in the district the course of a newly discovered lode was rarely known until underground work had well advanced, and consequently few of the claims were laid out along what afterwards proved to be lines of outcrop. Furthermore, many of the lodes, such as the "Captain system" of the Portland mine and the Dorothy vein of the Gold Coin mine, apparently do not reach the surface. Under these circumstances, discussion of the lode fissures is limited to those whose positions and courses have been determined by underground work.

In a hilly region the lines of outcrop of inclined veins, when plotted on a map, are complicated by curvature due to the irregularity of the topographic surface. In a study of the fissure systems of a district such as that of Cripple Creek, it is desirable to eliminate this unessential complexity and to consider the traces of the fissures upon one or more horizontal planes. In Pl. XII the principal lodes of the district are represented with the courses and relative positions that they would have if they outcropped on a level plain 9,500 feet above the sea. A few veins, known only at considerable distances above or below the 9,500-foot plane, are represented by dotted lines, and have the elevation at which they are known nearest to 9,500 feet indicated in figures. The diagram shows also the outlines of the main volcanic neck and of the Beacon Hill phonolite plug at the surface, data being insufficient for fully delineating these features upon the 9,500-foot plane.

As shown in Pl. XII, the productive fissures are most strongly and abundantly developed in the volcanic neck. They are not confined to the neck, however, for there is a very important group near Victor, partly in granite and partly in the volcanic rocks, and there is a prominent group in the granite of Beacon Hill. Productive fissures occur also at other points in the granites and gneiss of the prevolcanic plateau. But even when all outlying fissures are considered, the grouping of the lodes within a small area, which is that of the volcanic neck plus a sector of a narrow concentric zone of the granitic rim, is the most striking fact of distribution brought out by the diagram. Within this general group the fissures of Beacon Hill constitute a subgroup clustered about the phonolite plug which forms the core of the hill.

Within the volcanic neck the fissures are most abundant and persistent in its southern half. They are crowded within the V-shaped or crescentic area wherein, as previously shown, the breccia extends to great depth and most clearly fills a part of the old volcanic throat. In the very center of the generally productive tract and roughly bounded by lines connecting the summits of Globe, Ironclad, Bull, Raven, and Gold hills is an area within which few important productive fissures are known. This relatively barren ground includes the superficially isolated granite mass of Bull and Ironclad hills and the schist mass of Fairview. North of this area, extending to Tenderfoot and Carbonate hills, is a part of the district which, while moderately productive, exhibits far less fissuring than does the portion stretching from Anaconda to Victor and from Victor to Altman.

It is certain that the district contains many important fissures not shown in Pl. XII, but that plate probably expresses fairly well the essential facts of lode


PLAN OF THE PRINCIPAL FISSURES
OF THE
CRIPPLE CREEK DISTRICT
COLORADO
SHOWN AS INTERSECTING A PLANE 9,500 FEET ABOVE SEA LEVEL
The geological boundaries are projected vertically from the surface upon this plane
By Waldemar Lindgren and F. L. Ransome
Scale
500 0 500 1000 1500 2000 2500 feet
1905
The volcanic neck
The Beacon Hill phonolite plug
Granite, gneiss, and schists
Phonolite dikes
Basic dikes
Lodes
N
Hoosier
Gold King
C.O.D.
Gold Pass
Gold King
Conundrum
Midget
Lead
Cobb
Bonanza King
City View
Chance
Potter
Maloney
Weston
Pointer
Puzzle
Caledonia
Lexington
Anaconda
Work
Colorado Boss
Howard Flat
No. 2
Le Clair
Mary Mc Kinney
Monumental
Doctor-Jackpot
Smith Reilly
North Star
Mattie D
Walter
Ingham
Walter
Raven
Elkton
C.K.&N.
El Paso
Tillery
Prince Albert
Paradise
Gold Dollar
Lindsay
Sunshine
WEH
Central
Damon
Wild Horse
Warbeale
Empire No. 2
Pharmacist
Pharmacist No. 2
Isabella dike
Buena Vista
Klondike
Wilson
Campbell
Cheyenne
E. Victor 9,350'
W. Victor
Deadwood veins
Deadwood dike
Shurtleff No. 1
Shurtleff No. 2
Findley
Mineral Rock
Orphan May
Favorite
Joe Dandy
Lovett vein
Whisper
East
Doctor vein
Dante
Moose
Wallace
Vale
Vale City
Indicator
Lillie
Last Dollar
Madoc
Lost Anna
Captain
Hidden Treasure
Group
Bobtail
Anex
Dead Pine
Gregory
Kuss
Portland
Diamond
Stronk
Independence
Dorothy
Gold Coin
Montana
Cashen
LaBella
Sixes
Revenue
Middlevein
Harrison
Legal Tender

distribution. That the fissuring is in fact local and does not extend indefinitely and with undiminished intensity into the surrounding rocks of the prevolcanic plateau is indicated not only by the results of mining development as plotted in Pl. XII, but by the behavior of underground water and by the distribution of basic dikes, as will subsequently be shown.

DIRECTION OF FISSURING.

The major fissures, as appears in Pl. XII, have a recognizable though irregular radial plan. In the western and southwestern parts of the district the prevailing strike is northeasterly; in the southern part it is northerly; and in the southeastern and eastern parts of the productive area a northwesterly strike predominates. There is much irregularity, and there are some fissures in all parts of the field that do not conform to this plan. When, however, account is taken of the heterogeneous character of the material filling the volcanic neck and the many dikes and irregular intrusive masses tending to deflect fissures from courses that they might follow in a homogeneous medium, it is less surprising that individual fissures should be eccentric than that the fissuring should on the whole so clearly exhibit a definite arrangement.

While the general disposition of the fissures is radial, they converge rather to various parts of a central tract than to a single point. This tract is that already referred to as containing relatively few important fissures and as corresponding approximately with the drainage basin of Squaw Gulch above Anaconda. It includes the island-like mass of granite of Bull and Ironclad hills and the similar schist mass of Fairview. North of this tract lies a mass of breccia extending to Tenderfoot and Carbonate hills, in which the rather scanty known fissures suggest little systematic arrangement. The general radial plan thus prevails over a sector comprising about 270° of the rudely circular productive area.

The radial arrangement of the lode fissures is shared to a certain extent by the dikes, particularly by the "basalt" dikes. It would thus seem that whatever the nature of the stresses which produced the lode fissures, similar stresses must have formed the fissures followed by the basic dikes. The ore deposition and some of the fissuring were later than the dike intrusions, but it is not certain that the fissures themselves can be separated into an earlier and a later group—that filled with "basalt," this with ore. It is probable that the basic magma was injected into a part of the earlier fissures, the remainder being left empty and in part subsequently filled with ore.

The Cripple Creek lodes, as will be shown later, have a sheeted structure. As sheeting is a characteristic result of compressive stress and as the fissures produced by a generally simple stress, like the compression of a block of glass in a vice, tend to form two intersecting groups of parallel conjugate fissures, the occurrence of a radial system rather than of two or more conjugate systems is noteworthy. The latter feature is common to many districts, even where the lodes are not regular sheeted zones and are therefore not so clearly due to compression. A general radial grouping of the fissures over a whole mining district is comparatively rare, and where associated with well-defined sheeting indicates the operation of compressive stresses of rather unusual character.

Besides the dominant radial arrangement, it should be noted that northwest and northeast veins are present together in various parts of the district, as in the Isabella, Molly Kathleen, and Abe Lincoln mines. The presence of both sets of fissures is particularly marked in the Isabella mine, in the northeastern part of the district, where the northeast or "cross" veins have a local radial grouping with northeastern convergence (fig. 44, p. 388). This development of intersecting sheeted zones is indicative of compressive stress, especially as on the whole the two systems seem to have formed simultaneously and do not as a rule fault each other, though there may be some offsets, as in the case of the Klondike and Isabella veins.

There are many other examples of local groups of divergent fissures besides that of the Isabella cross veins. Thus the principal fissures of the Victor, Vindicator, and Golden Cycle mines show a tendency to branch or diverge toward the northwest. The principal lodes of Stratton's Independence mine, on the other hand, diverge toward the southeast, and those of the Gold Coin to the south.

DIPS.

Most of the fissures are steeply inclined, the average dip being about 75°. Many are practically vertical and dips lower than 50° are rare. Fairly regular dips down to 1,200 feet in depth are shown by the Lillie (vertical), the Buena Vista (60°), Pharmacist (60°), and the Findley (85°) lodes (figs. 50 and 52, pp. 414, 420). There are, however, a few fissures which lie at unusually low angles, notably those of the Howard flat vein in the Mary McKinney and Anaconda mines, of "the flat vein" in Stratton's Independence mine, and several unnamed fissures in the Damon and War Eagle mines. The average dip of these flat veins is probably about 20°. Some of those in the Damon are nearly horizontal, but others dip at 45°. There is thus no sharp distinction, as regards dip, between the so-called flat veins and the nearly vertical lodes.

While in any local group the fissures dipping in one direction usually greatly predominate over those dipping in the other, yet adjacent lodes seldom all dip in the same direction. No systematic relation has been found between the dips, on the one hand, and the distribution of the fissures or the general structure of the district, on the other.

PERSISTENCE.

In a district like Cripple Creek, where knowledge of the lodes is derived almost exclusively from underground work and where the lodes themselves are often ill defined, discussion of the persistence of the fissures can not entirely escape a vagueness inherent in the subject. Miners are concerned with a fissure only so far as it carries, or seems likely to carry, ore. Although exploration in some cases has been pushed to the point where a fissure or fissure zone can no longer be distinguished from the irregular jointing present in nearly all rocks, in other cases the search for ore has been abandoned while the fissure could still be readily followed and while its length or depth remained undetermined. Few fissures have been explored so carefully that their extent in the directions of strike and dip is known.

In the Cripple Creek district individual fissures, or fissure zones of such regularity and narrowness that they may be classed as lodes, are rarely known to exceed

half a mile in length. Lodes of approximately this length are the Mary McKinney, Doctor-Jackpot, and Buena Vista. Some of the broader zones of nearly parallel, linked, or imbricated fissures are, however, traceable for over a mile.

Many of the most productive fissure zones are remarkably short. The so-called Captain system in the Portland mine, for example, in which the fissures, while collectively rich, are at best individually small and inconspicuous, contains few lodes that can be traced for over 300 feet. Cross cuts have more than once passed within a few feet of ore bodies 50 or more feet in width which were discovered only by subsequent exploration. In such broad zones of individually nonpersistent fissures there is often great difficulty in identifying veins crosscut at levels 100 feet apart, without actually stoping them. This is especially the case in the Portland, Stratton's Independence, and Vindicator mines. The productive veins in the granite of the Ajax mine, southwest of the shaft, are probably all less than 500 feet in length. In the Anchoria-Leland mine some fissure zones which are very regular for short distances dwindle in a few hundred feet to a single indistinct crack or come to an end at the junction with another fissure zone of different strike and dip. In the Last Dollar mine the main system of parallel fissures is crossed by east-west cross veins which can be followed only for short distances.

Information concerning the persistence of fissures in depth is even less satisfactory than that relating to length, as in many cases it is impossible to discriminate clearly between depth of pay shoots and depth of fissuring. The ore and the fissure zone are not necessarily coextensive, though often little is known of the extension of the fissures below the bottom of an ore shoot.

In general the persistence of a fissure down the dip seems to be roughly proportional to the length of the fissure. The long fissures, such as those of the Elkton and Mary McKinney lodes, can probably be followed far below the present bottoms of the mines. Many of the shorter fissures, however, are known to die out at moderate depth and are often succeeded by overlapping parallel fissures of similar character.

These relations are well illustrated in the Portland mine. The No. 1 Hidden Treasure vein was first recognized on the 350-foot level and was productive down to level 9. If the fissure zone continues to level 10, it is very inconspicuous. The No. 2 Hidden Treasure has been productive from level 6 to level 8. The No. 3 Hidden Treasure is not known above level 6, although at the bottom of the mine it is the only lode of the group which was known at the time of visit. The short lodes of the Captain group are of little importance above the 220-foot level, attain their maximum development near the 350-foot and 500-foot levels, and become very indistinct on level 7, although there are still traces of this group of fissures on level 10. Within the group individual fissures, or narrow zones of fissures, die out and overlap as do the Hidden Treasure lodes. The No. 4 Lee, on the other hand, though not a long lode, is unusually persistent in depth, being known on practically all the levels of the Portland mine. The Diamond vein, a fissure zone in granite in the same mine, is not known above level 5. Its fissures are unproductive, though distinct, on level 10. The Portland vein becomes very indistinct below level 6 and on the lower levels is unknown.

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In Stratton's Independence mine the Emerson and Grant lodes apparently die out near level 5, being unknown at lower levels. The No. 6 vein, on the other hand, is not known above level 5. In the Ajax mine the zone of fissuring known as the Apex vein is known only above level 4. In the Gold Coin mine the Dorothy lode first appears near level 8 and continues to the bottom of the mine. On the 1,200-foot level of the Vindicator mine the strong No. 1 vein, known all the way from the surface to the 1,000-foot level, does not appear. Nonpersistence of lodes is shown also in the Molly Kathleen mine, where the fissures on the 700-foot level do not correspond to those on the 200-foot level, and in the Abe Lincoln mine. The Buena Vista lode remains well defined on the 1,200-foot level, but has been followed northeast on that level to a point where it becomes very indistinct. Fissures not known at the surface have been found in the lower levels of the Gold Coin and Hull City mines.

Other illustrations of the fact that the lode fissures do not all begin at the surface and extend indefinitely downward, but that many of them are at least as well defined as regards their upper or lower limits as they are along their lines of strike, may be found in the detailed descriptions of mines in the latter part of this report.

In some places the fissures are very irregular, the ore occurring in stockworks made up of many short veins and seams belonging to several fissure systems. Such are some of the deposits in the Anaconda mine near the Mary McKinney line, in the gneiss of the Midget mine, in the Sheriff, Homestake, and New Haven mines, and in the Stratton properties on Globe Hill. Many short veins in one small mine are shown in the Dante (fig. 42, p. 371) and also in the Monument and Dillon mines (Pl. V, p. 26).

The question whether the fissures are as large and as abundant at greater depth as they are near the surface is a very important one as regards the economic future of the district. Unfortunately it is a question which, considered independently of the vertical distribution of ore bodies, requires for its satisfactory answer more complete data than are at present obtainable. That some fissures practically die out below is certain; but it is equally true that others, which are not known at the surface, appear in the deeper workings of the mines. As the extent of a productive fissure is generally less definitely determined than the extent of its contained ore bodies, the decision whether with increasing depth of workings more fissures appear than disappear, or vice versa, is not easily reached.

Detailed examination of practically all the accessible mines in the Cripple Creek district has, however, led to the conclusion that the fissures do, in general, become less abundant and less conspicuous as greater depth is attained. No mine exhibits this feature better than Stratton's Independence, in which the very complex systems of productive fissures on the fifth and higher levels contrast most strikingly with the few insignificant and unproductive fractures visible on level 14. In a less degree the same feature is shown in many others of the deep mines. It should be clearly understood, however, that this statement applies to the fissuring considered as a whole, and is made with the knowledge that some fissures appear in depth which are not visible near the surface and that therefore some fissures, so far as experience goes, increase in size downward.

INFLUENCE OF COUNTRY ROCK.

Fissures are most abundant in the breccia and in the Pikes Peak granite adjacent to the volcanic neck. Productive lodes occur, however, in all the other rocks within or near the neck, with the possible exception of the schist. The latite-phonolite, on the whole, seems less favorable than breccia to the development of ore-bearing fissures. Many fissures in breccia, such as the Captain veins of the Portland mine, terminate at or near the contact with masses of latite-phonolite, though others, like the Pharmacist, the Isabella system, and the Vindicator system, pass from breccia into latite-phonolite without noticeable change.

Owing to their tendency to develop a platy parting parallel to their walls, dikes of phonolite or "basalt" when they happen to lie in the general direction of fissuring, frequently become sheeted zones. As examples of such occurrences may be mentioned parts of the Independence vein, the Portland vein, the Montana vein of the Gold Coin mine, the Apex vein of the Ajax mine, and the Cobb vein of the Moon-Anchor mine. In the lower levels of the Hull City mine one of the veins follows a dike of latite-phonolite, 10 feet wide, in breccia. This is the only instance observed in which a dike of this rock contained ore.

When, however, a dike lies across the planes of fissuring, the fissures may continue through the phonolite, but more often they become indistinct or irregular in that rock, as will be described when an account is given of the detailed structural features of the fissures.

The general behavior of a fissure zone at a contact between two rocks depends largely upon the angle at which the plane of the lode meets the plane of the contact. If the two are nearly perpendicular the fissures may stop at the contact or they may cut through it without deflection. Instances of a fissure zone ending abruptly at a contact between two rocks are not common in the district, though there is often a marked change in the character of the ore at such points. The Diamond vein of the Portland mine, which is in granite, ends against the breccia, but the original relation has been obscured by slight faulting along the contact. The Gold Coin-Dead Pine fissure zone in granite has been followed to the contact with the breccia, where it apparently terminates. The No. 6 vein of Stratton's Independence mine is known only in the granite, and the Emerson vein of the same mine is known only in the breccia. It could not be determined, however, at the time of visit, whether these fissures actually end at the contact. The Independence and Bobtail veins, on the other hand, pass from granite to breccia without deflection, though the Independence, like the No. 2 vein of the Portland mine, coincides with a portion of the contact that happens to lie in its course. The C. K. & N. fissure zone, which is regular and persistent in the granite, ends on the west against the phonolite sill of the Old Gold mine.

When a fissure zone and contact meet at an acute angle the fissures may change their course and follow the contact, particularly if it is the wall of a dike, as in the case of the C. K. & N. vein and the El Paso phonolite dike, described on pages 351–352, 356. In some instances, such as that of the El Paso vein (fig. 39, p. 350), the deflection is only partial, the fissures finally crossing the dike and continuing on the other side with their original course.

It is rather remarkable that the contact between the breccia and the surrounding granite is so rarely the seat of ore deposition, though some of the most important ore bodies in the district are found in its immediate vicinity. The contact itself seems to contain ore only where, as in the case of the Independence vein and the No. 2 vein of the Portland mine, it is locally coincident with a zone of fissuring which is productive also at other points. A possible exception to this last statement is the Contact vein in the W. P. H. and Damon mines, which follows the contact between schist and breccia for at least 300 feet in depth, dipping steeply southwest. It is ore bearing in places.

The Wild Horse vein, with its long curved course, deserves special mention. Near the surface it follows approximately the contact between the granite and the breccia, but in depth it passes entirely into the granite. The dip is irregular, being in some places vertical and in others to the west at a high angle.

STRUCTURAL FEATURES.

The structure associated with the deposits most characteristic of the district is that known as a sheeted zone. As here developed, such zones consist of a varying number of narrow, approximately parallel fissures which collectively form a lode ranging from a few inches to 50 or 60 feet, or rarely 100 feet, in width. Within such uncommonly wide belts of fracture, however, can usually be distinguished two or more zones of concentrated fissuring which lie close enough together to be mined as a whole. In other words the very wide belts are compound sheeted zones, of which the most conspicuous examples are some of the Captain veins in the Portland mine. Usually the sheeted zones are from 2 to 10 feet in width.

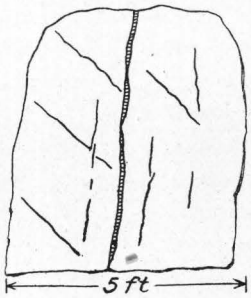


FIG. 4.—Structure of La Bella vein, Golden Cycle mine, level 9. Rock is very fresh latite-phonolite. Central seam carries visible calaverite. Screenings across whole width assay 2 ounces per ton.

As a rule the fissures are mere cracks, showing no brecciation, slickensiding, or other evidence of tangential movement of the walls. There are some notable exceptions to this statement, as will presently be seen, and appreciable displacement has occurred along some of the veins. But the movement of one wall past the other has probably in few instances exceeded 1 or 2 feet.

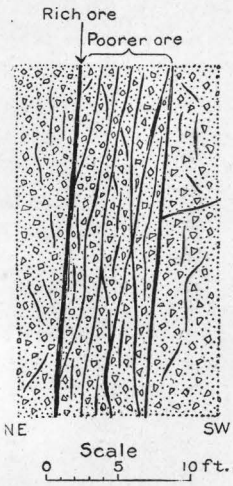
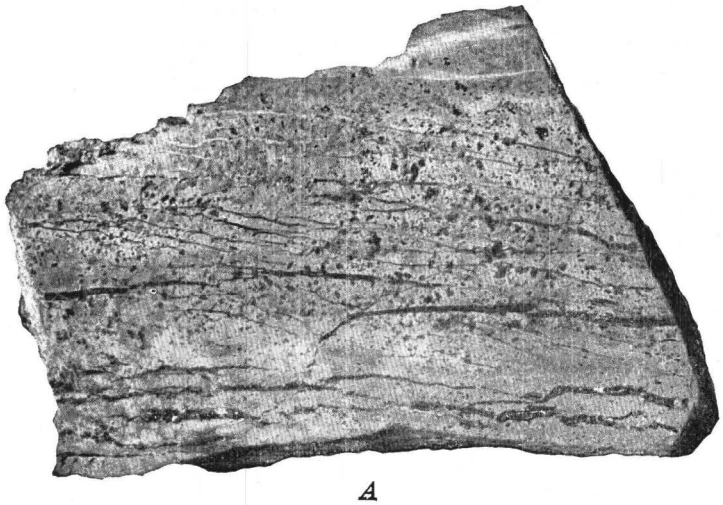


FIG. 5.—Legal tender vein, Golden Cycle mine, level 10. Fresh breccia with oxidized seams. Main clay seam assays 300 ounces. All seams carry values.

A sheeted zone on a small scale is well shown by Pl. XIII, from specimens from the mineralized basic dike of the Conundrum mine. In this case the fissures are filled with fluorite.

Very often, however, a single narrow fissure is accompanied by irregular fracturing of the adjacent rock. Such a structure, which is not properly a sheeted zone, is illustrated in fig. 4, a sketch of the La Bella vein on level 9 of the Golden Cycle mine. The country rock in this case is latite-phonolite. A few lodes, also, are associated with more curved and irregular fissuring than pertains to a sheeted zone, and might be called stringer lodes. This type, which is not characteristic



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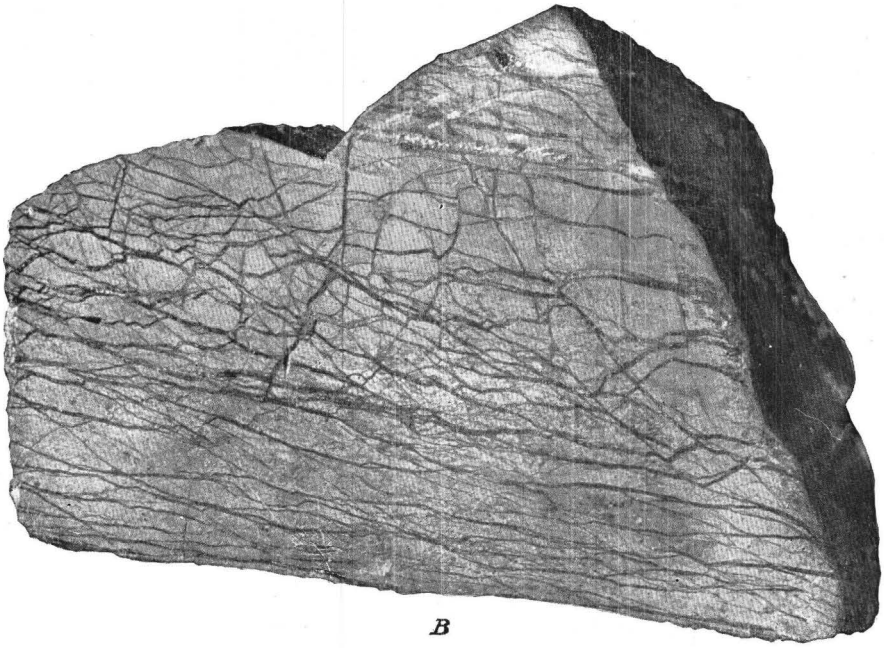


B

VEIN STRUCTURE, CONUNDRUM MINE.

Pieces of basic dike showing fluorite veinlets; pyrite disseminated throughout the rock.

of the district, finds partial exemplification in the No. 1 Lee vein of the Portland mine.

Among the numerous and important lodes coming properly under the designation of sheeted zone, several structural varieties can be distinguished and are sometimes exhibited in different parts of the same lode. A common form is that

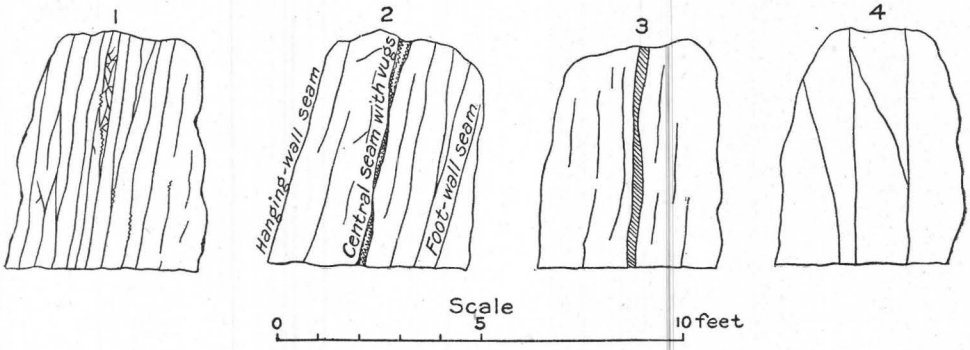


FIG. 6.—Veins in Last Dollar mine. 1. Main vein, 40 feet above level 12. Typical sheeted and partly brecciated zone in fresh latite-phonolite. Seams coated with quartz, dolomite, and calaverite. 2. Cross veins with medial vug holes, level 10. 3. Vein, west drift, main cross vein, level 5, showing middle filled fluorite vein. 4. Cross vein No. 3, at east side line, level 5.

characterized by the presence of two main parallel fissures, usually 3 or 4 feet apart, accompanied by less regular and less persistent fractures in the intervening and adjacent rock. As an example of this type may be cited the Legal Tender vein, in breccia, as seen on level 10 of the Golden Cycle (fig. 5), and the Doctor-Jackpot vein, also in breccia. The Gold Coin vein and A, B, and C veins of the Ajax mine show a similar structure in the granite.

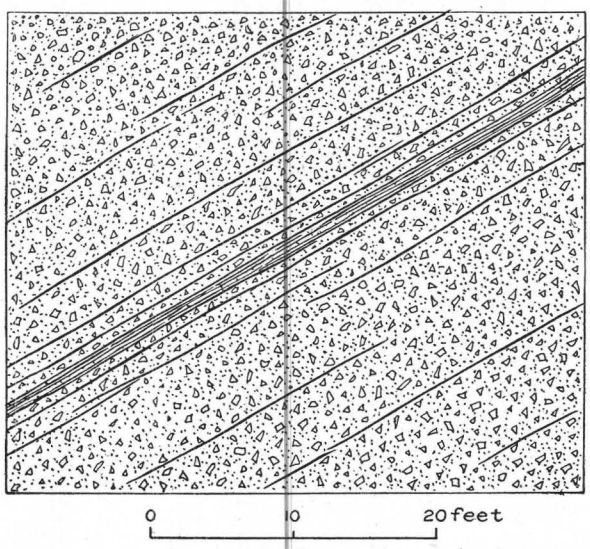


FIG. 7.—Structure of Howard flat vein, Anaconda mine, adit level. Illustrates close sheeting in middle part of vein, the fissures becoming gradually farther apart in the foot and hanging walls.

In another common type of sheeted zone the parallel fissures are more numerous, and are spaced with some regularity, as illustrated in fig. 6. There is usually a medial portion of the lode, ranging from a few inches to a foot or two in width, within which the rock is divided into a large number of very thin plates by fissures often less than an inch apart. This band of intense sheeting is accompanied on both sides by parallel fissures which are spaced farther and farther apart, so that the sheeted zone as a whole merges gradually into the country rock. This type is well exemplified by the Howard flat vein, in the southern part of the adit level of the Anaconda mine (fig. 7),

by other flat veins in the Mary McKinney mine and by the Doctor-Jackpot, Chance, Matoa, and many other lodes, particularly those in the breccia.

There are a large number of sheeted zones in breccia and in granite, which are composed of many parallel or nearly parallel fissures, but which differ from the type just described in the absence of a well-defined medial zone and in the rather less regular character of the fractures. This type is admirably illustrated by the wider Captain veins in the breccia of the Portland mine, some of which are stoped to a width of 120 feet. It is not in these widest parts, however, that the sheeted structure is best seen, for in the large stopes the jointing, as appears in Pl. XV, *B*, is often so irregular that the lode-like character is lost. In the narrower Captain veins, on the other hand, the fracturing as shown in Pl. XIV and in fig. 8 retains the character of a sheeted zone. Fissures over half an inch in width are rarely seen in the Captain stopes and the ore often occurs in scarcely visible cracks. Other good examples of such broad zones of general sheeting are the Anaconda lode (Pl. XIV) and parts of the No. 2 vein of the Mary McKinney mine. In the granite the sheeted zones, while similar in character to those just described in the breccia, are usually narrower. As examples of this general type of structure in granite may be mentioned the Diamond vein in the Portland mine, the No. 6 vein in Stratton's Independence mine, the Granite vein, and the C. K. & N. vein. In the Ajax mine there is a peculiar association of a sheeted zone with the flat fissures, illustrated in fig. 9. These flat fissures carry ore for 30 or 40 feet from the main sheeted zone.

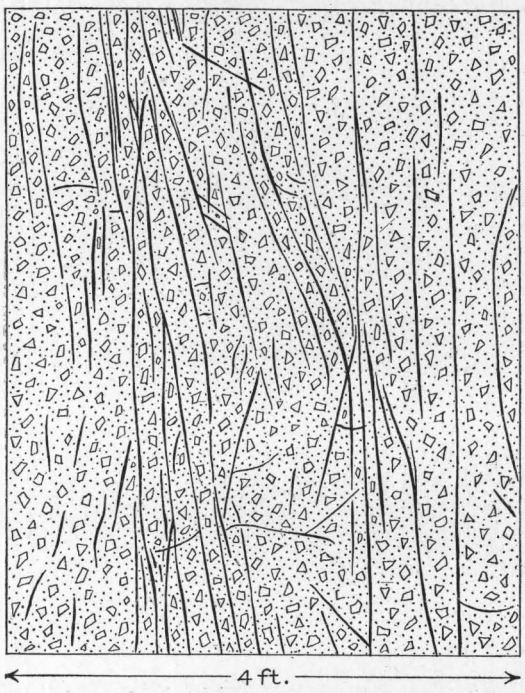


FIG. 8.—North face of No. 8 Captain vein, Portland mine, level 6, showing sheeting in breccia.

There is sometimes one fissure of a sheeted zone which is distinctly larger than the others and which usually contains the richest ore. The dominant fissure of the C. K. & N. vein, for example, is in some places 4 inches wide, and contains slabs of country rock which were loose before they were cemented by ore. The Pointer lode, in syenite, also has a dominant fissure which

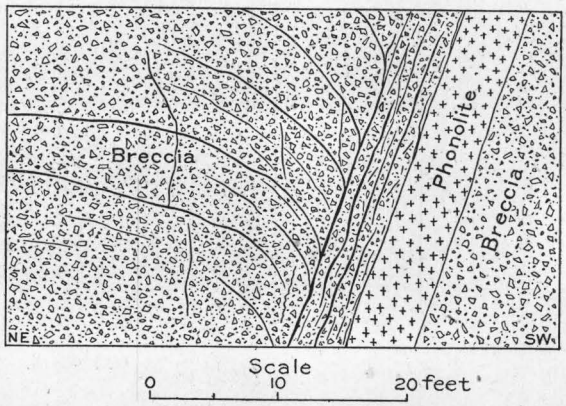
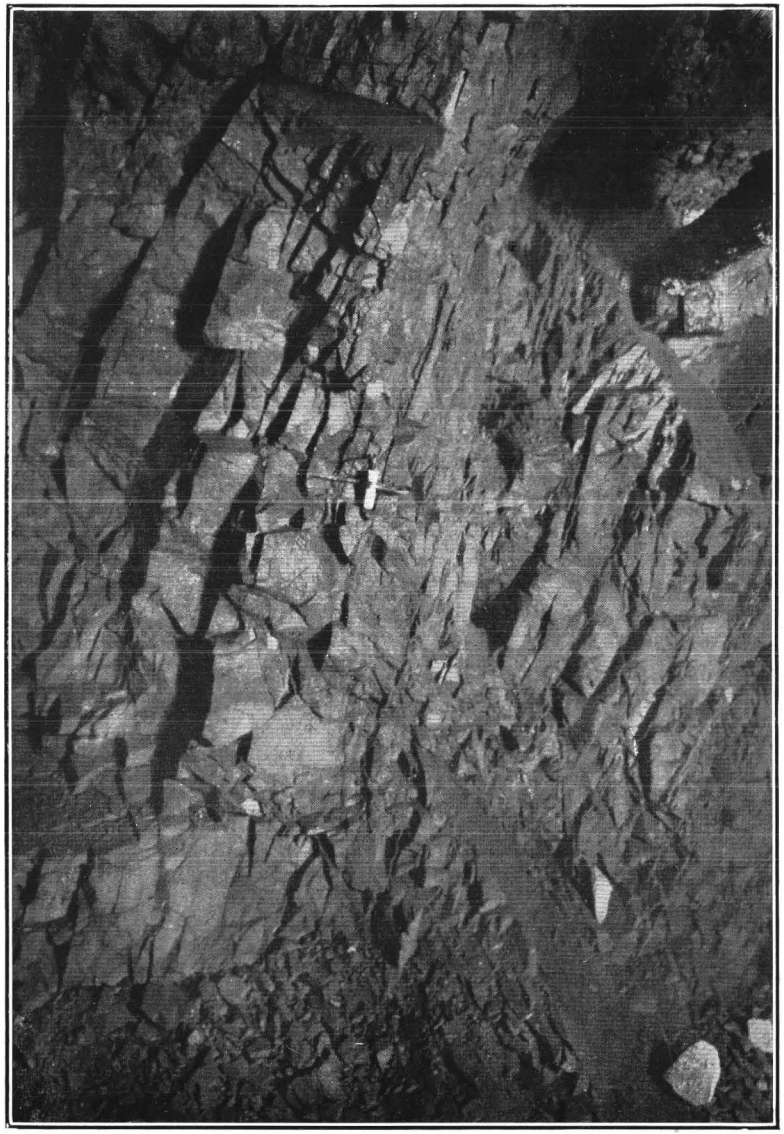


FIG. 9.—Sheeted zone and "flats" of the Apex vein, Ajax mine.



A

B

VEIN STRUCTURE, PORTLAND MINE, SHOWING SHEETING OF BRECCIA.

A, North face of No. 3 Captain vein, level 5; *B*, north face of No. 8 Captain vein, level 6.

in a few places is 5 inches wide, and veinlets of 2 inches in width are common in nearly all the large mines.

Although the prevailing narrowness of the productive fissures is one of the most characteristic features of the district, there are not lacking numerous examples of fissures which opened to considerable width. The Blue Bird lode in some places contains a vein, 3 feet wide, of solid fluorite and quartz inclosing fragments of breccia (figs. 10 and 11). Parts of the Work vein, or Black vein, as it is called, in the Mary McKinney mine, consist of a foot of fluorite or vuggy quartz between well-defined walls, accompanied by parallel sheeting. The Howard flat vein, as exposed in the Ophelia tunnel, shows by its large vuggy cavities that it must originally have been a sheeted zone with occasional openings 2 or 3 feet wide. The cross veins of the Last Dollar mine are apparently not very persistent, yet one of them on level 12 showed a local gaping of the fissure walls to a width of 2 feet. The cross lode on level 11 of the Findley mine has a middle vein of compact fluorite and quartz up to 15 inches wide, with a few small parallel seams on each side. The middle fissure of the Buena Vista lode contains in places a similar vein up to 6 inches wide. Portions of the Doctor-Jackpot lode and the Lead vein of the Moon-Anchor mine fill fissures which opened to widths of 6 inches or more. In some cases these wide fissures occur merely in portions of a lode which elsewhere shows close parallel sheeting. In other cases, such as the work vein, the presence of a fairly thick plate of quartz and fluorite, or of other vein filling, is characteristic of the lode.

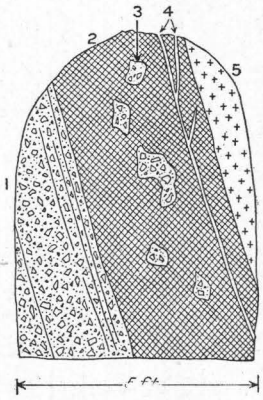


FIG. 10.—Section of part of Blue Bird Vein, level 13, showing massive vein of quartz and fluorite between phonolite and breccia. 1. Breccia. 2. Massive quartz and fluorite. 3. Fragment of breccia. 4. Dolomite veinlet. 5. Phonolite.

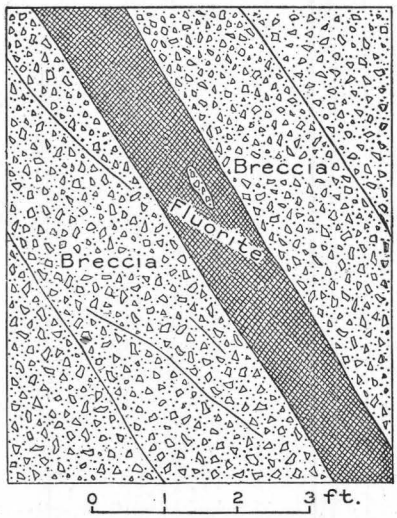


FIG. 11.—Structure of Blue Bird vein, level 9, showing filled fluorite vein in middle.

In the upper parts of some of the lodes, the original structure is obscured by oxidation, whereby the sheeted structure is often lost and the vein forms a clayey streak sometimes several feet wide. Within this zone may occur veinlets of kaolin or alunite up to a foot wide. The most conspicuous example of this alteration is the Wild Horse vein, which is entirely oxidized in its productive portion to a depth of 1,000 feet. It is a structureless clayey mass, up to 25 feet wide, with two or more well-defined but curved and irregular walls. These walls are not continuous, but die out in places and are succeeded by others.

Although most of the veins show by their structure and by their failure to dislocate the various dikes and intrusive sheets which they cross that the opening of their fissures was not accompanied by noticeable faulting, there are a few lodes, such as the Bobtail vein in the Portland mine, the Mary McKinney vein, the Doctor-Jackpot vein, and the Gold Coin vein, which have a somewhat different character.

The Bobtail vein is a sheeted zone that for at least a part of its course follows an older fissure in the granite. This fissure is filled with breccia composed chiefly of granitic material. It is probable, however, that this breccia is formed of particles that were carried into an open fissure at the time of eruptive activity rather than to trituration of the fissure walls by great movement.

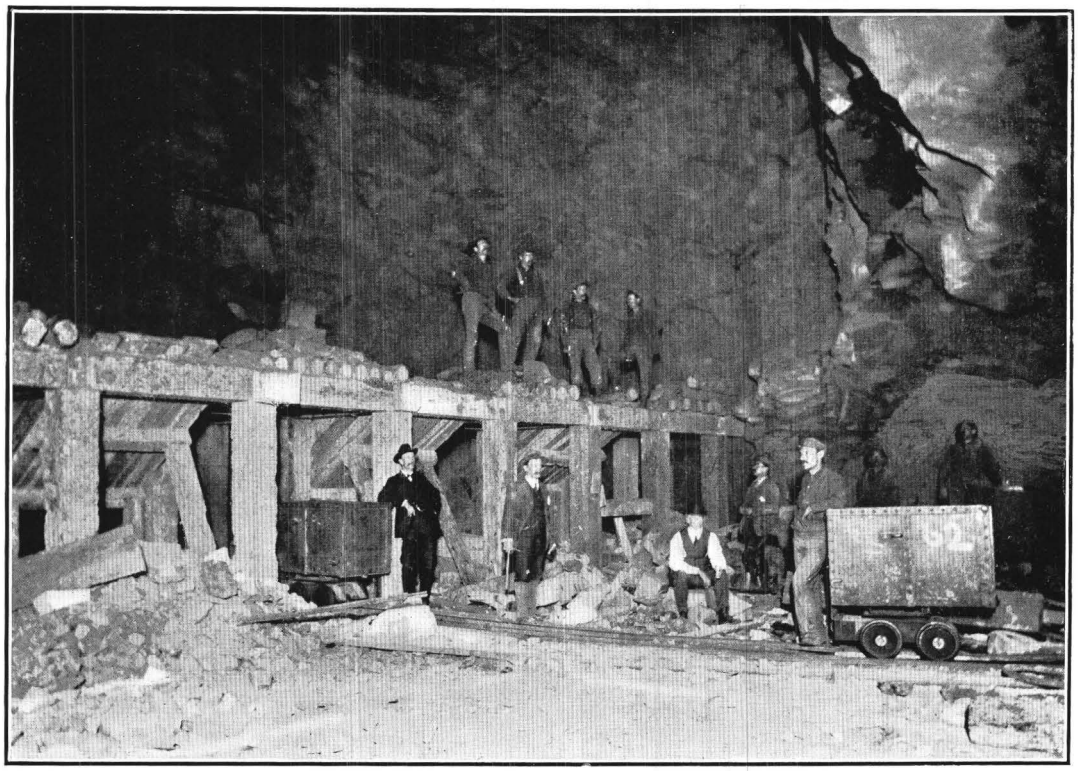
Parts of the sheeted zone of the Mary McKinney vein contain a dominant fissure up to about 5 inches in width, which is filled with fragments of phonolite partially replaced by roscoelite and fluorite. In this case the movement along the fissure zone was sufficient, at least locally, to brecciate the sheeted phonolite. In the Wardel vein, in the Anchoria-Leland mine, the thinly sheeted breccia of the medial part of the lode is in some places shattered, showing movement along the fissure zone.

The Doctor-Jackpot lode exhibits slight slickensides along portions of its regular foot-wall fissures. The displacement, however, is probably slight, as great movement could hardly fail to brecciate the thin sheets of the fissure zone. There has evidently been some movement along the Mattie D. vein of the Doctor-Jackpot mine, as shown by brecciation along the foot-wall fissure. The Cardinal vein, a crushed zone 1 foot wide in granite, shows well-defined horizontal slickensiding along the hanging wall on the 200-foot level. In parts of the Gold Coin vein, near the north end of the mine, the closely sheeted granite grades into brecciated material 3 or 4 inches wide. The movement necessary to effect this brecciation of the thin laminæ of rock was probably slight and was certainly local.

The structures thus far described are those associated with lodes traversing large masses of uniform rock, such as breccia, latite-phonolite, syenite, or granite. Many of the fissures, however, pass from one rock into another or follow dikes and it is necessary to briefly note the structural details connected with such associations.

The phonolite dikes have a general tendency, as is revealed by weathering, to split into thin slabs roughly parallel to the dike walls. Fissuring along the line of such a dike merely accentuates this inherent structure, and forms a well-defined sheeted zone which may involve the whole width of the dike or may constitute a narrow zone along one or both walls. A considerable number of the lodes in the district are wholly or in part sheeted phonolite dikes. As examples, may be mentioned the Independence and Portland veins and the Cobb vein of the Moon-Anchor mine. A number of other lodes, such as the Apex vein of the Ajax mine, lie in the breccia or granite alongside phonolite dikes.

In those cases where a fissure zone and a dike or mass of phonolite intersect nearly at a right angle, the platy parting of the phonolite tends to destroy the regularity of the sheeted zone. Thus the Walter vein of the Elkton mine, which in the breccia is a regular sheeted zone, becomes very irregular in the masses of phonolite described on page 333, and splits up into fissures running in various directions, many of them being nearly horizontal. The Spur and Coin veins of the Gold Coin mine also lose their regularity and become indistinct in an intrusive phonolite sheet which they cross near level 6. In the Isabella mine the Cheyenne vein, below level 10, and the Empire No. 2 vein, on level 11, become small and barren seams when they enter phonolite.



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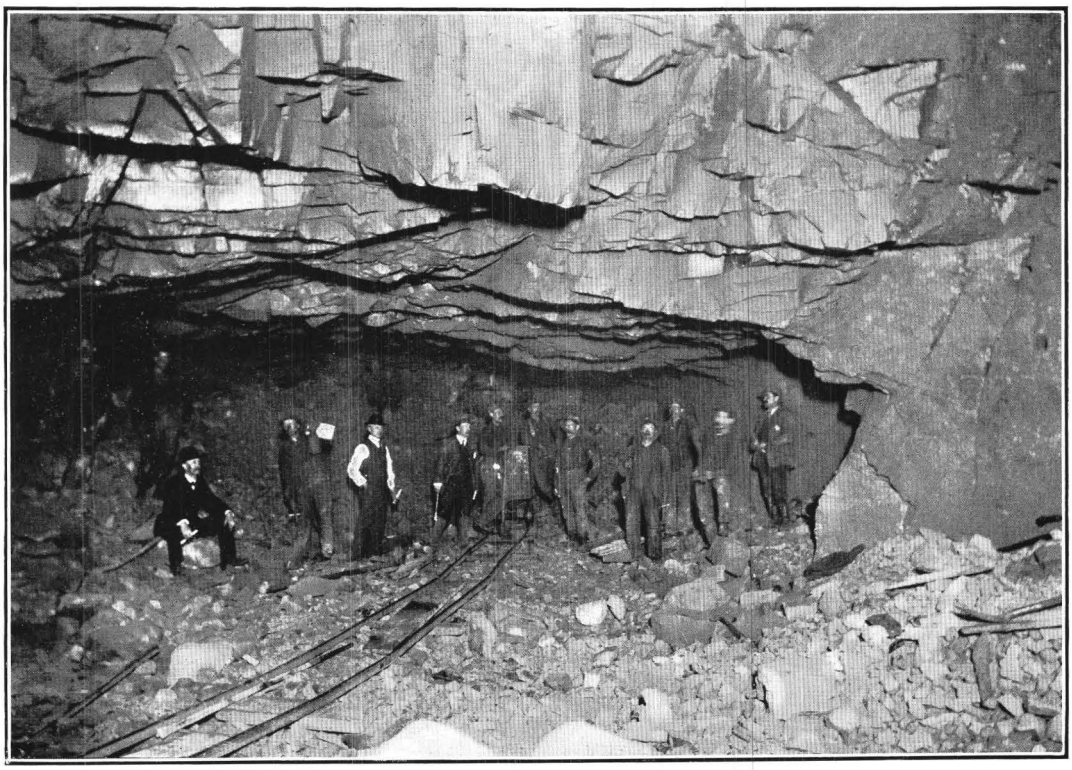


B

VEIN STRUCTURE, LEVEL 4, PORTLAND MINE.

A. Stope on No. 5 Captain vein, showing width of ore.
B. Stope on Nos. 4 and 5 Captain veins, showing wide sheeting, scarcely distinguishable from ordinary jointing.

Productive fissure zones along basic dikes are in a general way similar to those along phonolite dikes. The basic dikes, like the phonolite dikes, readily develop platy parting parallel to their walls (Pl. XVI, *B*). As a rule, however, the fissures in the "basalt" are smaller than those in phonolite, and in some cases, as in parts of the Conundrum lode, may form an exceedingly complicated network, as shown in Pl. XIII (p. 160).

Some sheeted zones, at the point where they cross a contact between two rocks, such as breccia and granite or breccia and phonolite, expand in one or both of the rocks into a network of irregular fractures. Such a mass of irregular fissures occurs in the granite of the El Paso mine, where the El Paso vein crosses from granite into a phonolite dike, and forms an important ore body described on page 354. Some of the ore bodies in the Prince Albert and Dead Pine mines are similarly related to the intersection of a fissure zone with a contact plane.

INTERSECTIONS.

The crossing of one fissure zone by another is a common occurrence in the Cripple Creek district, notwithstanding the general radial arrangement of the most important lodes. Often the intersecting fissures have a strike nearly at right angles with the main fissure zone and are then usually known as cross veins. In other cases the strikes of the intersecting fissures are less than 45° apart and the shorter lode is often called a spur vein. In still other crossings the intersection is between a nearly vertical fissure zone and a so-called flat vein.

In most cases the fissures intersect without noticeable displacement of one by the other, a fact that is in full harmony with the usually very slight movement along the fissures indicated by their structural peculiarities. The rock near the intersection, however, is often irregularly fissured and in many instances constitutes an ore body, so that the details of the crossing are not always clear. Intersections without visible fault displacement are so numerous that only a small number of the observed examples can be here given. Many additional occurrences are noted in the detailed descriptions of the mines.

In the northern part of the Mary McKinney mine (see fig. 32, p. 323) the Mary McKinney, No. 1, No. 2, No. 4, No. 6, Black, No. 3 flat, No. 5 flat, and other veins intersect at various points without faulting. Near many of the intersections the rocks are traversed by subsidiary fractures containing ore and forming with the main fissures some of the widest ore bodies in the mine. In Stratton's Independence mine the flat vein, a nearly horizontal sheeted zone, is crossed by the fissures of the Independence lode. The conditions for detecting the occurrence of any displacement are here unusually favorable, but no faulting is apparent. In the northern part of the mine the Independence, Bobtail, Emerson, Grant, and other lodes all converge in a general way so as to meet the similarly converging Bobtail, Diamond, and No. 2 veins of the Portland mine. These lodes come together in a region of very complex fissuring, in which, however, there is no evidence of appreciable faulting. The Abe Lincoln, Anchoria-Leland, Midget, and Anaconda mines all afford examples of fissure zones intersecting without faulting.

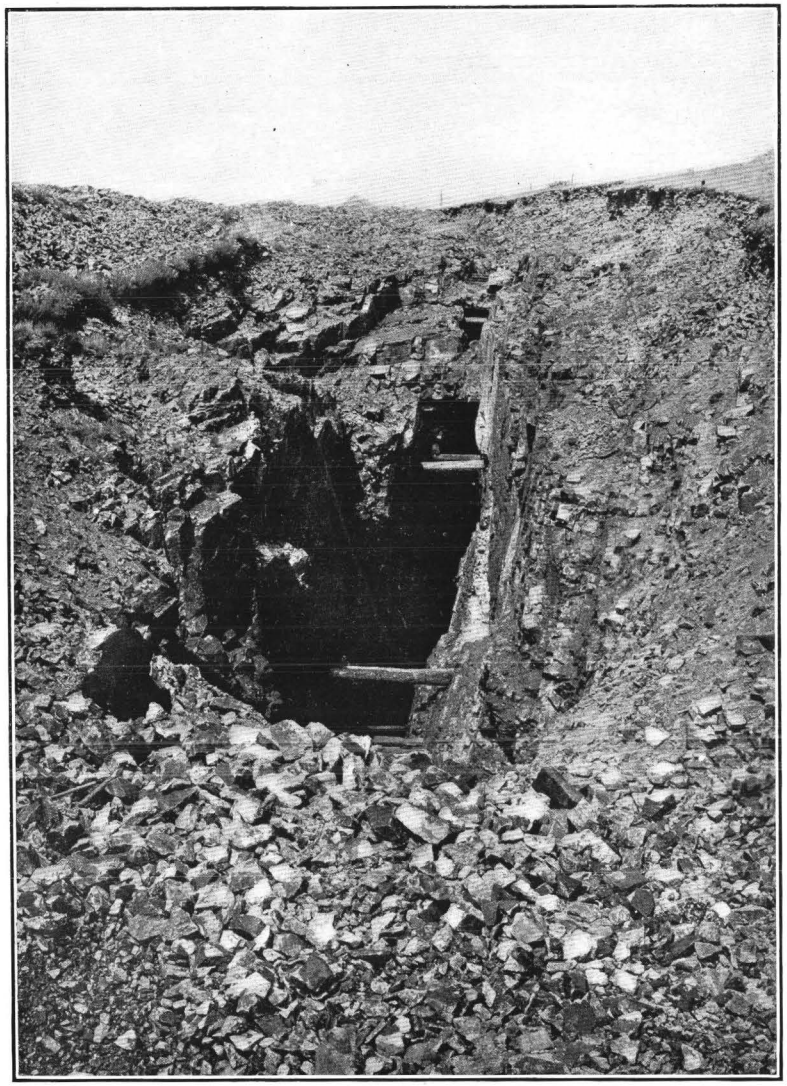
There are a few cases, however, of one fissure faulting another. Some of the faulting fissures are productive. Others are barren and usually contain soft clay-like gouge. In the Anchoria-Leland mine the fissure zone known as the Fault vein

usually contains one or more seams of gouge carrying a little pyrite, but no ore. It slightly offsets the City View dike and perhaps also the Chance and Matoa lodes. (See fig. 25, p. 293.) The displacement is probably less than 6 feet. In the southern part of the Mary McKinney mine, the Mary McKinney fissure zone faults a generally barren cross fissure known as the Jackpot vein, though it is not the productive lode known in the Doctor-Jackpot mine. The throw in this case corresponds to a reversed or thrust fault and can scarcely exceed 15 feet. In the Elkton mine the Elkton or Walter lode is slightly displaced near the breccia-granite contact by the barren fissure known as the Dead vein, or better as the Thompson fault. In some places this is a simple fissure containing a foot or more of soft slickensided gouge. Elsewhere it consists of two or more narrower fissures filled with similar material. The net displacement, though not susceptible of measurement, is probably not over 100 feet and may be very much less.

Some slight faulting was noticed in the Jerry Johnson and W. P. H. mines, a flat vein in one place having displaced the W. P. H. vein for a few feet. The Shurtloff vein faults a prominent cross vein on level 11 of the Findley mine, the east part being thrown 6 feet northward. In the Isabella mine, on level 11, the northwest-southeast Pinto basic dike is faulted by the nearly east-west Empire No. 2 vein, the southeast part of the dike being thrown 10 feet to the east. In the same mine the Buena Vista vein, striking northwest, is apparently faulted by the Klondike vein, the southeast part of the Buena Vista being offset from 20 to 50 feet to the southwest. It is possible in this case, however, that both fissures were formed at the same time and that the Buena Vista vein is merely deflected from one sheeted zone to another. The Pharmacist vein, striking 60° E. and dipping northwest at 60°, is faulted by the Zenobia vein striking from N. at 20° E. to north-south and dipping west at from 60° to 80°. The east part of the Pharmacist is offset from 10 to 20 feet to the southeast. Both are productive lodes. Their intersection pitches north and is exposed to a depth of several hundred feet in the Zenobia incline.

In the El Paso mine the nearly east-west C. K. & N. lode is intersected by fissures having general northeasterly strikes and roughly parallel with the El Paso and Tillery veins (fig. 39, p. 350). Some of these fissures do not visibly offset the C. K. & N. vein. In one case the ore of the C. K. & N. vein turns and follows one of these cross fissures for about 100 feet and then resumes its normal course. In another case the C. K. & N. vein is offset for about 100 feet, the intersecting fissure containing no ore. This may possibly be a fault, formed after the deposition of the ore in the C. K. & N. vein; but it is more probable that the offsets in the C. K. & N. fissure zone are due to the fact that it was formed in rocks already traversed by the northeasterly fissure zones of which the El Paso lode is the most prominent member. That is, it is in the main an original structure and is not due to faulting after the deposition of the ore or even after the formation of the C. K. & N. fissures.

In the Gold Coin mine there is a prominent fissure zone known as the Cashen fault, which strikes N. 20° E. and dips northwest at 51°. It contains in places from 4 to 5 feet of crushed and altered country rock forming a soft clayey gouge, and has the appearance of a fault of considerable throw. Nevertheless the Coin lode and the Montana phonolite dike, both of which are intersected by the Cashen



A

B

VEIN STRUCTURE.

A. Surface workings, showing Anaconda vein, a regular and narrow sheeted zone in breccia.
B. Basic dike, Portland mine, level 5, showing platy parting; seams in this case are filled with calcite and carry no value.

fault, show no noticeable displacement. The net throw of the fault must be very small and the dislocation may be older than the fissure zone of the Coin lode.

ORIGIN OF FISSURES.

It has been shown that the principal fissures are confined to an area little larger than that of the Cripple Creek volcanic neck; that they have a general radial arrangement, and that their formation was accompanied by very slight faulting. It appears further that the basic dikes have a similar radial grouping; in fact, the fissures occupied wholly or in part by dikes and those occupied by ore are so similar in character and so closely related in direction and distribution that they were probably formed in the same manner, if not at the same time.

The basic dikes and the ore-bearing fissures are younger than any of the phonolite intrusions and originated after the volcanic breccia had been cemented into a firm rock. The sheeted zones were certainly formed in part before the intrusion of the basic dikes. This is clearly shown in the Granite mine, where a "basalt" dike turns from one fissure to follow the Bobtail lode, and in the Elkton mine, where parts of the Raven lode consist of a zone of sheeted breccia from which the "basalt" dike is locally absent. Had this sheeting been produced after the intrusion, the dike should be fissured like the breccia. This, however, is not the case. The sequence of events seems to have been as follows: (1) Sheeting of the indurated breccia, (2) intrusion of basic dikes along parts of the sheeted zone, (3) slight fissuring of the dikes, probably in part by mere contraction in cooling, whereby they were divided near the walls into thin plates, and (4) ore deposition. That the breccia had been much fissured and even shattered before the basic intrusions and that all of the resulting fissures were not filled by the dikes is well shown in the Moose mine. It is probable that some sheeting followed the basic intrusions, but it is rarely possible to distinguish this from the earlier fissuring. We may conclude, then, that some of the productive fissures were formed before the basic intrusions, that some were formed after the intruded rock had solidified, and that fissuring and intrusion were closely associated in point of geological time.

The character of the fissures is suggestive of fracturing under light or moderate load. Facts supporting this suggestion are (1) the greater number and width of the fissures near the surface, (2) the branching of the upper parts of some fissures, such as the Bobtail veins in Stratton's Independence mine, and (3) the change in dip of some fissures, the superficial portion having usually the flatter dip. Though at first glance the generally small size of the openings produced by the fissuring might be considered as indicative of fracturing under heavy load, yet the explanation of this feature is thought to be that the fracturing stresses were relieved by comparatively slight deformation of the rigid rock mass. Had the stresses been regional instead of confined to the volcanic neck the initial fracturing might have been followed by considerable faulting along the fissures before equilibrium was restored.

The conclusion that the fissures were formed under relatively light load does not rest entirely upon the study of the fissures, but is supported by general geological considerations relating to the development of the present topography, as shown on page 36, and by the distribution of pay shoots, as suggested on page 215.

The areal distribution of the fissures, their radial plan, and their connection with the basic dikes show that they were produced by local rather than regional stresses. It is true, as Penrose has shown, that the granite of the prevolcanic plateau is conspicuously sheeted at points distant from the productive area, as in Eightmile Canyon, but this sheeting is associated with no known ore deposits and is not clearly related to the fissuring of the Cripple Creek district. It seems most reasonable to regard the Cripple Creek fissures as having some genetic connection with the local volcanic center.

The nature of the stresses that fissured the rocks is not easily determined. The character of the fissures shows that the stresses were of a kind that could be relieved by comparatively slight strain. The rocks were in most places merely fractured and not noticeably displaced. Had the tangential movement along the fissures been greater it might have supplied a clue to the directions and character of the forces that produced the faulting. In the present case, however, the facts do not enable us to decide with certainty which of a number of hypotheses is applicable. The inconspicuous character of the fissures, their radial disposition, and the absence of notable faulting suggested at one period in their study earthquake shocks, emanating from some point under the central part of the district, as a possible explanation. It is difficult, however, to account by this hypothesis for the characteristic sheeted structure of the lodes, which seems to demand an explanation involving compressive stresses. The hypothesis which on the whole seems most in harmony with the facts is that the entire mass of breccia and volcanic rocks, after the phonolitic eruptions had ceased and the breccia had become firmly cemented, settled down very slightly within the steep-walled volcanic funnel in the ancient rocks of the plateau. As the walls of the volcanic neck are somewhat irregular and as in general they converge downward, such slight sinking, by forcing a rigid mass to adjust itself to a slightly smaller space of different shape, would produce compressive stresses in the subsiding mass and to some extent in the inclosing granitic rocks. The stresses would be relieved by fractures characterized by their number and by diversity of trend rather than by great size or by conspicuous faulting. The amount of settling necessary to produce fissuring of the kind found in the district would be extremely slight and need call for no greater faulting along the general line of the granite-breccia contact than is known to exist.

This hypothesis also affords an explanation of the observed relation between the fissuring and the basic dikes. The dikes may be regarded as the final magmatic residuum of the volcanic reservoir, squeezed quietly into some of the fissures formed by the slight settling of the solidified products of earlier eruptions. Fissuring and the intrusion of the basic dikes, according to this hypothesis, are genetically related and represent the dying out of the volcanic forces. They were the final structural manifestations of volcanism and were succeeded by gaseous and aqueous emanations and by ore deposition.

It is possible that the removal by erosion of the volcanic cone that in late Tertiary time covered the central part of the Cripple Creek district may have resulted in some readjustment of the rocks relieved of this local load. While it does not seem that such unloading could initiate the formation of the ore-bearing fissures, it may have increased their width.

CHAPTER VIII.—THE ORES.

GENERAL CHARACTER.

The characteristic feature of the Cripple Creek ores is the occurrence of the gold in combination with tellurium, chiefly as calaverite, but partly also as the more argentiferous sylvanite,[a] and probably to a minor extent as other gold, silver, and lead tellurides. Native gold appears to be absent from the telluride ores, except as it may be set free by the oxidation of these tellurides. Pyrite is widely disseminated through the country rock and also occurs commonly in small amounts in the fissures, associated with tellurides. Galena and sphalerite are sparingly present in the majority of the veins. Tetrahedrite, or gray copper ore, and stibnite are of frequent occurrence. Molybdenite in small quantities is probably always present. The tetrahedrite is usually rich in silver, and also contains gold. Possibly, however, the latter metal is due to admixed calaverite, as the two minerals often are found in intimate intergrowth. The galena and zinc blende rarely contain enough of the precious minerals to form ore. Auriferous pyrite is often reported, but in the cases investigated the gold was found to be derived from admixed tellurides (p. 170). Metallic minerals found only as great rarities are hübnerite, specularite, chalcopyrite, chalcocite, and arsenopyrite.

The usual gangue minerals of the ores are quartz, fluorite, and dolomite; more rarely chalcedony and opal. Roscoelite and rhodochrosite are also found in a few places. Celestite, the sulphate of strontium, occurs as little acicular crystals in quartz vugs and forms the gangue of some exceptional veins. Calcite occurs interstitially in much of the breccia near the ore bodies, but is rarely found in distinct crystalline form with the ore minerals. Secondary potassium feldspar (adularia or valencianite) is common in the ores. It is especially abundant in the ores inclosed in granite, particularly those in the Pikes Peak type.

Owing to the occurrence of the ore minerals and gangue as the filling of narrow fissures, joints, and cracks in the sheeted zones which usually constitute the lodes, or as a very incomplete replacement of the country rock, the ores of Cripple Creek as mined have approximately the composition of the somewhat altered rocks which immediately adjoin the veins. The quantity of metallic or gangue minerals is thus in nearly all cases relatively insignificant. By reason of the slight metasomatic alteration the rocks in the lodes approximate somewhat closely to the normal composition of the fresh country rock, be it granite or any of the volcanic rocks of the district.

Oxidized ores, while still worked in many properties, are of relatively less importance than when Penrose described the district. They contain the characteristic dull gold, often in pseudomorphous skeletons, resulting from the oxidation of the tellurides, associated with tellurite (tellurium dioxide), emmonsite or durdenite (both

[a] Calaverite, (Au, Ag) Te_2; tellurium, 57.4 per cent; gold, 39.5 per cent; silver, 3.1 per cent. Sylvanite, (Au, Ag) Te_2; tellurium, 62.1 per cent; gold, 24.5 per cent; silver, 13.4 per cent.

hydrated ferric tellurites), and probably other oxidized compounds of tellurium and iron. These minerals occur in association with kaolin, alunite, and ferruginous clays, which result from the oxidation of the country rock in which the vein is contained. The deep workings of the present day show that kaolin is always connected with oxidation, and is not a product of the original mineralization of the district, as was supposed by Penrose.

COMPOSITION AND VALUE.

Gold and silver are the only metals utilized in the Cripple Creek ores. The small amounts of copper, molybdenum, antimony, lead, and zinc are of no economic importance. Tellurium is likewise allowed to go to waste, as there is insignificant demand for it and its recovery would be very costly. The average amount of gold in the ores is probably between 1.5 and 2 ounces, or from $30 to $40 per ton. In some of the larger mines the average value sinks to 1.25 ounces or even 1 ounce per ton, the latter figure corresponding to 0.0035 per cent. From a lower economic limit of about $12 per ton the values of individual shipments swing through a wide range up to ores carrying $5,000 or even $50,000 per ton. A shipment of 27½ tons from level 10 of the Cheyenne vein, Isabella mine, yielded $219,000, according to reports, and in 1904 a shipment of 2,901.42 pounds of El Paso ore afforded on assay 2,592.68 ounces of gold and 299.33 ounces of silver per ton and yielded $75,248.79 net, or over 8 per cent gold. This would indicate that one-third of the quantity consisted of pure calaverite, on the assumption that this was the only auriferous mineral present. Oxidized ores which contain free gold only may under favorable circumstances be subjected to direct cyaniding and yield a profit with a tenor in gold of about $5.

The statement is often made that some of the pyrite in the veins contains high gold values. In most cases this is due to admixed telluride. Penrose[a] leans toward the same view and states that two pure crystallized specimens examined by Hillebrand did not contain a trace of gold. A sample was taken of a heavy sulphide filling in a cross vein on level 8, Last Dollar mine. The vein was several inches wide, and consisted of granular pyrite and sphalerite, with a little molybdenum, lead, and copper. An assay by Dr. E. T. Allen and a determination of tellurium by Hillebrand gave Te, 0.016 per cent; Au, 0.0015 per cent (0.44 ounce per ton); Ag, 0.017 per cent (4.9 ounces per ton). The molecular ratio is 126 Te : 7 Au : 157 Ag, corresponding approximately to a proportion of 42 sylvanite [(Ag, Au) Te_2] and 225 hessite (Ag_2Te), leaving a surplus of 23 Te, which might possibly belong to lead or some of the other baser metals. The pyrite evidently contains no gold.

The pyrite of the altered country rock is always poor in gold. A specimen of coarse pyrite with sphalerite from the breccia in the Hull City mine, level 7, near Vindicator line, contained only 0.20 ounce of silver and 0.04 ounce gold per ton. Whether free gold is present in the telluride ores is a debatable question. It may and probably does occur locally, but it is likely to be in very small amounts. Analyses 2 and 3 of the table below show that a small part of the gold in the telluride ore from the El Paso mine, presumably entirely free from oxidation, would be free gold if all of the silver were assumed to be present as tellurides. But as there

[a] Mining geology of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 122.

is probably some silver mineral present, possibly tetrahedrite, which is known to occur at the El Paso—a surplus of silver may belong to this, and the gold and tellurium, with some silver, would combine to form calaverite without free gold. As is well known from other mining districts, especially Kalgoorlie, free gold may occur in considerable quantities with tellurides.

The Cripple Creek ores, as a rule, contain very little silver, the average proportion being about 1 ounce of silver to 10 ounces of gold. In the Portland and Stratton's Independence mines the proportion is very much less, the silver from the Portland in 1901 amounting to only 2.4 ounces for each 100 ounces of gold. Rich parcels of gold ores often contain a surprisingly small quantity of silver. In the shoot on the 245-foot level in the W. P. H. mine even the richest ore, valued at several thousand dollars per ton, contained but a few ounces of silver per ton. The "fines" from the El Paso mine analyzed by Hillebrand and Allen,[a] which were practically free from oxidation, contained from 2.19 to 3.00 ounces silver against 14.53 to 19.63 ounces gold. In the Blue Bird, Doctor-Jackpot, Conundrum, Pointer, and other mines containing notable amounts of tetrahedrite or galena the proportion of silver rises considerably above the average. Very rarely small lots of ore contain a higher value in silver than in gold. A shipment of 1,000 pounds of gray copper ore from the Accident mine contained 2,500 ounces silver and 25 ounces gold per ton. Somewhat similar silver ore occurred in the Pointer mine. A recent shipment from the Red Spruce mine on Gold Hill is stated to have contained 50 ounces of silver and $5 in gold per ton.[b]

That the average tenor of the ores of Cripple Creek is decreasing somewhat is an unquestionable fact. Penrose[c] says that the average value of all ore shipped up to 1894 would be between $50 and $85 per ton. The Mint report for 1897 (p. 122) states that the average value lies between $35 and $40 per ton, while in the same report for 1899 (p. 99) $45 is given as the average value of the ore. At the present time it is from $30 to $40 per ton. The early figures of 1894 may be disregarded, since high expenses and excessive freight prohibited the shipping of low-grade ore. The Portland data show a very decided decrease, as follows:

Tenor of gold ore from Portland mine.

	Per ton.		Per ton.
1894	$71.00	1902	$26.00
1895	54.00	1903	29.00
1897	60.00	1904	26.92
1900	39.00	1905	23.60

A value of $30 may represent the average of some of the largest mines, but most of the smaller ones and many of the large ones ship ore much richer than this. Some of the decrease is unquestionably caused by lowered operating and reduction expenses, and it is doubtful whether more than a small fraction should be charged to the actual falling off of values in depth. If this really takes place, it is probably due to a slightly lower tenor in the unoxidized ores than in those which have been subjected to oxidation.

[a] Bull. U. S. Geol. Survey No. 253, 1905, p. 9.
[b] Min. and Sci. Press, San Francisco, October 1, 1904.
[c] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 132.

Chemical analyses of Cripple Creek ores.

	I.	II.	III.	IV.	V.	VI.	VII.
Silica	57.81	54.91	54.68	55.98	59.12	56.70	59.58
Alumina	20.13	17.80	17.87	17.09	18.77	19.35	16.00
Iron	.....	4.80	5.30	3.44	3.38	4.20	.67
Magnesia	.86	.36	.20	.47	.32	.37	.03
Lime	1.32	2.04	2.65	.71	.38	.....	2.03
Alkalies	10.53	12.00	12.00	.....	.....	13.97	12.91
Manganese dioxide	.31	.66	.94	.....	.....	.....	.....
Baryta	.22	.....	.....	.....	.....	.....	.11
Titanium dioxide	.66	.....	.....	.....	.....	.....	.75
Copper	.0064	Trace.	Trace.	.....	.....	.....	.....
Lead	.0071	Trace.	Trace.	.....	.....	.....	.....
Zinc	.....	.60	.64	.....	.....	.....	.....
Arsenic	.0944	.....	.....	.....	.....	.....	.....
Tellurium	.0152	Trace.	Trace.	.....	.....	.10	.....
Molybdenum	.0368	.....	.....	.....	.....	.....	.01
Sulphur	.....	2.49	2.25	1.77	1.23	4.75	.....
Carbon dioxide	.....	2.00	.....	.....	.....	.....	.26
Fluorite	.68	.....	.....	.....	.....	.....	1.42
Pyrite	2.50	.....	.....	.....	.....	.....	4.78
Barium sulphate	.....	.18	.24	.....	.....	.....	.....
Combined water	.93	.....	.....	.....	.....	.50	.81

I. Ore beds of United States Reduction and Refining Company, Standard mill, Colorado City, February, 1904.
II. Ore bed 91, Portland mill, Colorado City. Average silver one-fourth ounce per ton.
III. Ore bed 91b, Portland mill, Colorado City. Average silver one-fourth ounce per ton.
IV. Golden Cycle ore, 300 tons. Analysts, Von Schulz & Son. Gold 0.98 ounce, silver 0.62 ounce per ton.
V. Golden Cycle ore, 600 tons. Analysts, Von Schulz & Son. Gold 1.52 ounces, silver 1.04 ounces per ton.
VI. Specimen Moose ore. Analyst, F. C. Knight. Gold 12.24 ounces, silver 6.70 ounces per ton.
VII. Granite ore, Ajax mine. Analyst, W. F. Hillebrand.

Analysis I represents mixed ores, oxidized to some extent and derived both from breccia and from latite-phonolite. Analyses II and III represent the normal ore from the Portland mine, largely in breccia country rock and slightly oxidized. Analyses IV and V show average Golden Cycle ore, largely from veins in breccia and mostly oxidized. These analyses substantiate the statement made that the ores, speaking approximately, have the same composition as the country rock, the only notable exception being the granite ore, which is very low in silica compared to the unaltered rock. The amount of pyrite varies from 2 to 5 per cent, the latter figure being rarely exceeded in the average composition. Fluorite is always present, but the amount is not often more than 2 per cent and is commonly much less. One or two per cent of carbon dioxide is ordinarily present. Copper, lead, zinc, and molybdenum, with arsenic and antimony, are present in most cases, but the quantities are insignificant. Bismuth and vanadium have been found in ores from Stratton's Independence mine.

The following very carefully made determinations of the metallic contents of rich ores should be added:

Partial analyses of ores from Cripple Creek.

	1.	2.	3.
Gold	0.35	0.0506	0.060
Silver	None or trace.	.0075	.0103
Copper	.03	.0059	.0070
Lead	[a] .18	.....	.....
Bismuth	.0025	.....	.....
Molybdenum	.018	.0015	.0018
Tellurium	.....	.0742	.092
Tellurium dioxide	.36	.....	.....

[a] From another sample of same class of ore.

1. Oxidized ore from 100-foot level of Stratton's Independence mine. Analyst, W. F. Hillebrand. Mine assays give 107 ounces gold per ton.

2. Telluride ore, El Paso mine. Au and Mo determined on 100 g.; Te on 50 g. Analyst, W. F. Hillebrand. Results of assays: 2.19 to 2.07 ounces Ag, 14.53 to 15.60 ounces Au, per ton.

3. Similar ore, El Paso mine. Analyst, W. F. Hillebrand. Results of assays: 2.87 to 3.00 ounces Ag, 17.75 to 19.63 ounces Au, per ton.

According to Mr. G. D. Doveton,[a] the ores as prepared for shipment have a composition within the limits indicated in the following table:

Limits of composition of Cripple Creek ores.

SiO_2	60 -70	Mn	0.0- .10
Al_2O_3	16 -23	Cu	0.0- 2.5
CaO	1 - 5	Te	Trace- .01
MgO	0.1- 0.3	Zn	0.0- .1
BaO	0.0- 0.25	As	0.0- 2.5
Fe	1.5-10	Fl	0.0-10.0
S	1.5- 5	Na_2O+K_2O	4.0-12.0
Pb	0.0- .25		

The maxima given for copper and arsenic occur very rarely.

THE FISSURE FILLINGS.

MINERALOGY.

The most abundant mineral in the fissure fillings or veins is quartz. It is in nearly all cases associated with fluorite, whose purple color often renders it more conspicuous than the quartz, even when the latter predominates. Much of the so-called fluorite, or "purple quartz," of the veins, such as occurs in great abundance in the Blue Bird vein and in the Black or Work vein of the Mary McKinney mine, is a finely crystalline aggregate of both minerals. The relative abundance of the quartz and fluorite varies greatly in different lodes and even in different parts of the same lode. Dolomite, though not present in all of the veins, is in many places an important gangue mineral. It is especially abundant in the Hidden Treasure and other veins in the northern part of the Portland mine and in the Vindicator, Mary McKinney, and Last Dollar mines.

[a] Min. Jour. (London), December 23, 1905.

Pyrite occurs in all of the lodes, often intimately associated with the rich tellurides. It is sometimes supposed to be auriferous, but tests made on pyritic ores have in all cases shown the presence of tellurium, and careful chemical examination of pyrite crystals (see p. 170) has failed to detect a trace of gold. It is probable, therefore, that the pyrite of the Cripple Creek veins merely plays the part of a gangue mineral. The gold found in such pyritic ores as are stoped in the Lee and Lost Anna veins in the Portland mine and in the Elkton, Last Dollar, and Gold Coin mines probably occurs as a telluride mechanically inclosed in the pyrite. In a polished specimen of ore from the C. K. & N. mine such a relation of calaverite and pyrite is clearly visible (fig. 13, p. 181).

Sphalerite, while not on the whole so abundant as pyrite, is present in nearly all the veins, and in some, such as the Bonanza King (Midget mine), Conundrum, and Lead (Moon-Anchor mine) it is found in considerable quantity. Bunches of galena and sphalerite in the Conundrum vein are in some cases several feet long and up to 6 inches wide. Usually, however, sphalerite is an inconspicuous constituent. The ore of the Portland mine contains about 1 per cent of zinc blende, and this is probably over rather than under the general average for the district.

The distribution and occurrence of galena are much like those of sphalerite. Small quantities can be detected in many of the lodes, and it is probably present as invisible particles in others. Occasionally, as in the Pointer, Conundrum, Bonanza King, and Lead veins, it forms a notable proportion of the ore, which in such places is usually of low grade. Sporadic bunches of galena occur, however, in close association with the rich auriferous tellurides, as in the Abe Lincoln mine.

In addition to quartz, fluorite, dolomite, pyrite, sphalerite, and galena, which in varying proportions are the usual mineralogical associates of the tellurides, the lodes contain numerous other minerals which are less abundant. Among these are tetrahedrite, which has been noted in over 20 veins in the district (see p. 121), and molybdenite, which, while rarely conspicuous, frequently accompanies the tellurides and has been identified in many of the mines. Stibnite has a similar association with the rich ores and is probably present in small quantity in most of the prominent lodes. Chalcopyrite, in other regions so often accompanying pyrite, sphalerite, galena, and tetrahedrite, is remarkably rare in the Cripple Creek district and was noted only in the Blue Bird mine. Hübnerite occurs in the Puzzle vein (cut by the Ophelia tunnel), but, so far as known, nowhere else in the district.

Among what are usually termed the nonmetallic vein minerals are some which, while not so abundant as quartz, fluorite, or dolomite, are yet characteristic of the Cripple Creek veins. Such a mineral is celestite, which has been noticed in slender prisms in a large number of the veins. Hollow pseudomorphs of quartz after this mineral are common in most of the prominent lodes. Orthoclase, as a vein mineral, is fairly common in the lodes, although it is especially characteristic of the metasomatic ores in granite. Roscoelite occurs as a gangue mineral in the Mary McKinney and Ajax mines and probably elsewhere in the district. Chalcedony and opal are not uncommon as films and crusts lining quartzose vugs. Rhodochrosite occurs, so far as known, only in the Pointer, Moon-Anchor, and Fluorine mines. Calcite and barite, both common vein minerals in other districts, are rarely found in the

Cripple Creek lodes. Biotite, associated with pyrite, is known only in the abnormal Dolly Varden vein where exposed in the Ophelia tunnel.

The gold in the unoxidized ores of the lodes occurs in combination with tellurium as calaverite, sylvanite, or krennerite. Calaverite is the most abundant telluride of the three, krennerite being apparently the least common. The identification of the various tellurides usually requires refined crystallographic and chemical work, though calaverite can sometimes be distinguished from sylvanite by its more yellow color. As such refinement is not practicable in every case, the relative abundance of the three species, particularly of krennerite and calaverite, which have approximately the same composition, remains somewhat in doubt. The occurrence of native gold, while not unknown in the unoxidized parts of the lodes, is so rare as to be regarded as a curiosity.

For more detailed descriptions of the minerals occurring in the lodes, and for an account of the products resulting from the oxidation of the original fissure fillings, the reader is referred to the sections on the mineralogy of the district and on the processes of oxidation.

The order in which the vein minerals were deposited (paragenesis) is not the same in all fissures nor even in all parts of one fissure. In many of the lodes, moreover, a mineral which was deposited near the wall and which therefore belongs to an early stage in the process of vein growth occurs also in the vugs along the medial portion of the crustified vein. Pyrite, for example, while in many cases one of the earlier of the vein minerals, is sometimes found in small crystals implanted upon the quartz, fluorite, or dolomite which line the vugs, and in the C. K. & N. mine it incrusts crystals of calaverite. Other minerals which are known to have formed successively in the same vein are quartz, fluorite, sphalerite, and tetrahedrite. As a general rule the tellurides were formed during the later stages of fissure filling, as is shown by their prevalent occurrence as projecting crystals in the vugs. Occasionally, however, tellurides have crystallized simultaneously with quartz, fluorite, or dolomite at an earlier stage, so that they are embedded in a compact gangue of one or more of these minerals, as in the El Paso and C. K. & N. mines. Sphalerite and galena, occasionally associated with barite, as in the Tillery vein of the El Paso mine, are usually older than any tellurides that may accompany them, although in the Abe Lincoln mine the difference in age seems to be slight. Dolomite, fluorite, and quartz are frequently intercrystallized in a way to show that they were formed at the same time. In some cases a definite sequence is discernible, as in the Hidden Treasure vein, where fluorite was followed by dolomite and dolomite by quartz. In other cases, as was observed in ore from the Findley mine, dolomite is incrusted by fluorite. Specimens from the Doctor-Jackpot vein show an early crystallization of pyrite and tetrahedrite, followed by dolomite upon which tetrahedrite occurs again as implanted crystals, followed by celestite, quartz, and pyrite in the order named. While celestite is sometimes one of the youngest minerals in the veins, as observed, for example, in the C. K. & N. vein, it is often altered to hollow siliceous pseudomorphs and these in turn embedded in quartz. It was evidently formed at more than one period, as will be seen when the structure of the Howard flat vein is described, and in the Elkton mine (Walter vein) its relation to quartz carrying calaverite is such as to indicate that the celestite is the older mineral. Specimens

from the El Paso mine, level 3, C. K. & N. vein, show that an original crust of celestite is converted into pseudomorphs of quartz coated by quartz crystals on which a still later generation of fluorite and lastly quartz is again deposited.

At the Blue Bird mine a fissure filling of "purple quartz," a fine-grained aggregate of quartz grains in which still smaller cubes of fluorite lie embedded, has been broken, and the new cementing material consists of various forms of quartz, chalcedony, and opal, usually appearing as a yellowish or white flinty material. One specimen of this shows under the microscope a network of bars of cryptocrystalline silica, the interstices between which are filled by clear radial chalcedony, including a few grains of fluorite. Some of this silica bears evidence of being pseudomorphs after a doubtful mineral now dissolved. Replacement of dolomite is shown by specimens from the Orpha May dump. Quartz crusts are here covered by small pyrite crystals and sharply defined primary rhombohedrons of dolomite, all of which are coated by a yellow fiber of opal, in most cases forming a thin, empty shell, the original mineral having been dissolved. Like the tellurides, however, celestite, on the whole, is particularly characteristic of the medial vuggy portions of the veins. Chalcedony and opal belong to a late stage of the vein formation and occur characteristically as films or botryoidal incrustations in the vugs.

In the narrow veins and seams which cut through the altered rock near the fissures a very definite order of succession is often noted. Adularia in well-developed crystals or crystalline aggregates is the first mineral deposited and coats the walls, while the interior of the vein is filled with granular quartz, in which as the latest product rhombohedrons of dolomite are contained (Pl. XVII, *B*). In latite-phonolite of the Findley mine the succession is adularia (oldest), dolomite with calaverite, fluorite, quartz (youngest); the surface of the quartz is dull and corroded. Wavellite is a primary vein mineral and in places forms tiny filled veinlets accompanied by pyrite. The walls of these veinlets are lined with adularia.

To speak very broadly, the vein filling began by the deposition of adularia and the base sulphides, such as pyrite, sphalerite, and galena; then followed deposits of quartz, fluorite, and dolomite, sometimes repeated, and toward the last tellurides and celestite, followed in some places by repeated deposition of quartz and fluorite. The closing chapter is in some veins represented by extensive deposition of quartz and chalcedony, frequently replacing the celestite and coating all other constituents. Molybdenite is usually intergrown with pyrite and zinc blende, indicating that it is one of the older vein minerals.

STRUCTURE.

To a certain extent the larger structures of the lodes have been described in the section devoted to the fissures. The present section relates particularly to the modes in which the various minerals are arranged within individual fissures.

The Cripple Creek veins are characterized in general by a vuggy structure. Some fissures are solidly filled with vein matter, but this, on the whole, is not common. Usually the walls of the fissures are covered with crystalline crusts which have grown together here and there along the medial plane of the vein, having numerous cavities lined with projecting crystals of quartz, fluorite, and other minerals. In most cases the crusts are comparatively thin and the vugs narrow. In some lodes

the veinlets which contain the tellurides are no thicker than a sheet of paper, as may be seen in the Captain stopes in the Portland mine, in the northern part of the Mary McKinney mine, in the stopes in gneiss in the Midget and Abe Lincoln mine, and in many of the lodes in phonolite dikes. Even such minute fissures are not everywhere completely filled. They are generally planes of easy fracture and their walls, when cleft apart, are seen to be covered with a thin drusy coating, consisting in most cases of quartz or fluorite, with crystals of calaverite. In the Captain stopes the drusy coating is usually dolomite. In the gneiss of the Abe Lincoln and Midget mines many of the gold-bearing fractures are so narrow as to be visible only by the aid of a lens. As a rule, each little fissure, however, is associated with a zone of metasomatic alteration in the gneiss, suggestive in its general appearance of the bands of greisen accompanying cassiterite veinlets, such as those of Geyer in Saxony. This zone is usually greenish, lacks the brilliant scales of biotite elsewhere abundant in the gneiss, and may be an inch or more wide. It is thus in most cases a more conspicuous feature than the fissure which it accompanies. The veinlets themselves commonly consist of films of pyrite or quartz and tellurides, and many of them, as may be seen with a lens, are minutely vuggy.

The majority of the individual veins in the district range from the width of those just described up to 5 or 6 inches, and the vugs have a corresponding range in size. The crustified minerals on the fissure walls grow outward somewhat unevenly, so that vugs occur irregularly in the veins instead of being uniformly arranged along the medial plane. Moreover, some parts of a vein may be solidly filled with tellurides and gangue, while other parts show merely thin crusts on the walls, as may be seen in the C. K. & N. vein and in some of the flat veins in the Mary McKinney mine. In some sheeted zones slabs of country rock became loosened when the fissures were opened. Subsequent deposition of vein minerals has covered these detached fragments with crystalline coatings and cemented them at points of contact to the fissure walls, leaving vuggy spaces into which it is possible to thrust an arm. Some of the best examples of such gaping sheeted zones were seen in the C. K. & N. and Blue Bird mines. Where the fissuring is locally irregular, as in the pay shoot of the El Paso vein alongside the phonolite dike (see p. 351), the entire ore body may consist of a mass of rock fragments cemented together by little vuggy veinlets of quartz or other gangue mineral, carrying tellurides of gold. Where the shattering has been more intense and where more or less of the shattered rock has been removed in solution, each fragment may be surrounded by an envelope of quartz and fluorite, as in a curious expansion of the Elkton lode presently to be described.

Although the vugs are usually small and often minute, a few veins in the district contain cavities of notable size. The Howard flat vein, where cut in the Ophelia tunnel, has vugs large enough for a man to crawl into, and lined with rough crystalline incrustations of quartz and fluorite. The crystals of these minerals have evidently in part grown around hollow siliceous pseudomorphs, probably after celestite. In one of the cross veins in the Last Dollar mine, on level 12, occurred a vug 12 feet long and 2 feet wide. Probably the largest and most remarkable cavity in the district was that on level 7 of the Elkton mine, whence issued the

water which in 1901 flooded the lower levels of the mine. This, as diagrammatically sketched in fig. 12, is a lateral offshoot from the Elkton lode at a point where the breccia had been locally shattered. Apparently the finer fragments were partly removed in solution, and the larger ones and the walls of the irregular cavity were coated with crystals of quartz and fluorite, which in part were accompanied by tellurides. In this case the fluorite is not merely a coating on the fragments which partly filled the cavity, but has to some extent metasomatically replaced them.

The crystalline crusts which coat the walls of the fissures seldom show well-defined continuous banding such as is often found in crustified veins of greater width and of more abundant filling. The development of such a structure requires a fairly definite mineralogical sequence or paragenesis and fissures of greater average width than those of Cripple Creek, so that the crusts as successively deposited will be thick enough and continuous enough to be distinctive in spite of minor irregularities of crystal growth. Fairly regular banding was noted, however, in the Galena mine, the order of crystallization being (1) quartz, galena, and sphalerite; (2) radial pyrite; (3) sphalerite; and (4) fluorite, rhodochrosite, and sphalerite. A rather indistinct banding of quartz and fluorite was observed also in the C. K. & N. vein, on level 4 of the El Paso mine. The Mary McKinney lode is apt to show a sharply defined filled central vein. A specimen of one-half of the vein, 3 inches in thickness, shows that the deposition began by two narrow fluorite bands separated by a narrow quartz seam. On top of the second fluorite band calaverite crystals are deposited; then follow mixed quartz and fluorite coated by thin, yellow opal and cryptocrystalline chalcedony.

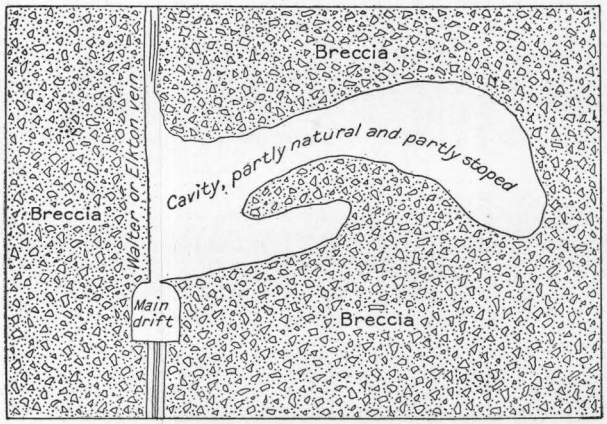


FIG. 12.—Sketch section across expansion of vein on level 7, Elkton mine, looking north.

The Gold Coin vein, on level 12, shows distinct banding. Next the wall is deposited quartz with pyrite, zinc blende, and galena; then follows 3 mm. of solid comb quartz covered by a drusy mass of crystallized quartz and fluorite. The Puzzle vein in a similar manner shows crusts about 1 inch thick, consisting of zinc blende and galena covered by a quartz crust on which slender crystals of calaverite appear.

In general, then, the typical vein of Cripple Creek consists of one or more fissures ranging from 1 to 6 inches in width, whose walls are lined with crystalline crusts of quartz, fluorite, or dolomite. Along parts of the vein the crusts are thick enough to meet and the vein is solidly filled with tellurides and gangue, but in most parts the medial line of the vein is open or vuggy, and the crystals of calaverite or sylvanite project with crystals of the gangue minerals into the vugs. In many

veins the tellurides are practically confined to the vugs, and this is certainly their most characteristic occurrence; but in a few cases they are embedded in the compact or solid portion of the vein as well.

There are numerous variations from what may be regarded as the typical vein. Some fissures are completely filled with granular pyrite, as in some of the seams of the Doctor-Jackpot lode; some with a crumbling mass of pyrite and fluorite, as a vein exposed in the Granite mine, on level 6, north of the shaft; some with a hard, fine-grained, dark-purple aggregate of quartz and fluorite, as parts of the Blue Bird, Buena Vista, Doctor-Jackpot, and Work veins, and a cross vein in the Findley mine, which is in places 15 inches wide. Such fissure fillings, however, are seldom productive. Some fissures, like the Howard flat vein, are in some places much wider than the typical veins; but although much ore has come from the Howard vein, it has not been obtained from the exceptionally wide and vuggy portions. Some fissures, like parts of the Gold Coin and Mary McKinney veins, were originally filled with brecciated rock derived from their walls. This crushed material was in part cemented and in part metasomatically replaced by gangue minerals and ore. The Bobtail vein of the Portland mine is also a mineralized breccia-filled fissure. In this case, however, the breccia does not seem to have been derived from the walls of the fissure.

The filling of the Pointer vein, which is in places 2 or 3 inches wide, has a peculiar cellular structure, the cavities being lined with small crystals of quartz and fluorite. The structure is due in part to the filling of fissures in a sheeted zone and in part to a combination of metasomatic replacement and solution of the thin slabs of rock between the fissures.

As regards minor structural details, the veins present few features worthy of note. The vein quartz, when seen in thin section under the microscope, rarely if ever shows such optical homogeneity as is characteristic of the quartz of the Mesozoic gold veins of the Pacific coast. The Cripple Creek quartz has a wavy extinction between crossed nicols and shows a pronounced radial optical structure, as if each crystal grain were composed of submicroscopic radial fibers. The structure is suggestive of chalcedony, but is more shadowy, with less regularity and sharpness of definition of the constituent fibers. A similar structure is common in the quartz of the San Juan region, Colorado. While having some resemblance to the well-known strain phenomena produced in crystals by pressure, the structure here described can scarcely be explained as a result of strain. The structure is particularly well shown in quartz crystals projecting into vugs, as in the Howard flat vein, and although the vugs may have been filled with liquid under pressure, such hydrostatic pressure could hardly produce strain phenomena. In the Gold Coin vein crystals of quartz with this radial optical structure are incrusted with chalcedony. The boundary between the two minerals is not sharp, and there seems to have been no break between the deposition of quartz and that of chalcedony. This suggests that the structure of the optically anomalous quartz is also minutely fibrous and in no way due to pressure upon a formed or partially formed crystal. It is noted that a lack of optical homogeneity is characteristic also of the adularia crystals that project into the vugs of the ore metasomatically deposited in the Pikes Peak granite.

PLATE XVII.

Photomicrographs of Ores.

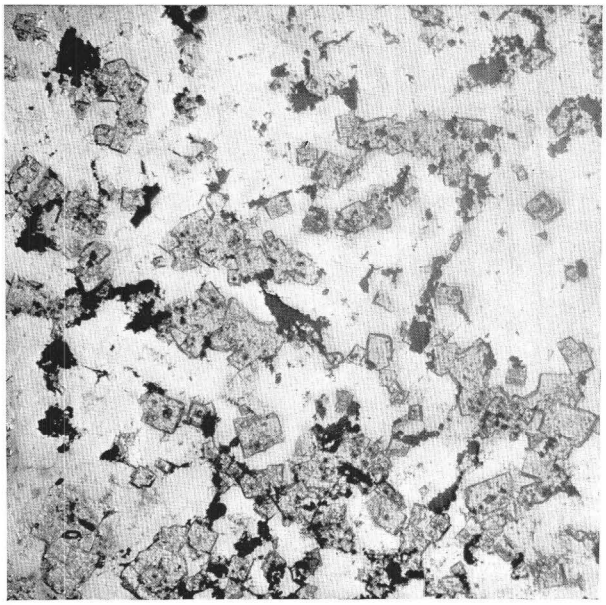
A. "Purple quartz" (8 C. C.), Morning Glory mine, 750-foot level, Doctor vein. Light-gray cubes=fluorite. White cementing mass=microgranular quartz. Black=pyrite. Magnified 28 diameters.

B. Filled veinlet in altered latite-phonolite (680 C. C.), Last Dollar mine, level 11. *g*=granular quartz; *f*=fluorite; *d*=dolomite; *a*=adularia. Magnified 28 diameters.

C. Quartz from Howard flat vein, Ophelia tunnel (648 C. C.), deposited on celestite and replacing this mineral. Crossed nicols showing radial structure and variation of grain. Magnified 28 diameters.

D. Altered latite-phonolite, level 12, Last Dollar mine, showing pyroxene crystal replaced by pyrite, dolomite, and fluorite. Black=pyrite. Magnified 28 diameters.

E. Altered latite-phonolite (452 C. C.), Last Dollar mine, showing titanite crystals altered to rutile, calcite, and quartz. Black around periphery=rutile. Light center=quartz and calcite. Magnified 40 diameters.



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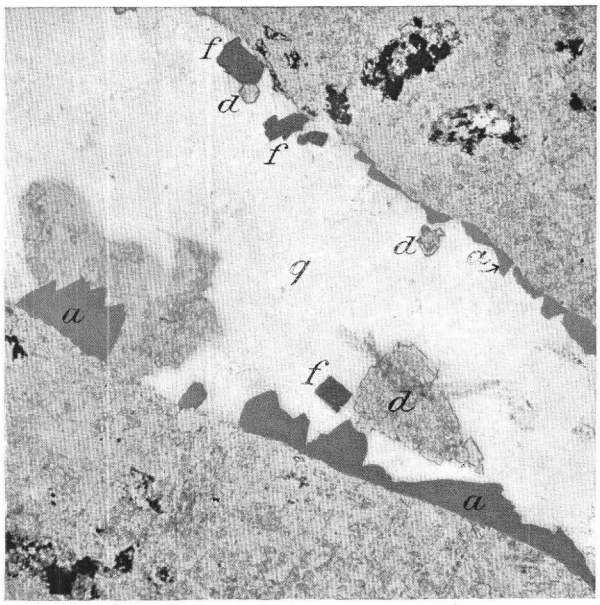

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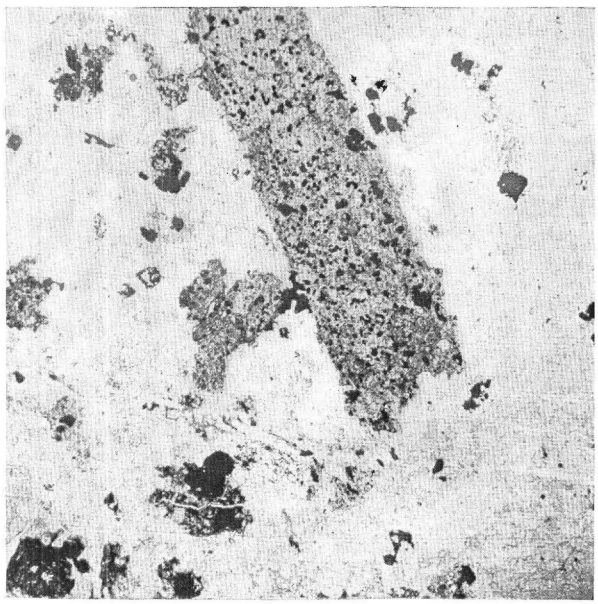

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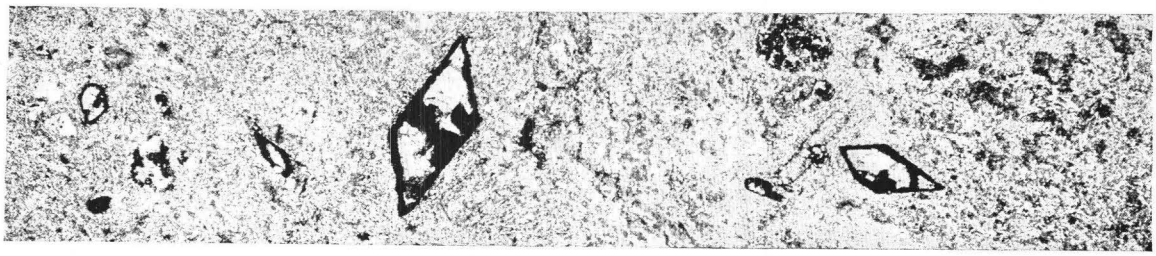


E

PHOTOMICROGRAPHS OF ORES.

The quartz is apt to vary considerably in texture in a single specimen, ranging from rock of fine grain, but with still distinctly visible partly idiomorphic individuals, to rather coarse vein quartz (Pl. XVII, *C*). The pyrite crystals are usually inclosed in quartz; rarely in fluorite.

Fluid inclusions are abundant and often show moving bubbles which do not disappear or change form upon heating to +35° C. and above. The fluid is, therefore, in all probability an aqueous solution. The inclusions are apt to have extremely irregular forms and often contain some solid material besides the fluid and the bubble, but this material is not crystallized; it forms irregular masses and adhesion to the walls.

The so-called "purple quartz" or "massive fluorite" of some of the veins is usually a mixture of quartz, fluorite, and dolomite in various proportions. It is deep purple and has a fine, evenly granular texture. The microscope shows that the dominant mineral is generally quartz in allotriomorphic grains. Included in the quartz are small cubes of fluorite and in many cases rhombohedrons of dolomite (Pl. XVII, *A*). The fluorite, as is usual in the darker varieties of this mineral, is very unevenly colored, the deep-purple pigment occurring in little flecks here and there in the cubes. On the whole, thin sections show much less purple than the deep color of the material, as seen in masses, would suggest. In most cases the quartz-fluorite aggregate is purely a fissure filling. In the Elkton mine, however, on level 7, granular fluorite with some quartz has metasomatically replaced breccia. Thin sections of this material show the same uneven coloration, the most deeply colored cubes or grains being those which are in contact with the breccia along the irregular surface of replacement. At a little distance from this contact the fluorite as seen in thin section is nearly colorless. This suggests that the fluorite grains may in some cases naturally lose their deep color which presumably is due to included organic material.

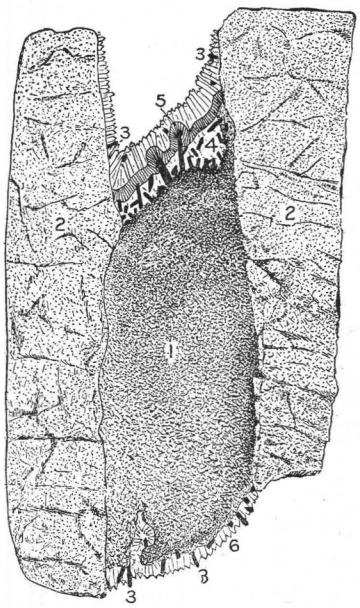


FIG. 13.—Local structure in C. K. & N. vein. Walls consist of reddish granite containing pyrite in cracks perpendicular to vein. Inclosed fragment of altered rock in open fissure and crusted by calaverite and quartz covered by radial pyrite. On top of the latter comb quartz. 1. Fragment of altered rock wedged in fissure. 2. Minutely fissured granite with pyrite. 3. Calaverite. 4. Earlier generation of quartz. 5. Radial pyrite. 6. Later generation of quartz.

A rather unusual vein filling was noted at one point in the C. K. & N. vein. The principal fissure is here an inch wide and for the most part is only partly filled with vuggy quartz and calaverite. At one place, however, the vein is filled with a fine-grained dark-gray mass about 3 inches long, which appears to have been originally a fragment of rock wedged into the fissure. This fragment has been metasomatically altered to an aggregate of quartz and minute crystals of pyrite, with here and there a speck of calaverite. Incrusting the ends of the fragment and the walls of the fissure is a layer of quartz and calaverite of varying width. Coating this and almost enveloping some of the

calaverite crystals is a layer of radial pyrite with a minutely botryoidal surface. This layer in turn is incrusted by comb quartz containing some calaverite. The structure of this ore is shown somewhat diagrammatically in fig. 13.

The occurrence of hollow, acicular, or prismatic pseudomorphs, which are probably in all cases formed by the incrustation of celestite by a shell of drusy quartz and the subsequent solution and removal of the strontium sulphate, frequently gives a characteristic structure to the vein fillings. Sometimes these pseudomorphs, which are usually opaque and are milk white or yellow, are completely embedded in the quartz or, less commonly, in fluorite. In most cases, however, they project into the vugs, and with their incrusting quartz crystals form a particularly rough crystalline lining, as may be well seen in the Howard flat vein in the Ophelia tunnel. The original celestite crystals, as shown by the pseudomorphs and by the crystals seen in the C. K. & N. vein, are slender needles, usually of rhombic cross section and tapering to a point. In the Howard flat vein such needles have been radially incrusted with quartz crystals so as to form little stalactites with diameters ten to twenty times that of the original celestite needle, and with lengths of 1 or 2 inches. On these stalactites were implanted a second generation of celestite crystals which have in turn been incrusted with quartz and dissolved away. Some of the pseudomorphs which showed a hollow central canal partly filled with a white earthy substance were analyzed by Mr. George Steiger, who found that they contained 2.04 per cent BaO, 0.04 per cent SrO, 0.06 per cent CaO, and an amount of SO_3 which probably would suffice to form sulphates in combination with the bases. It is possible that the original mineral was barite, but the crystal form rather points to celestite with a small percentage of baryta. During the pseudomorphic action the more soluble sulphates of strontia would be carried away, leaving a residual of not easily soluble barite. Some of the hollow pseudomorphs found in the ores have cross sections that are sharply rectangular instead of rhombic. Such pseudomorphs were observed in the Golden Cycle mine and, embedded in chalcedony, in the Blue Bird mine. The original mineral after which these shells are pseudomorphs has not been ascertained. It may have been celestite of a different crystal habit from that characterizing the known occurrences of this mineral in the district.

EXCEPTIONAL VARIETIES OF VEINS.

LEAD-ZINC VEINS.

Narrow veins with quartz gangue, predominating galena or zinc blende, and subordinate telluride occur along the western side of the district from Poverty Gulch down to Squaw Gulch and the vicinity of the Pointer and Puzzle mines. The strike is usually northeasterly. No strict line separates these veins from the normal telluride veins. Where there is much galena some silver is present, but the high silver values are, as a rule, connected with the occurrence of tetrahedrite. Many of the galena veins are close to normal telluride veins.

CELESTITE VEIN.

The only occurrence of a celestite vein was found in level 7 of the Ironclad mine, where the crosscut to the main vein intersects a massive vein about 1 foot wide and striking northeasterly. The vein, which is poor in gold, but is said to carry some lead, contains streaks of limonite and clay, but consists chiefly of white granular celestite, coated with chalky crusts of a hydrous sulphate of strontia.

BIOTITE-FELDSPAR VEIN.

A biotite-feldspar vein, the only one of this very remarkable type, was found in the Ophelia tunnel, about 6,000 feet from the portal, in the Dolly Varden claim. Penrose[a] mentions a possible similar occurrence on the Ocean Wave claim, which could not be definitely located, but gives no details. The vein, which crosses the tunnel with a general northerly direction, appears as a zone of narrow but well-defined stringers, the aggregate thickness of which is 6 to 10 feet. They consist of white drusy feldspar; pyrite, partly with crystal outlines, and black biotite, the latter in well-crystallized hexagonal prisms. All three minerals are intimately intergrown; pyrite and small foils of biotite are disseminated for some distance into the surrounding rock, which is sharply separated from the vein filling. The feldspar consists of coarsely granular orthoclase with narrow intergrown lamellæ of albite. An analysis of the feldspar by Mr. George Steiger yielded 13.27 per cent K_2O, 1.36 per cent Na_2O, and 0.04 per cent CaO. The biotite lies embedded in the feldspar as large ragged foils of pale yellowish-brown color and wide axial angle. The pyrite contains only 0.08 ounce of gold and 0.20 ounce of silver per ton. The whole occurrence is very unusual. The type of the feldspar with albite lamellæ is granitic and has not before been observed in distinct veins, to which class this deposit undoubtedly belongs. It is not an altered granitic dike. It is so entirely different from the other types of deposits in the district that it must have been formed under unusual conditions, probably at a greater degree of heat than prevailed during the principal vein-forming epoch.

[a] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 129.

CHAPTER IX.—PROCESSES OF ALTERATION.

METASOMATISM IN CONNECTION WITH VEIN FORMATION.

EXTENT OF ALTERATION.

The volcanic rocks of Cripple Creek have been extensively altered, so much so that in places it is impossible to obtain entirely fresh specimens. This alteration may be traced to three causes—vein formation, ordinary hydrometamorphism, and direct oxidation. The first of these is not now operative, while the two latter processes are still actively engaged and are apt to superimpose their effects on the alteration due to vein formation. The more important of these two is oxidation, which is described in detail on pages 196 to 204. Ordinary hydrometamorphism producing chlorite, serpentine, sericite, etc., is caused by surface waters below the zone of oxidation. Its changes are not very far-reaching and only in very few cases has it radically altered the mineralogical composition of the rocks.

To processes of vein formation may unhesitatingly be referred the greater part of the alteration below the reach of oxidizing waters. All rocks have been affected, the breccia most of all in consequence of its porous and permeable character. There are, in fact, comparatively few places where the breccia retains its original appearance. Latite-phonolite and syenite have yielded less readily to alteration, and fresh specimens may be obtained from all of the bodies mapped. Phonolite and basalt dikes, especially the latter, are usually more or less affected, while the larger outlying phonolite masses are, in most cases, practically fresh. The Beacon Hill phonolite has suffered much more than the ring of phonolite intrusions which, contained in granite, surround the central breccia. Granite, schist, and gneiss are only locally altered near the breccia contact or near veins traversing them.

CHARACTER OF ALTERATION.

On the whole, and compared to similar changes in other districts, the alteration of the Cripple Creek rocks is remarkably slight. It is elsewhere not uncommon near gold-quartz veins to find diorites, amphibolites, or diabases completely changed to white, soft rocks chiefly composed of sericite, quartz, and carbonates. Here, on the contrary, alteration very rarely obliterates the original character of the rock as seen under the microscope or in specimen. The minerals formed are pyrite, associated occasionally, but not commonly, with a little zinc blende or galena, further sericite, adularia, dolomite, fluorite, and quartz; the latter is wholly subordinate and forms only under certain exceptional conditions, resulting in complete replacement of the rock by quartz and pyrite. Sometimes apatite also forms. Besides sericite, roscoelite (a yellowish-green vanadium mica) and a light-green mica of doubtful composition are sometimes present, and rutile, with some calcite, develops from titanite.

Chemically the process when carried to completion involves an almost entire loss of soda and a corresponding gain of potash attending the formation of sericite and adularia. Small amounts of sulphur, carbon dioxide, and fluorine are introduced. The percentage of silica is usually slightly reduced and a leaching of magnesia and lime is sometimes evident. After all, the most important process is the replacement of soda by potash, so commonly resulting elsewhere from the action of thermal waters at moderate temperature and pressure on ordinary feldspathic rocks.

METASOMATIC MINERALS.

Among the metallic minerals pyrite is easily the most common, and develops abundantly by replacement as small crystals in the groundmass of the porphyritic rocks or in the cementing mass of the breccia, as well as in phenocrysts or in the minerals of granular rocks. The form is usually that of the pyritohedron combined with the cube; some larger masses have irregular outlines. Although the mineral develops throughout the rock, it is most abundant near replaced phenocrysts of pyroxene, amphibole, or biotite; it also forms directly from magnetite, and on the whole the iron seems to be supplied by the original minerals of the rock, and the transformation is effected simply by the addition of sulphur derived from hydrogen sulphide or from sodium sulphide.

Zinc blende appears occasionally in the altered rocks, but is, on the whole, very rare; it is associated with pyrite as anhedral grains of dark-brown color. Other sulphides are very seldom observed.

Tellurides, chiefly calaverite, appear as metasomatic minerals in granite, schist, breccia, or phonolite, and also in the basic dikes. It forms anhedral grains, rarely prisms, and is associated with pyrite. Another form of its occurrence is as minute crystals coating small cavities of dissolution in various rocks, such as granite and phonolite. Compared to its abundant development as crusts in fissures, its metasomatic distribution is very limited.

Magnetite, specularite, pyroxenes, and amphiboles do not appear as metasomatic minerals in these deposits, and are, in fact, unstable under the influence of these vein-forming agencies. Epidote is very rare, and probably also unstable under these conditions.

Sericite is common, although the extensive sericitization seen in the wall rocks of many classes of veins is here absent. The mineral forms, to some extent, as small foils and fibers in orthoclase (Pl. XVIII, *B*), though wholly sericitized crystals are very seldom encountered. Much more commonly it forms as minute fibers in the sodic silicates, such as nepheline, sodalite, and analcite, also in soda-lime feldspars, and in pyroxenes, amphiboles, and brown micas. The yellowish-green vanadium mica, roscoelite, is seen occasionally in granite (Ajax mine) or in breccia (Mary McKinney mine).

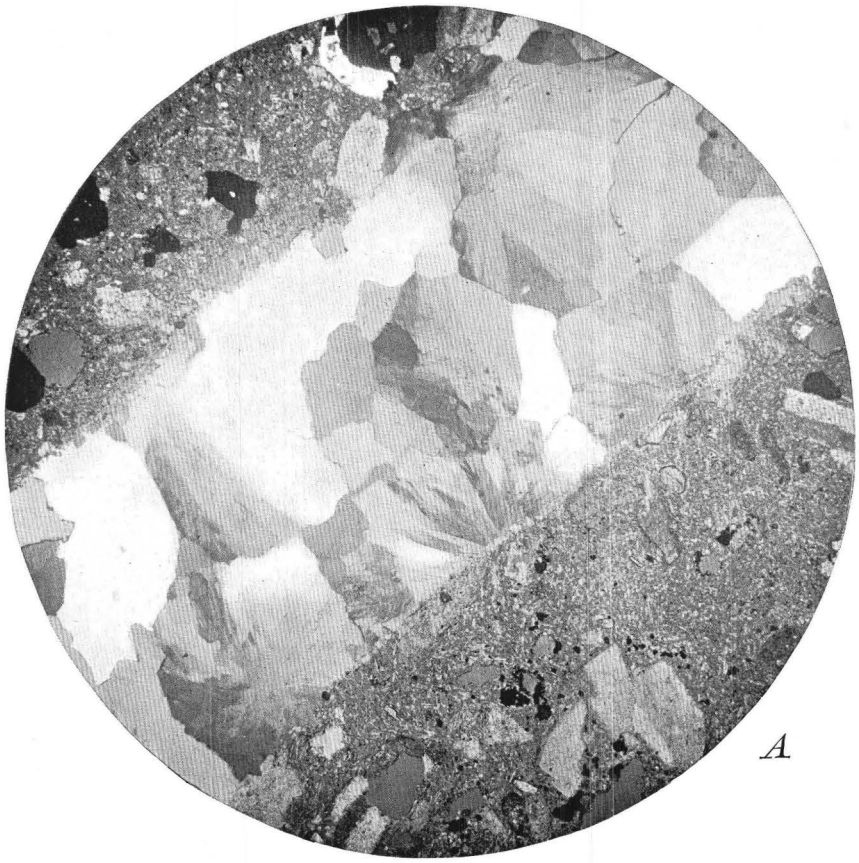
As a first stage in common hydrometamorphism, as well as in hydrothermal metamorphism, of biotite, amphibole, and pyroxene in gneisses, latite-phonolites, and similar rocks, a variety of mica is often noted which does not seem to correspond to any known variety. Its aggregates of small shreds and foils of deep grass-green to yellowish-green and brownish-green color have a noticeable though not very strong pleochroism and vivid colors of polarization.

PLATE XVIII.

Photomicrographs of Ores.

A. Quartz veinlet with radial structure in breccia, Empire State mine, level 10; crossed nicols. Magnified 28 diameters.

B. Phenocrysts of orthoclase in latite-phonolite, Gold Sovereign mine, level 7, showing sericitization. Lighter central areas indicate abundant microcrystalline aggregates of sericite, while in the darker peripheral spaces more feldspar remains. Black areas indicate pyrite. On veinlets and in small spaces of dissolution adularia has developed. Crossed nicols. Magnified 28 diameters.



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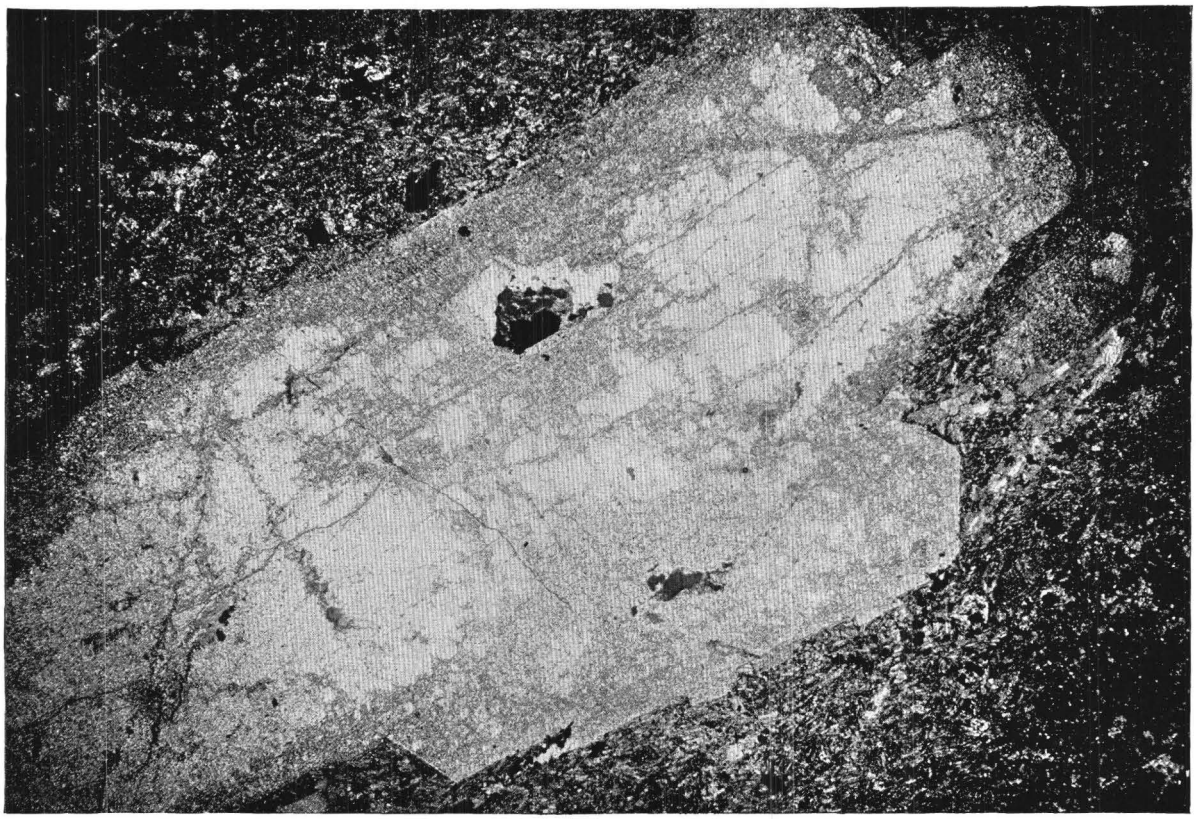

B

PHOTOMICROGRAPHS OF ORES.

Serpentine develops in places from ferromagnesian silicates under the influence of incipient vein action, but is probably soon altered to carbonates.

Adularia is a pure potassium feldspar which occurs in some mineral veins.[a] The Cripple Creek deposits contain a considerable amount of this mineral, both as fissure-filling and more prominently as a metasomatic product.[b] It nearly always shows crystallographic outlines, and as the forms are combinations of the prism and a dome, the outline of the crystals usually shows a rhombic, somewhat elongated form. Larger grains often have peculiar optical irregularities, somewhat like that of the quartz in the filled veins of Cripple Creek (p. 179), the mass being divided into several irregularly defined sections with slightly differing optical orientation.

Adularia forms in all the various rocks, most abundantly, however, in the metasomatically altered granite, the so-called granite ore. In little veinlets its crystals coat the walls as they do in cavities of dissolution, where the central part is apt to consist of dolomite or fluorite with pyrite. In the mass of the rock it occurs as rhombic sections or is attached to old orthoclase crystals, as marginal growths with parallel orientation or healing fissures in the same. Sometimes the distinction from the primary orthoclase may be difficult, but the more recent mineral is usually very clear and free from inclusions. In the granite much of the older feldspar is microcline, but the secondary mineral never belongs to this species. It is somewhat surprising to see sericite and adularia develop in the same rock, side by side (Pl. XVIII, *B*); in some instances, indeed, fibers of sericite are developed in a mass of adularia. However, the principal part of the adularia is confined to the granite, while in the volcanic rocks sericite is more abundant. To a certain extent the formation of adularia is due to the prevalence of the orthoclase in the original rock, for, as pointed out by Van Hise,[c] the mineral species most abundantly present have the advantage over other kinds of minerals, which are absent or sparingly present, in determining the character and the orientation of new additions. Thus, quartz will develop most abundantly in siliceous rocks and orthoclase in those rich in that kind of feldspar.

Quartz is formed during the alteration of sericite from orthoclase and during the decomposition of ferromagnesian silicates, but it appears to be carried away in soluble form. At any rate, quartz is not of general occurrence as a metasomatic product, though it is often deposited on fissures. Quartz crystals are seldom deposited in the small cavities of dissolution so common in the volcanic rocks. Adularia is far more common. Some occurrences of silicified rocks will be described below, but they occupy a rather exceptional position.

Dolomite and calcite are common constituents of the altered rocks of all kinds. Dolomite replaces the cementing mass in breccia, the ferromagnesian silicates in latite-phonolites, and develops almost as easily in the orthoclase. The dolomite always tends toward a crystalline development, the form being a more or less roughly outlined normal rhombohedron. Siderite develops from magnetite in small quantities.

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[a] Lindgren, W., Orthoclase as a gangue mineral in a fissure vein: Am. Jour. Sci., 4th ser., vol. 5, pp. 418–420.

[b] Lindgren, W., Metasomatic processes in fissure veins: Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 612.

[c] A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904. p. 122.

Fluorite is rarely very abundant, but is widely distributed. It has not the same tendency to crystallographic development as in the filled veins, but occurs in little masses filling small cavities of dissolution or replacing any one of the constituents of the rock. The color is always purple, frequently deepened in spots.

Rutile forms easily from titanite; pseudomorphs of rutile, calcite, and chalcedony after crystals of titanite are common in the latite-phonolites.

METASOMATIC CHANGES IN PHONOLITE.

The changes which have taken place are rarely very far-reaching. A phonolite dike, followed by the vein, on the 370-foot level in the C. K. & N mine shows small cavities of dissolution coated by quartz, pyrite, fluorite, and tellurides. Under the microscope the structure of the rock is seen to be perfectly preserved. The ægirine-augite is replaced by calcite and nests of serpentine; pyrite is abundant in small crystals, in many places probably replacing magnetite. There is very little sericite, and the orthoclase seems practically fresh. This phonolite is a low-grade ore.

A fine-grained dike from level 10 of the Last Dollar mine, 100 feet south of the shaft, shows dolomite or calcite distributed throughout the rock; here also magnetite is converted to pyrite and siderite. Small pyrite crystals are abundant and veinlets of adularia, carbonates, pyrite, zinc blende, and galena traverse the rock; the adularia is the earliest mineral formed. This altered dike is not classed as ore. A light yellowish-gray phonolite from the Cheyenne vein on level 11 of the Isabella mine, 800 feet south of the Lee shaft, is a normal rock containing very little pyrite and some fluorite in irregular aggregates. The nepheline is converted to sericite, while the orthoclase appears unaltered. However, many of these rocks may contain much more adularia than is apparent.

METASOMATIC CHANGES IN SYENITE.

The normal syenite from the Last Dollar mine contains no carbonates and, sericite, green mica, and chlorite are only slightly developed. The magnetite is not altered. The rock along the vein at the north end of level 11 in the same mine is a syenite which has been subjected to unusually strong metasomatic action. It is bleached and softened and contains much pyrite, besides some black zinc blende and fluorite. The latter three minerals, with much quartz and adularia, form irregularly outlined replacement veins. Under the microscope the most abundant constituent is a granular orthoclase, while the ferromagnesian silicates and the magnetite have disappeared. Dolomite in anhedrons and rhombohedral forms mixed with a little sericite replaces this orthoclase abundantly. Sharply defined cubes and pyritohedrons of pyrite are plentiful, together with grains of black zinc blende. Rims of adularia sometimes surround the pyrite. Cavities of dissolution contain nests of quartz, adularia, and fluorspar; veinlets, probably chiefly formed by replacement, contain carbonates, quartz, and adularia, and in one place calaverite with tetrahedrite; tellurides do not, however, appear in the mass of the rock.

METASOMATIC CHANGES IN LATITE-PHONOLITE.

The altered phases of the latite-phonolites are best studied at the Golden Cycle and Vindicator mines. Pyrite and dolomite are the minerals most abundantly introduced, but the alteration is not always uniform, so that in some specimens either of these two minerals may be lacking. There is usually a development of sericite and adularia.

The discussion may best begin by a description of the altered latite-phonolite of the dike along the Independence lode in Stratton's Independence mine, collected in the Washington shaft by Cross. The analysis of the rock was made by W. F. Hillebrand in 1894, but has hitherto been unpublished. The rock is a yellowish-gray, fine-grained porphyritic latite-phonolite, with close relationship to the phonolites. There is a tendency to platy structure, emphasized by numerous small cavities of dissolution coated with crusts of fluorite, adularia, pyrite, and a soft material which seems to be a mixture of sericite and kaolin. Throughout the rock are small specks of fluorite and pyrite. Under the microscope the large phenocrysts of orthoclase are little altered; the groundmass consists of narrow laths of generally unaltered orthoclase, between which lies an interstitial mass of fine sericite fibers clearly replacing the analcite, sodalite, or nepheline which, in the fresh rocks, are apt to occupy this position. Small crystals of pyrite are distributed throughout. Spaces of dissolution are plentiful and are filled with adularia, while the central part is occupied by fluorite. In one place fibers of sericite project into the adularia. No biotite, amphibole, or pyroxene are visible, and these minerals have no doubt been thoroughly decomposed. Neither are there any carbonates in this rock, though other specimens of the same dike collected by us contain a considerable amount of these minerals replacing ferromagnesian silicates.

Analyses of altered and fresh latite-phonolites.

[Analysts, W. F. Hillebrand (A. and B), W. T. Schaller (C.).]

	A.	B.	C.		A.	B.	C.
SiO_2	56.74	59.38	57.91	P_2O_5	.25	.08	.....
Al_2O_3	20.30	19.47	.....	SO_3	.....	.37	.....
Fe_2O_3	1.06	1.60	.....	Cl	.....	.22	.....
FeO	.....	1.19	.....	F	Undetermined.	.....	.....
MgO	.23	.36	.33	S	.....	.....	1.12
CaO	.57	1.96	.81	MnO	None.	.15	.....
Na_2O	.62	7.80	.45	BaO	.19	.13	.....
K_2O	13.36	5.83	13.35	SrO	Trace.	.03	.....
H_2O-	.33	.11	.....	Li_2O	Trace.	Trace.	.....
H_2O+	1.15	.69	.....	FeS_2	4.65	.....	.....
TiO_2	.58	.58	.....				
ZrO_2	.07	.10	.....		100.10	100.05	.....
CO_2	.....	.....	.66				

A. Altered latite-phonolite, Washington shaft, Stratton's Independence mine.
B. Fresh latite-phonolite, west slope Bull Cliff (Petrographic reference collection No. 624).
C. Altered latite-phonolite, level 11, vein No. 3, Vindicator mine (Cripple Creek collection No. 687).

Under B is given, for comparison, an analysis of a latite-phonolite poor in lime, which probably best corresponds to the composition of the original rock of A. This is, of course, an assumption, but the chemical composition of the Cripple Creek rocks is so well known that it can not be far from the truth. There are no volcanic rocks known from the district in which potassium predominates in the manner shown by A. The principal change, then, consists in a transformation of sodic silicates to potassic (sericite and adularia), and in the introduction of sulphur and fluorine. There is probably a slight loss of silica and a gain of water, though the fresh rocks usually contain 1 or 2 per cent chemically combined water which may be applied to the formation of secondary sericite. There is also a loss of chlorine and sulphuric acid from sodalite and hauynite, and a loss of a part of the lime, while magnesia, iron baryta, and titania have remained about constant.

The rocks from the Golden Cycle mine are not conspicuously altered, except for small and abundant sharply defined crystals of pyrite; sometimes they are slightly bleached. The pyroxene crystals are converted to sericite or carbonates, or both, but chlorite and serpentine are generally absent. Veinlets of adularia intersect the rocks. With the maximum of alteration perhaps 10 per cent of dolomite and 10 per cent of sericite have developed in the rock. The orthoclase contains fibers of sericite along the cleavage planes and sometimes irregularly replacing dolomite; very rarely, however, is the entire crystal replaced. Magnetite alters into pyrite.

In the latite-phonolite of the Vindicator, Last Dollar, American Eagle, and Gold Sovereign mines the alteration is along the same lines, although dolomitic carbonates with a decided tendency to crystallization are abundant and replace both feldspars and pyroxenes. The amount of new-formed minerals rarely exceeds 15 per cent. In the latite-phonolite from the Last Dollar mine it is again noted that the small sodalite crystals first become sericitized. Pyroxene is converted to dolomite, with a little fluorite, serpentine, and pyrite (Pl. XVII, *D*). The large rounded magnetite grains are surrounded by white rings of siderite and the remaining part is more or less completely converted to pyrite. Titanite alters into marginal rutile with centers of calcite and chalcedony (Pl. XVII, *E*.) A latite-phonolite from the dump of the American Eagle shaft shows abundant cavities of dissolution filled with adularia, pyrite, rutile, and sericite. In one case tufted sericite coats the walls of the rounded cavity, which is filled with adularia.

A latite-phonolite from the 1,300-foot level of the mine is a greenish-gray rock with crusted veinlets of light-greenish dolomite containing calaverite; this is surmounted by fluorite crystals covered again by clear hyalitic silica. The metasomatic alteration is slight. Pyroxene crystals are converted to serpentine and chlorite with magnetite, and the latter, near the veinlets, alters to pyrite. Crystals of pyrite are distributed through the groundmass and sericite and adularia develop in the orthoclase, the adularia usually filling cavities of dissolution.

Another specimen from a very wide and rich part of No. 3 vein in the Vindicator mine, on level 11, is a greenish-gray latite-phonolite, in which some orthoclase crystals are visible. It contains much finely divided pyrite and seams of molybdenite and calaverite. While the seams are rich, the rock between them is considered as barren. The microscope shows a large amount of orthoclase, both as phenocrysts and microliths in the groundmass. Sericite and carbonate occur in moderate quantity

as very fine-grained aggregates. Analysis C on page 189 may be calculated as follows: SiO_2, 57.91; $CaCO_3$, 1.50; MgO, 0.33; FeS_2, 2.10; Na_2O, 0.45; K_2O, 13.35. Compared with analysis B it shows practically the same chemical result as analysis A. The great predominance of K_2O can not be explained simply by the formation of sericite, but the rock must contain an abundance of adularia.

METASOMATIC CHANGES IN BRECCIA.

The volcanic breccia is far more extensively altered than any of the rocks thus far described. Its great porosity, often equivalent to that of a sandstone, fully explains this; the various chemically active solutions easily penetrated this rock by diffusion and convection. In the central part of the district, where fissures are abundant, as on Raven Hill and Gold Hill, it would be very difficult to find any entirely unaltered breccia. On the northern slope of Bull Cliff and on Big Bull Mountain, where there are few mineral deposits, much of the breccia is practically unchanged, except for a consolidation and hardening which in any rock of this kind involves some chemical processes. Such breccia is free from pyrite and appears as a purplish to brownish rock, the individual fragments of phonolitic rock being clearly visible. Unaltered breccia also occurs to the southwest of the Golden Cycle mine in a long crosscut; here it is loose and sandy. Crosscuts north from the Vindicator and Isabella mines also run into unaltered breccia. In some kinds the angular fragments are several inches in diameter, while other breccias are very fine grained—in fact, look rather like unstratified tuffs. Granitic fragments of all sizes are plentiful at almost all places, but are naturally most abundant near the granite contacts. The altered breccia is a hard, bluish-gray or greenish-gray rock in which the individual fragments are sometimes difficult to observe. The most general change appears in the destruction of the dark silicates and their replacement by sericite, carbonates, and pyrite. Often a little residual serpentine is also seen. Pyrite is the commonest metasomatic mineral, and occurs widely distributed as very small crystals. The next mineral in point of abundance is a dolomitic carbonate sometimes also calcite, which replaces the cementing groundmass or any of the fragments and often shows roughly rhombohedral forms. Sericite in moderate quantities and some adularia appear in most altered breccias; the former partly, very rarely wholly, replacing the feldspars or the cement, the latter preferring the veinlets or the cavities of dissolution. Anhedral fluorite appears in sporadic development replacing groundmass, and sometimes contains inclusions of carbonates and secondary apatite (specimens 708, 709 C. C.). The porous cement of the breccias sometimes allows zinc blende and molybdenite to be deposited with pyrite. Calaverite also is known as a metasomatic mineral, for example, in the cement of a phonolite breccia from the W. P. H. mine, where it appears as irregular, soft, silvery-white grains. On the whole, the changes are entirely similar to those described in latite-phonolite.

A breccia from the Golden Cycle mine within the sheeted zone of the Legal Tender vein, between levels 8 and 9, is gray, hard, and fine grained, with abundant small and angular fragments of phonolitic rocks, in which the orthoclase microliths are almost the only remaining original constituents. There are also many small pieces of granitic feldspars and a cement of the same character as the fragments.

Small crystals of pyrite are distributed throughout the cement and the fragments, and carbonates have also developed abundantly in both. There is a moderate amount of very fine aggregates of sericite. No secondary adularia could be detected.

Partial analysis of altered breccia from the Golden Cycle mine.

[W. T. Schaller, analyst.]

SiO_2	54.57	K_2O	7.50
CaO	2.79	CO_2	3.42
MgO	1.06	S (total)	1.29
Na_2O	3.85		

This may be recalculated to SiO_2, 54.57; $CaCO_3$, 4.97; $MgCO_3$, 2.23; $FeCO_3$, 0.17; FeS_2, 2.42; Na_2O, 3.85; K_2O, 7.50, and shows that, though the substitution of K_2O for Na_2O has not been complete, the rock contains much more potash than would be expected from its intermediate position between the composition of a granite and a phonolitic rock. At the same time, there is as much pyrite and much more carbonates than in the altered latite-phonolite described from the Vindicator mine (p. 190). Some silica has been removed, while probably very little lime has been lost.

METASOMATIC CHANGES IN SCHIST AND GNEISS.

The gneiss is generally unaffected by hydrothermal metamorphism, but adjacent to veins some changes are often observed, as is well shown in specimens from the Abe Lincoln mine, consisting of a reddish gneiss with narrow seams coated by quartz combs and a little pyrite and calaverite. These seams are surrounded by a greenish bleached zone 1 or 2 inches wide, containing disseminated pyrite and looking almost as if it contained epidote.

Under the microscope the veinlets show much adularia, chiefly deposited along the walls and covered by quartz. In the rock itself, which is originally composed of quartz, orthoclase, and biotite, the latter mineral is the only one which has suffered extensive alteration, though the orthoclase contains some disseminated sericite. The biotite is transformed to dolomite with much crystallized pyrite and some of the peculiar light-green mica described on page 77. The latter gives the peculiar yellowish-green color to the rock. A little adularia, often with crystal form, is also present and in places it appears to replace biotite, a fact also observed in the granite ore. In the Bonanza King lode of the Midget mine pyrite, galena, and zinc blende sometimes replace fissured gneiss. Schist fragments occurring in breccia in the W. P. H. mine consist of quartz, sillimanite, muscovite, and magnetite. The only alteration observed is that the original magnetite is changed into pyrite and that irregular grains of calaverite have developed.

METASOMATIC CHANGES IN BASIC DIKES.

The various dark-colored basic dikes classified as monchiquites, vogesites, and trachydolerites are rarely seen in fresh condition, but are apt to form soft, greenish gray sheets in which the products of common hydrometamorphism and hydrothermal metamorphism may be superimposed. Calcite develops very abundantly, especially along the platy structure so often seen, but this is a common thing in dikes of this character and has not necessarily any connection with vein-forming agencies. Zeolites also form in many places, as do serpentine, epidote, talc, and iddingsite.

When mineralized the basic dikes become filled with minute crystals of pyrite and traversed by veinlets of quartz and calaverite. Sometimes calaverite forms metasomatically in the altered basalt. Specks and also larger bunches of galena and zinc blende develop in the basic dike of the Conundrum mine.

A peculiar variety of metasomatic alteration has affected portions of the principal basic dike in the Elkton mine, south of the main shaft. The altered rock is light gray, porous, and thickly sprinkled with minute crystals of pyrite. The porosity is due to numerous little cavities of dissolution which are lined with small white crystals. Similar crystals coat the walls of the irregular seams traversing the rock. The material of the dike shows no trace of its original structure and is evidently much altered.

The microscope shows that the dike has been locally changed to an aggregate of adularia, apatite, pyrite, sericite, and probably some calaverite. The apatite, which is remarkably abundant, is in slender greenish-white prisms of an entirely different habit from the stout smoky crystals characteristic of the latite-phonolite. The drusy crystals coating the pores and seams in the rock are adularia. No chemical analysis has been made of this material, but there has clearly been a considerable addition of potash sulphur and phosphoric acid to the original dike rock.

METASOMATIC CHANGES IN GRANITE.

The Pikes Peak granite, along the breccia contact from the Elkton to Stratton's Independence mine, is a reddish coarse-grained rock, noticeably deficient in dark constituents and frequently poor in quartz. It consists chiefly of microcline, some individuals of which are noticeably larger than the rest and give the rock a semiporphyritic appearance; besides microcline, some quartz, oligoclase, microperthite, orthoclase, and biotite are present, the latter often chloritized and containing a little magnetite and epidote. A typical analysis of the Pikes Peak granite contains SiO_2, 77.03 per cent; MgO, 0.04 per cent; CaO, 0.80 per cent; Na_2O, 3.21 per cent; K_2O, 4.92 per cent, but in the locality mentioned the amount of quartz is often smaller than would be indicated by the figures given, and the rock is rather a quartz-syenite, ranging over to a normal syenite, as shown by analysis A in the table on page 194.

Near lodes this granite is often subject to marked metasomatic change; the reddish color changes to a light gray; the rock contains disseminated pyrite, sphalerite, fluorite, and tellurides and becomes very noticeably drusy and honeycombed, the vugs being coated with the minerals just indicated. This is the so-called granite ore, which is of great economic importance in the part of the district outlined above. Penrose[a] noticed this ore, especially from Stratton's Independence mine, but assumed that the change involved consisted of the dissolution of quartz, leaving a porous mass of feldspar. The characteristic feature of this mode of alteration[b] is, however, the abundant solution of orthoclase and microcline and reprecipitation as typical adularia. The quartz grains are also attacked and newly formed quartz deposited together with adularia. The biotite is the first mineral to be replaced by various other minerals, among them pyrite, calcite or dolomite, fluorite, adularia,

[a] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 201.

[b] First described by Lindgren, W., Metasomatic processes in fissure veins: Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 656.

and roscoelite. Small pentagonal crystals of pyrite, as well as sphalerite, develop throughout the rock also; strings of these pyrite crystals joined by a thin sheet of quartz in some places penetrating the orthoclase. Light-colored sphalerite, intimately mixed with galena, occurs replacing orthoclase in ore from the Ajax mine. Small replacement veinlets as well as filled veinlets of adularia, quartz, and fluorite penetrate the rock and abundant irregular cavities of dissolution are coated with the same mineral associated with calaverite in well-crystallized form.

The secondary adularia is often deposited in optical continuity about the remains of original feldspars. Sericite occurs in shreds in the orthoclase, but forms no important part of the rock. When granular quartz is developed it often possesses the optical "flamboyant" structure characteristic of Cripple Creek vein quartz. Apatite remains unaltered. Particularly large masses of granite ore were mined at the Ajax mine and two specimens of closely contiguous altered and unaltered granite from this mine were analyzed.

Specimen 345 C. C., the analysis of which is shown under A in the table below, is a syenitic modification of the normal granite. It contains in the order of abundance, microcline, oligoclase, quartz, biotite, magnetite, apatite, and zircon. The oligoclase shows slight sericitization. The biotite is fresh.

Specimen 344 C. C. (analysis B), taken at a distance of 1 foot from 345, shows much of the original microcline and quartz, although newly formed adularia is also abundantly present. Pyrite is disseminated throughout the rock, but also forms by replacement of original magnetite. The oligoclase is partly sericitized, and the biotite is transformed into aggregates of pyrite, fluorite, adularia, and a yellowish-green mica, which, without much doubt, is roscoelite. A small quantity of calcite or an allied carbonate appears as nests in the microcline.

Analyses of fresh and altered granitic rock.

[Analyst, W. F. Hillebrand.]

	A.	B.		A.	B.
SiO_2	66.20	59.58	SO_3	None.	None.
Al_2O_3	14.33	16.00	Cl	Trace.	(?)
Fe_2O_3	2.09	.30	F	(?)	[a].69
FeO	1.93	.65	FeS_2	.12	[b] 4.78
MgO	.89	.03	MnO	.13	Trace.
CaO	1.39	2.03	BaO	.18	.11
Na_2O	2.58	.98	SrO	Trace.	.01
K_2O	7.31	11.93	Li_2O	Trace.	Trace.
H_2O-	.48	.32	V_2O_3	.....	.39
H_2O+	.83	.81	MoO_3	.....	.01
TiO_2	.65	.75		99.74	99.95
ZrO	.02	(?)	Less O	.....	.29
CO_2	.36	.26			99.66
P_2O_5	.25	.32			

[a] 1.42 CaF. [b] 2.55 S.

A (345 C. C.). Ajax mine, level 6.
B (344 C. C.). Ajax mine, level 6, 1 foot from 345.

The changes, as far as can be ascertained by a comparison of the analyses, involve a great loss of soda, which is more than compensated by an increase of over 4 per cent of potash. This corresponds to the development of soda-free adularia instead of sodic microcline and to the formation of sericite in the oligoclase. There is a distinct decrease of silica, which is probably carried away in soluble form. Magnesia is practically eliminated, while lime is slightly increased. Whether any actual addition has taken place is doubtful. Fluorine, vanadium, and molybdenum have been introduced. The iron remains constant, substantiating the statement made above that pyrite forms principally from the constituents of the rock. Little change is noted in titanium and phosphorus.

SILICIFICATION AND COMPLETE REPLACEMENT.

A silicification of the rocks along the veins is exceptional. It does not extend far from the vein, and is probably developed only in case of very porous or shattered rocks.

In several mines, and often associated with rich ore, occur small quantities of a dark, almost black, fine-grained and hard-vein material, which consists chiefly of quartz and pyrite, and which is probably due to replacement of detrital material or mud in which siliceous solutions could freely circulate. A drusy material of this kind from level 3 of the Isabella mine, 100 feet north of the Lee shaft, contains fine-grained quartz, with a little fluorite and abundant aggregates of pyrite, zinc blende, and molybdenite, as well as granular dolomite. A narrow, flat vein of this kind in an ore shoot on level 6 of the Abe Lincoln mine, in which gneiss is the prevailing country rock, consists of a granular mixture of quartz and idiomorphic adularia, abundant pyrite, grains of carbonate associated with felted nests of serpentine and sericite.

SEQUENCE OF PROCESSES.

The changes which have taken place in the rocks may be divided into those which are clearly and unquestionably caused by vein formation, as indicated by their occurrence along the lines of the mineralized fractures, and those affecting larger areas and less obviously produced by the solutions circulating on these fissures. Both Cross and Penrose[a] came to the conclusion that there were two or more epochs of alteration by hot waters and possibly also epochs of fumarole action by sulphuric acid, chlorine, and fluorine contained in the magma. They agree that the fissures and sheeted zones in the breccia could not have been produced in the soft and unconsolidated rock, and that, therefore, the general cementation and alteration of the breccia involving the formation of pyrite and sericite took place before the veins were formed.

Although this view has some supporting evidence, we can not fully subscribe to it. It is true that hot waters circulated through the volcanic rocks for a considerable period and that the solutions varied from time to time. Almost immediately after the explosive action had ceased the breccia must have been permeated by steam or superheated waters, and we hold that the rock pressure, together with the influence of this moisture, would have been sufficient to cement the loose mass in very short

[a] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 70, 161.

time, so that fissures could have been formed in it. But we believe that the widespread rock alteration in the breccia is so closely similar to that observed in veins that it was in all probability caused by the same or very similar waters, which we believe did not gain general access to the upper part of the volcano until breaks caused by the settling volcanic mass afforded them an ascending path.

Among the evidence offered by Penrose to substantiate the theory of an early period of metasomatism is the fact that the pyrite of the altered breccia rarely contains gold. The same thing applies, however, practically to all of the pyrite in the district, which, whether in veins or in rock, seems to contain an important amount of gold only when admixed with tellurides. The altered breccia is, moreover, quite commonly cut by little seams which may be rich in crustified tellurides. In the massive rocks, especially syenite and latite-phonolite, where the solutions circulated less easily, the localizing of general pyritization near the veins is much better marked than in the breccia.

EVIDENCE OF AQUEOUS ACTION.

In their general aspect the metasomatic changes in the rocks by the vein-forming agencies clearly indicate aqueous solutions. As long ago pointed out by Bunsen in his researches on the fumaroles of Iceland, and as recognized by Penrose,[a] the strongest evidence of this consists in the removal of certain constituents, such as lime and soda, which neither are volatile alone nor enter readily into combination with any gaseous solvents. Further evidence is afforded by the deposition in regular layers shown in the seams cutting the altered rock. The widespread occurrence of earthy carbonates as a product of alteration also points in the same direction as does the general mode of attack on the rock by the solvents. We believe it to be firmly established that the metasomatism has been effected by aqueous solutions. That gases, such as carbon dioxide and hydrogen sulphide, were present in abundance is indicated by the general distribution of calcite, dolomite, and pyrite through the rocks, but these gases were present dissolved in water. The H_2S might possibly have been replaced or aided by Na_2S, though the extremely wide distribution of pyrite rather points to an easily diffusible gas. Both Cross and Penrose[b] express their belief that some volatile compound of fluorine may have been present, especially to effect the deposition of fluorite and the formation of the peculiar replacements known as granite ore. We can not share this belief, holding that both cases can easily be accounted for by deposition from alkaline solutions.

OXIDATION.

With few exceptions, and these on Beacon Hill and Poverty Gulch, the telluride ores near the surface are always oxidized to a brownish, clayey material. This oxidation along the veins naturally extends to far greater depth than the general oxidation of the country rock, and a partial oxidation may be found even at depths of 1,200 feet. It is very common to find brown streaks, due to limonite, following the narrow seams of the lode, while the surrounding breccia or massive rock appears entirely free from oxidation.

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[a] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 160.

[b] Op. cit., pp. 69, 161.

ORIGINAL WATER LEVEL.

According to the few data available, the original water surface of the district stood at an elevation of about 9,500 feet in the western part. Doubtless it rose slightly underneath the Bull Cliff region, reached 9,557 (910 feet below the surface) in the Isabella mine, and is even reported at 9,730 (516 feet below the surface) in the Hull City mine. In the southeastern part of the district the original water level in the Portland stood at 9,459, or about 540 feet below the collar of No. 1 shaft; in Stratton's Independence at 9,576, or 274 feet below the surface; and in the Gold Coin mine at 9,403, or 368 feet below the surface.

ROCK OXIDATION.

As stated above, the general oxidation of the rocks does not correspond to the water level, but ceases long before the latter has been reached and usually at a depth of at most 200 feet below the surface; sometimes, and especially in the case of massive rocks, such as granite or latite-phonolite, fresh material appears a very short distance below the surface. At Stratton's Independence the oxidation of the breccia is only partial at a depth of 100 feet below the surface. To the general rule given above there are one or two notable exceptions. Over a large area on Globe Hill, embracing the Deerhorn, Lady Stith, Plymouth Rock, and Ironclad shafts the breccia is throughly oxidized and traversed by irregular systems of joints and short fissures. Globe Hill is opened in depth by the Chicago tunnel, the portal of which is located near the Abe Lincoln mine and has an elevation of about 9,700 feet; the total length is 4,200 feet and it extends to the vicinity of the Plymouth Rock shaft. For the greater distance from the portal the tunnel is in unoxidized breccia, but 1,200 feet from the breast evidences of oxidation begin to be apparent, and near the end, about 700 feet underneath Globe Hill, the breccia is entirely disintegrated, forming a soft, clayey, red material which necessitates stout timbering. This condition extends at least to the bottom of the Plymouth Rock shaft, about 150 feet below the tunnel level, or an elevation of 9,550 feet. Similar complete oxidation reaches at least to 700 feet below the surface in the Ironclad shaft. In the middle of this area is located the Deerhorn shaft, the lowest level of which is 565 feet below the surface. Exploratory crosscuts extend from this shaft 600 or 700 feet in several directions without change of formation. A mass of gypsum, with some fluorite and a little pyrite, is exposed in the lower 300 feet of the shaft (p. 284). Oxidized material appears to surround it on all sides. The explanation of this unusually deep oxidation is probably that extensive shattering preceded a local and very intense thermal-spring action, which by dissolving much material rendered the breccia so porous as to fall an easy prey to oxidizing processes. A somewhat similar case is that of the Wild Horse mine, where the shattered and pyritic granite breccia, as well as the vein contained in it, is entirely oxidized to a depth of 1,150 feet, or to an elevation of 9,500 feet.

VEIN OXIDATION.

In a very general way the depth of oxidation of the veins coincides with the depth of the water level, but here again there are numerous exceptions and qualifications to be noted. Fresh tellurides often occur high above the water level, especially in hard and massive rocks. On the other hand, partial oxidation is in many cases apt to extend for several hundred feet below that level.

At the Abe Lincoln and Beacon Hill mines unaltered tellurides appeared practically at the surface, as would be expected from the high stand of the water level at these mines, the elevations of which are 9,611 and 9,370 feet. But the same applied to the Gold King and C. O. D. mines, high up in Poverty Gulch, with elevations of about 9,850 feet. At the Moon-Anchor mine, on Gold Hill, oxidized ore extended down to the 600-foot level, or to an elevation of 9,200 feet. At the Doctor-Jackpot mine oxidation reached only a short distance below the surface in the Jackpot vein, while in the Doctor vein the ores were oxidized down to a depth of 650 feet below the surface, or an elevation of 9,078 feet.

On Bull Hill the water level should lie about 700 feet below the surface, or at an elevation of 9,600 feet, although no accurate observations are available because the region was drained by tunnels long before the shaft had attained its depth. At many of the small mines on this hill tellurides were, however, met much higher than 700 feet. The Zenobia vein is entirely oxidized down to a depth of 500 feet.

In the Last Dollar the veins are entirely oxidized above the 800-foot level, or above an elevation of 9,600 feet. Below this unaltered tellurides form the ore. The adjoining Modoc mine contains in places oxidized ore down to a depth of 1,000 feet, although some tellurides were found on level 2. The Gold Sovereign mine shows partial oxidation to at least 550 feet, and on that level one-half of the Lovett vein is almost fresh, while the other half is entirely oxidized.

The water level of the Isabella mine was probably 900 feet deep (elevation 9,557) and complete oxidation of the veins certainly reached that depth in the breccia, partial oxidation being noted at least 100 feet lower. But in the latite-phonolite of the Buena Vista incline, on the same vein, tellurides were found on level 2 and on the lower levels the vein is scarcely attacked by oxidation.

On the south slope of Bull Cliff both water level and vein oxidation are deep. At the Hull City mine partial oxidation reaches down to 850 feet below the surface, while the original water level is reported as being only 516 feet deep. At the Vindicator mine the first water was found at 500 feet, or at an elevation of 9,700 feet. All veins are oxidized down to this level, and to some extent even down to the 800-foot level. The country rock is chiefly massive latite-phonolite. In the Golden Cycle mine, where breccia predominates as country rock, energetic oxidation has penetrated to unusual depths. The natural water level is unknown, but was, at any rate, less than 800 feet below the collar. The surface elevation is 10,066 feet, and the original water level may be tentatively given as at 9,500 feet, or 566 feet below the surface. Vein oxidation goes, however, much deeper than this, for between the 800- and 900-foot levels the veins are almost completely oxidized; a small amount of tellurides is, however, found in many places. The deepest level, 1,000 feet below the surface, was under water at the time of visit.

The only generalization which can be safely deduced from all these data is that the limit of complete vein oxidation as a rule coincides with the water level, but that in many cases this process may partially, rarely completely, alter the veins for about 300 feet below this water surface. Owing to the peculiar conditions of underground drainage in Cripple Creek, it is unlikely that the water level has been subjected to great fluctuations. It may have been somewhat higher, but it is doubtful whether it ever stood much lower than when the district was first discovered, for, as stated in the chapter on the ground water, the volcanic mass holds water somewhat like a sponge in a cup. At any rate, no evidence indicating notable fluctuations can be adduced.

STRUCTURE OF THE OXIDIZED VEINS.

Thorough oxidizing decomposition will destroy the original structure of this vein. In sheeted lodes with many small parallel fissures and joints the latter may become effaced and the lode appears as a homogeneous brown, soft mass. In other cases a central seam may be retained and usually appears as a streak of soft, more or less impure kaolin; in other cases it may be filled by white compact alunite, more rarely by jasperoid or opaline silica. Crusts of comb quartz, if originally present, lie included in the clayey seams, but neither the original fluorite nor the carbonates are ordinarily preserved. Very rich oxidized ore sometimes fills the central cavities of the lode like a thick brown mud of limonite, kaolin, and quartz sand, and easily flows out when the vein is opened. Such material often fills the open seams in veins where the oxidation is only very partial, as in level 12 of the Gold Coin mine. When this level was unwatered, after having been allowed to fill up and stand for a long time, the floor was found to be covered by a thick mud up to 2 feet deep, which was said to have contained 2 ounces of gold per ton. The Dorothy vein here consists of one main seam in granite, coated with quartz, fluorite, and tellurides, besides some pyrite, zinc blende, and galena, and normally showing an open space in the center a couple of inches wide.

OXIDIZING PROCESSES.

In general oxidation tends to transform sulphides, sulphosalts, and tellurides to oxygen salts and native metals, both of which may, under certain circumstances, be further changed or carried away by surface waters. The silicates in the veins are changed to a few minerals most stable under atmospheric influences, i. e., kaolin, quartz, manganese dioxide, and limonite. The carbonates of the earthy metals are carried away in solution, while those of manganese and iron are changed to oxides. As waters of acid reaction, frequently containing free sulphuric acid, prevail during oxidation of vein deposits, original quartz will not be attacked. New silica, generally hydrated, may be deposited by solutions derived from the decomposition of the silicates.

The processes are more difficult to follow and to establish by means of analyses than those due to primary vein formation, for it seems to be a characteristic feature of oxidation to segregate the new minerals in larger masses and thus produce a less homogeneous product; this is no doubt due to the energetic action of oxygen

and of the acids set free, as well as to the increasing mobility of substance near the surface. Oxidation tends to thorough change of composition and also to obliteration of structure of the original rock or vein.

Of the metallic minerals the tellurides form the most important division. The bond between the tellurium and the gold is not a strong one, and direct oxidation very easily produces residual pseudomorphs of free gold and tellurium dioxide (the mineral tellurite), which in presence of iron oxides easily changes to various tellurites such as the yellowish-green emmonsite. In the Bonanza King lode of the Midget mine occur veinlets of pyrite with tellurides. Within 30 or 40 feet of the surface oxidation has changed the tellurides to specks of native gold, while pyrite remains practically unaltered. The tellurides in fissures and joints, which form the most common mode of occurrence, will be most easily oxidized, while those occurring as metasomatic products in the rocks are not so readily reached by the surface waters. An instance of this occurred on the rich pocket of the generally oxidized W. P. H. vein, 250 feet below the suface. Some of the tellurides are found here as replacement in schist fragments and remain partially fresh at this relatively shallow level.

Pyrite also is attacked without much difficulty, especially in the vein fissures, and yields sulphuric acid and ferrous sulphate, which is easily oxidized to ferric sulphates and finally into ferric hydrate and free acid. The sulphuric acid attacks kaolin and probably also sericite, forming segregations of such impure alunite as is encountered, for instance, in the Last Dollar veins (p. 377).

Small quantities of basic ferric sulphates are fairly common in the oxidized zone, but can rarely be referred to definite mineral species (p. 125).

The rapid oxidation of pyrite is well illustrated by bowlders of breccia, containing 2 per cent of finely distributed pyrite, such as were found in surface pits near the C. O. D. mine. The rock consists of a normal breccia of granite and phonolite, with much fine material. Angular fragments of phonolite are up to 2 cm. long. A dark-brown skin covers the surface of the bowlders and evidently consists of limonite. Underneath it lies a light-gray zone of breccia, up to 1 cm. thick, while the center consists of the normal dark-gray breccia. Examination under the microscope shows that the only difference between these zones is that in the outer light-gray layer the pyrite has completely disappeared without leaving any limonite. No other changes are apparent in the rock. The pyrite has evidently been oxidized to sulphates and these have been carried to the surface by capillary action, there to be changed to limonite.

Galena and zinc blende are probably somewhat less easily attacked than pyrite, but eventually become oxidized, and when changed to insoluble lead sulphate and zinc silicate may remain or even be somewhat concentrated into the altered mass.

The molybdenite oxidizes very readily to yellow and blue molybdite and ilsemannite, and these products do not seem to be easily carried away. Tetrahedrite yields various forms of oxidized copper compounds, which, as usual, show considerable mobility. No oxidized products containing antimony have been recognized. The fluorite upon exposure to oxidation loses its deep-purple color and becomes disintegrated. Eventually a part of it is dissolved in surface waters.

The altered rocks in the veins contain orthoclase, sericite, chlorite, dolomitic carbonates, and magnetite, together with a small portion of biotite, augite, and hornblende which have resisted the alteration due to vein-forming action. The most prominent product of oxidation is kaolin, which often becomes segregated in large, pure-white masses. The iron-bearing minerals are converted to limonite, and the manganese in the silicates, and especially in the carbonates, separates as earthy pyrolusite or as wad. During these processes some silica becomes converted to the soluble state, and there is reason to believe that the oxidizing waters in places are rich in this constituent. This was particularly observed in the Zenobia mine down to the 500-foot level, where a slimy opaline silica seems to be deposited at the present time. Another evidence is in the occurrence of residual pseudomorphs of gold after tellurides, the spongy gold showing a coating of opal. In places the silica will be deposited as chalcedony or jasperoid colored red in various tints by ferric oxide.

The reaction between free sulphuric acid and the earthy carbonates produces gypsum, which has been noted at many points in the oxidized ores. The large mass of this mineral in the Deerhorn mine is, however, probably not formed during oxidation, but is more likely a primary deposit by hot waters. By the same reaction epsomite (hydrous sulphate of magnesia) and mallardite (hydrous sulphate of manganese) will be formed, and, being very soluble, frequently form a coating or effervescence on the walls of the mine workings in the upper levels. Zinc sulphate occasionally enters into these complex salts. Hydrous sodium sulphate and aluminum sulphate appear in the same manner and are evidently formed by combination of sulphuric acid with the soda set free during processes of kaolinization. A little potassium is contained in these sulphates, but the greater mass of this substance is tenaciously held in the rocks. The vein-forming processes involve a development of potash micas and potash feldspars from silicates containing sodium, and also from the orthoclase. The same tendency seems to persist in the oxidized ore to some extent, though well-defined micas are not known to develop. It is a well-known fact that some phonolites upon weathering are apt to become richer in potassium and poorer in sodium.[a] At any rate, the sericite due to vein-forming action tenaciously resists oxidation.

A black or dark-green hydrous ferric sulphate is sometimes encountered as a soft filling of cracks and fissures of the oxidized zone. When dry it assumes a yellowish brown color, and is in all probability identical with chloropal or with the mineral morencite[b] recently discovered in the Clifton copper mines of Arizona.

Phosphates are sometimes found in considerable quantities in oxidized ores, indicating local concentrations during the process.

In 1894 Dr. Richard Pearce, of Denver, contributed some important notes to the subject of oxidation of Cripple Creek ores.[c] He examined a specimen of ore from the Moose mine, evidently a partially replaced volcanic rock, one half of which was oxidized while the other half had remained fresh.

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[a] Roth, Allgemeine Geologie, vol. 2, p. 255.
[b] Am. Jour. Sci., 4th ser., vol. 18, December, 1904, p. 455.
[c] Proc. Colorado Sci. Soc., vol. 5, 1894–1896, pp. 11–16.

Partial analyses of oxidized and fresh ore from the Moose mine.

[Analyst, F. C. Knight.]

	Unoxidized portion.	Oxidized portion.		Unoxidized portion.	Oxidized portion.
Silica	56.70	50.55	Sulphur	4.75	.....
Alumina	19.35	19.93	Sulphur trioxide	.....	2.55
Iron	4.20	.....	Tellurium	.10	.....
Ferric oxide	.....	10.57	Tellurium oxide (TeO)	.....	.79
Magnesia	.37	.12	Silver	.022	None.
Alkalies (by difference)	13.967	12.131	Gold	.041	.049
Manganese dioxide	.....	.27			
Water	.50	3.05		100	100

In the fresh portion only 1.35 per cent of the alumina was soluble in hydrochloric acid, while in the oxidized portion 3.18 per cent proved soluble. In the latter a hydrated basic ferric sulphate was proved to be present.

In order to obtain further light upon the results of oxidation, some very rich, wholly oxidized ore from a vein in the breccia on the 100-foot level of Stratton's Independence mine was obtained through the kindness of Messrs. C. M. Becker and W. N. Travell, of the mine staff. The soft, dark-brown, powdery ore in two samples from different places was subjected to analysis by W. F. Hillebrand with the following result:

Analyses of oxidized ores from Cripple Creek.

	1.	2.		1.	2.
SiO_2	.....	54.45	Bi_2O_3	0.0025	0.0025
TiO_2	.....	.80	MoO_3	.018	.008
Al_2O_3	.....	14.45	TeO_2	.36	.19
Fe_2O_3	.....	[a] 9.94	Au	.35	.52
MnO_2	.....	[b] 1.71	Ag	None or trace.	.02
CaO	.....	1.14	SO_3	.....	.10
MgO	.....	.48	P_2O_5	.....	.50
K_2O	.....	9.96	H_2O	.....	Not estimated.
Na_2O	.....	.41	CO_2	.....	Trace.
ZnO	.....	[c] .53			95.4205
CuO	0.03	.03			
PbO	.....	.18			

[a] Both Fe_2O_3 and FeO present. [b] Both MnO_2 and MnO present. [c] Possibly high.

There are no sulphides. The difference is largely made up of combined water.

From the analyses and from what is known about the normal composition of unoxidized ore the following conclusions may be drawn, although it is of course realized that much more analytical work would be necessary for an exhaustive treatment of this difficult subject.

During oxidation the percentage of silica decreases moderately, probably by solution of silica set free during the decomposition of silicates. Alumina remains fairly constant, though it may locally concentrate to pure kaolin. The iron is apt to locally increase by concentration as limonite, though a part will be carried away as sulphate. Small amounts of lime and magnesia are probably leached from the

rock, but the quantity is not greatly changed. Manganese is greatly concentrated, locally, on the seams of the rock. As to alkalies, the accumulation of potassium begun during the vein-forming process is continued or at least maintained during oxidation. Pyrite is converted into sulphuric acid and sulphates, and the percentage of sulphur is greatly decreased in the oxidized ore. Part of it remains as sulphate, but as there appears to have been no corresponding decrease of the bases it would seem likely that a considerable part of it was carried away as free acid. Little change is noted in the titanium, while phosphoric acid and zinc appear to have increased. The small quantities of other metals do not seem to differ notably from those observed in fresh vein material (p. 172). An increase of water to 3 or 5 per cent is a natural consequence of the formation of kaolin and other hydrated salts; locally it may increase up to 14 per cent, which is the amount contained in pure kaolin.

INFLUENCE OF OXIDATION ON GOLD, SILVER, AND TELLURIUM.

In gold-quartz veins of the ordinary type it is common to find a very decided enrichment in the oxidized part of the deposit, due chiefly to a considerable reduction of volume of the ore by solution and removal of many of the constituents, mainly of the sulphides. In some cases a solution and reprecipitation of gold may have taken place, but this is assuredly not the rule. It is also common to find that a very decided leaching of silver has taken place in the upper part of oxidized veins containing this metal, and this leaching is often accompanied by deposition of chloride or native silver at moderate depth, and by argentite and other secondary silver-bearing minerals in a zone a short distance underneath the water level.

There is little indication of any decided enrichment of the oxidized ores in the Cripple Creek district. Owing to the structure of the veins and the small quantity of sulphides present, the reduction of volume of the oxidized veins is very slight; in fact, under certain circumstances an increase of volume may take place. The fresh telluride ore is apt to be extremely rich in places and high-grade pockets occur impartially in oxidized and fresh portions of the veins. The richest ore ever shipped from the district came from a depth of about 500 feet in the El Paso mine, where almost no oxidation occurs, even at the surface.

Whether a slight enrichment has taken place or not is not easy to decide. We incline to the belief that the oxidized ores as a whole are somewhat richer than the corresponding telluride ore. The results obtained by Pearce on the specimen from the Moose mine mentioned above (p. 201), one-half of which was oxidized, tend in the same direction. The fresh portion contained 12.24 ounces gold per ton, while the oxidized portion yielded 14.58 ounces. This difference may, however, simply depend upon unequal distribution of the gold.

Regarding the silver there is more decided evidence of leaching. Much silver occurred in the oxidized portions of the Moose and the Blue Bird veins, but there are no data from the production of the mines to show whether any leaching has taken place. Pearce's results would seem to indicate that a removal of silver had taken place during oxidation, for in the fresh ore he found 6.7 ounces silver per ton, while none was contained in the oxidized portion. The analyses of the oxidized ores of Stratton's Independence tend also to show a removal of silver, as does the fact that

the free gold of the ordinary oxidized ore is very often entirely free from silver. Possibly, as suggested by Pearce, the silver has been dissolved by ferric sulphate.

No evidence has been found to show that any part of the gold set free by oxidation has been dissolved and reprecipitated. The silver dissolved from the oxidized ores should be deposited as chloride and native metal just above or as sulphides below the water level. No evidence has been found that this process has taken place. The quantity of silver in the veins is, however, usually very small.

The analysis quoted in the paper by Pearce contains in the oxidized portion far more tellurium in oxidized form than would be required to form tellurides with the gold and silver. If this were a general fact it would indicate that a part of the gold had been dissolved. The two analyses by Hillebrand of samples from Stratton's Independence mine (p. 202) show, on the contrary, a very considerable deficiency of tellurium, and it is in fact easily to be comprehended that the relatively soluble oxidized tellurium compounds could have been carried away or locally concentrated.

SECONDARY SULPHIDE ENRICHMENT.

If oxidation of a deposit is accompanied by leaching of one or more metals, like copper, silver, or lead, by surface waters, it sometimes happens that the materials dissolved from the oxidized part of the veins will be precipitated as sulphides at a lower elevation, and generally just below the water level.

In districts where this so-called sulphide enrichment is known to have taken place the ore minerals exhibit in general an orderly sequence, both in relative abundance and in kind, from those characteristic of the most highly enriched ore to those constituting the original lean and unaltered ore. The secondary minerals produced are such as can result from rearrangement and concentration of elements present in different combinations in the primary ores. At certain points within this range of alteration it is possible to detect direct mineralogical evidence of the change of one mineral to another, effected by solutions moving downward from the zone of oxidation. In most cases the secondarily enriched ores bear a recognizable relation to the lower limit of oxidation.

Careful study of the Cripple Creek ore deposits has failed to discover that the hypothesis of secondary enrichment is supported by crucial evidence of the kind just indicated. The minerals are not arranged in any discoverable sequence, nor does the present investigation find anything to support the view that the rich telluride ores, as a rule, pass with increasing depth into low-grade pyritic ores. Frequently such ore as occurs below a depth of 1,000 feet is precisely the same in character as ore found within 100 feet of the surface. Tetrahedrite, which has been regarded by some, without definite proof, as a secondary mineral, occurs sporadically throughout the district and at all depths reached by present workings. No particularly rich ore occurs immediately below the oxidized zone. Briefly, no evidence has been found indicating that sulphides or tellurides have been formed in or below the oxidized zone by deposition of material dissolved by surface waters.

CHAPTER X.—THE ORE SHOOTS.

It is well known that the payable ores in auriferous lodes are rarely equally distributed in the lode, but form tabular bodies of more or less regular outline. The projections of these ore bodies on the plane of the lode often appear as elongated areas with greater vertical than horizontal extent. The ore bodies or shoots of Cripple Creek show great similarity to those of other gold-bearing veins; their limit in depth is usually as well defined as their extent in a horizontal direction.

The opportunities for the study of ore shoots have been exceptionally good in this district, as will be seen from a perusal of the detailed descriptions. If with all these observations there remain many doubtful and unexplained points in their occurrence, this must be laid to the great inherent difficulty of the subject. The deposition of ores depends not only on structural features, but also on imperfectly known laws of precipitation from complex solutions at high temperatures and pressures.

DIMENSIONS AND PITCH OF THE SHOOTS.

The general statement that the ore shoots are tabular bodies is based on the fact that the ore follows vein fissures and sheeted zones, and that consequently the thickness may be considered constant. In reality the thickness varies considerably. In some veins almost the whole value is concentrated in a central seam, although a width of 3 feet must be extracted on account of mining requirements. The most common case is that while the greater values are in one or two central seams a number of others also contain friable ore, which is extracted by screening the whole thickness taken out, say 4 feet. Frequently, however, the width containing valuable seams increases to 10 or even 20 feet, while in exceptional cases of many coalescing sheeted zones the stopes may attain a width of 50 feet, as in the Captain veins of the Portland mine. In gold-bearing veins consisting of thick quartz filling it is not uncommon for a certain width of this vein to contain the valuable ore, while the remainder may be of very low grade. Such a condition, which is apt to be caused by a reopening of the vein fissure and attendant enrichment, does not often occur in this district. A somewhat similar state of affairs has been observed in the Blue Bird mine, where the ore in places follows spar veinlets which are later than the main filling of "purple quartz."

If we assume that the shoot has an elongated, narrow shape, as usually is the case when projected on the plane of the vein, its geometrical relations may be designated as follows: Width or thickness, breadth, stope length, pitch length, and pitch. The thickness or width has already been discussed; the stope length is the distance along the drifts over which payable ore extends; the pitch length, or axial length, as it might also be termed, is the distance between the two extreme ends of the shoot; the pitch is the angle which the pitch length makes with the horizontal; the breadth is the horizontal width multiplied by the sine of the pitch.

The stope length is subject to great variations. In small shoots it may be but a few feet, while in the majority of ordinary ore bodies characteristic of the camp this dimension ranges from 50 to 300 feet. In exceptional cases, as in the Elkton and Mary McKinney veins, the stope length is 1,700 or 2,000 feet. Owing to the prevailing steep pitch there is little difference between the breadth and stope length. The pitch in the great majority of cases is steep, ranging from 45° to 90°, and is generally northward, but there are also a number of southward-pitching shoots. In some mines adjoining veins have shoots of opposite pitch. Thus in the Midget mine the Cobb ore shoot pitches 45° NE., while in the Bonanza King vein the pitch is 60° SW. A southward-pitching shoot is also found in the Hoosier, Ironclad, Pinnacle, and Joe Dandy mines. Reversal of pitch is sometimes observed. In the C. O. D. mine the shoot, with an average horizontal length of 100 feet, pitches 40° S., but below level 6 turns and becomes inclined northward, at the same time decreasing in value. A similar case was observed in the Granite mine, where the principal shoot, with a greatest stope length of 350 feet, pitches north from level 5 to level 7, while below it turns southward. The greatest thickness is 30 or 40 feet. In case there are several shoots in one lode, these do not necessarily have the same form nor the same pitch.

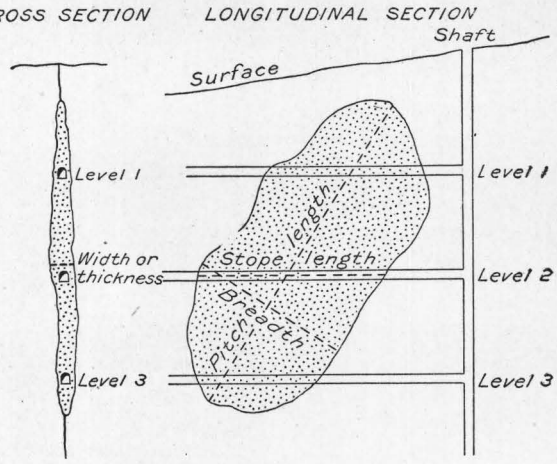
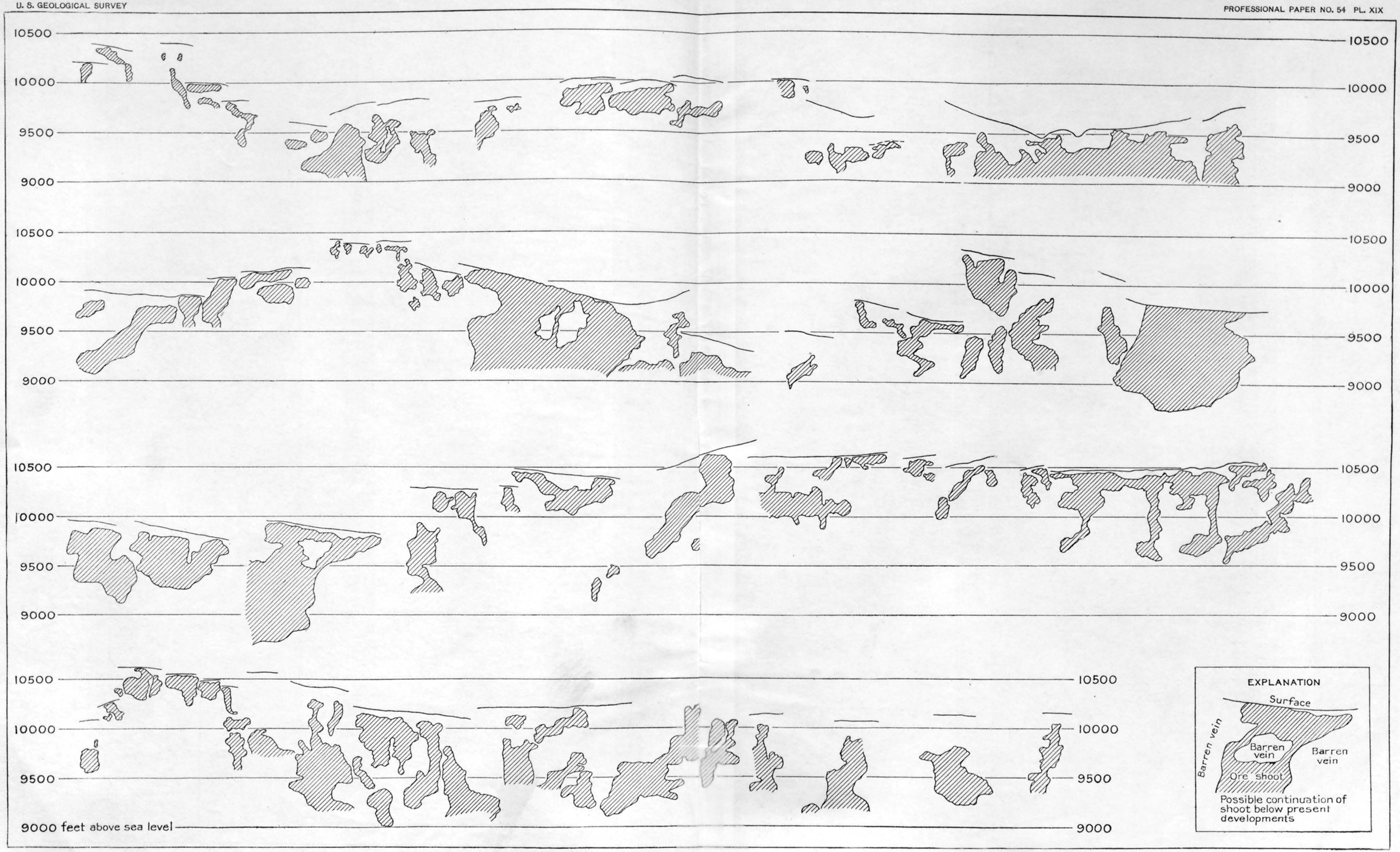


FIG. 14.—Diagram illustrating use of terms in descriptions of ore bodies.

The pitch length of the shoot varies greatly. An average in the more important mines would probably be 500 feet, but this is very considerably exceeded in many cases. The Lillie-Vindicator and the Stratton's Independence-Portland shoot (of the Independence No. 2 vein) are the longest actually proved, having attained 1,500 feet. The Cheyenne shoot of the Isabella mine is 1,250 feet long, and the same figures are recorded in the Wild Horse shoot. In other mines, like the Mary McKinney and the Elkton, the true length is as yet undetermined. It is necessary to distinguish between absolute and truncated pitch length, the latter term applying to those shoots which have been truncated by erosion. The Cheyenne shoot of the Isabella mine is one of the few larger ones in which the absolute length has been measured.

GENERAL FORM OF THE SHOOTS.

The preceding discussion has assumed that the ore shoots have the normal elongated form which is ordinarily characteristic of them. There are, however, many exceptions, as will be seen from Pl. XIX, which represents the outlines of a great number of Cripple Creek ore shoots. Ordinarily the ratio of pitch length and breadth for the ore shoots varies from 2 : 1 to 3 : 1. In the ore shoots which



SHAPE AND VERTICAL RANGE OF SOME OF THE PRINCIPAL ORE SHOOTS OF THE CRIPPLE CREEK DISTRICT, SHOWN IN LONGITUDINAL PROJECTION.

begin distinctly below the surface the elongated form is more strongly accentuated, the ratio between pitch length and breadth varying from $1\frac{1}{2}$: 1 to 5 : 1.

A few of the large ore shoots are practically equidimensional. This is more generally the case with the small shoots and here the horizontal extent is in a few instances greater than the vertical.

Sometimes the outlines are wholly irregular, and as the exact limit between what are considered the payable and barren portions of the vein is an arbitrary one, depending on local facilities and price of production, areas are often left unstoped in the middle of a shoot which properly belong to it. The Gold Coin mine, for example, has stoped squarely up to the line separating this mine from the Dead Pine mine. The smaller Dead Pine mine, however, can not work this ore, which here happens to to be low grade, so that stope maps give the false impression that the Gold Coin ore body ends at the Dead Pine line. Where the shoot has its normal elongated form it is very common to find little pockets or irregular masses of ore just above and below the points where it begins or ends. Thus, in the Isabella mine, small masses of ore were frequently found in the lower levels underneath the places where the ore shoot is developed in force above. The same is observed at many other mines and may in fact be considered as a general rule.

The outlines of the shoots are not usually limited by fissures or seams. Penrose describes such a case from the C. O. D. mine, and similar cases may be noted here and there. In the Gold Coin mine, for instance, the Cashen fault is the dividing line between the barren and the productive zone. Ordinarily, however, there are no such limiting seams. On the contrary, the ore gradually grows thinner and poorer toward the outside, begins to get bunchy, and finally ceases altogether, while the vein may continue as before in its general character, except that the calaverite is absent. Frequently, however, the limit of the ore shoot is attended with diminution in the width and strength of the sheeted zone.

When one ore shoot ceases in depth it is often observed that another one, somewhat overlapping, is apt to come in on an adjoining fissure. In some lodes the ore shoot as a whole is really a succession of imbricated bodies on adjoining planes.

Thorough exploration of the surroundings of a prominent ore shoot will probably be rewarded by the discovery of smaller bodies underneath, in the main direction of pitch.

RELATION TO SURFACE.

Of 60 pay shoots of Cripple Creek mines plotted together for purposes of comparison, 30 extend from the surface to a depth of less than 500 feet. The maximum individual production of these is less than $1,000,000.

Near 6 of these ore bodies further exploration developed new shoots below the old ones, but usually of smaller extent. In practically all 30 cases the development work had been carried down a few hundred feet below the last ore of the surface shoot. The form of these smaller shoots is often equidimensional; in a few cases the horizontal extent is greater than the vertical, or the shoot is wholly irregular; in many cases the shoot pitches steeply northward on the plane of the vein and the ratio of vertical to horizontal extent is 2:1 or 3:1.

In 8 of the 60 cases the shoot extended from the surface to a depth of 1,000 feet, or a little more, and ended. Further development to about 1,500 feet failed to find new shoots of any importance, though small pockets were often discovered. In 6 of these 8 cases the ratio of vertical to horizontal extent varies from 3:1 to 5:1, and the shoots usually pitch northward at angles of 60° to nearly 90° from the horizontal. In the remaining 2 cases the shoots have about the same horizontal as vertical extent. The maximum horizontal length is 1,300 feet, while 400 is much more common. In 2 of the 60 cases the pay shoot is 1,500 to 2,000 feet long, maximum depths of 600 and 1,000 feet having been attained and the bottom level being still in ore. In 13 of the 60 cases the shoot began over 200 feet below the surface; in 8 of these the bottom of the shoot has been reached, while in 5 the lowest level is still in ore. Steeply dipping, irregular elongated forms prevail. Many of this group of 13 represent veins parallel and close to those on which pay shoots outcropping at the surface were found.

These statements will give an idea of the form of the shoots. Of course, in the case of shoots reaching the surface, a certain part has probably been removed by erosion. Judging from the shoots which distinctly began below the surface, the normal form of the ore bodies is elongated, vertical, or pitching sharply northward, the ratio of vertical to horizontal extension varying from 1½:1 to 5:1. Some of these shoots are, however, of about equal dimensions, vertically and horizontally, while in a few the horizontal dimension is the greater.

RELATION TO COUNTRY ROCK.

In general the influence of country rock on the ore is very slight, and the causes governing the variations which may be detected are more apt to be due to physical differences relating to the fissuring in the various kinds of rock than to any chemical characteristics influencing the ore deposition. Ore shoots occur in all of the various rocks cut by the vein, granitic as well as phonolitic. The best ore shoots are found in breccia, and this is probably due to its greater permeability and the greater width of fissuring in this rock. Very large ore shoots are, however, also inclosed by latite-phonolite and syenite, as well as by granite. As instances of the latter may be cited the granite slopes in the Ajax, Portland, and Gold Coin mines, while the very important ore shoots of the Vindicator mine are almost exclusively contained in latite-phonolite.

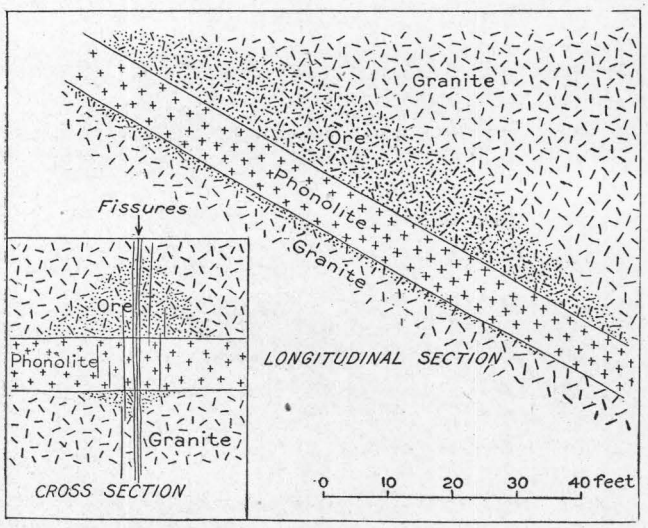


FIG. 15.—Cross section and longitudinal section of pay shoot in Prince Albert mine, showing its relation to phonolite sheet.

Between the Findley and Hull City mines the ore shoot leaves breccia and enters into latite-phonolite without marked change in composition or value. On the other hand, latite-phonolite and syenite are notably unproductive in the Portland mine (Pl. XXVIII, p. 434).

The relations of ore shoots to bodies of phonolite are sometimes significant. In some places the ore shoots are enriched when entering phonolite, while in other cases they are distinctly and markedly impoverished. In the Elkton mine the flat ore body corresponds roughly to the outline of a body of phonolite in which it occurs between two lines of vertical fissures 120 feet apart. The ore in this case is confined to this flat body of phonolite. An interesting case showing the localization of an ore shoot by a phonolite sheet is shown in fig. 15 (p. 208), representing a pay shoot in the Prince Albert mine on Beacon Hill. In this case a vertical fissure system intersects a flat dike of phonolite in granite. The ore has accumulated on the upper side of the dike, while below it there is only a very small quantity. It appears very much as if the solutions were locally descending and as if contraction of the fissures in the more resistant phonolite prevented the active circulation and induced precipitation on its upper side. An instance somewhat similar to this, but on a much larger scale, occurred in the Isabella mine; the Cheyenne ore shoot is suddenly cut off just below level 10, where the fissure leaves breccia and enters into a hard, compact phonolite. The richest part of the whole shoot was found here, resting immediately on top of the thick sheet of phonolite. Similar relations are said to have obtained in the adjoining Victor mine.

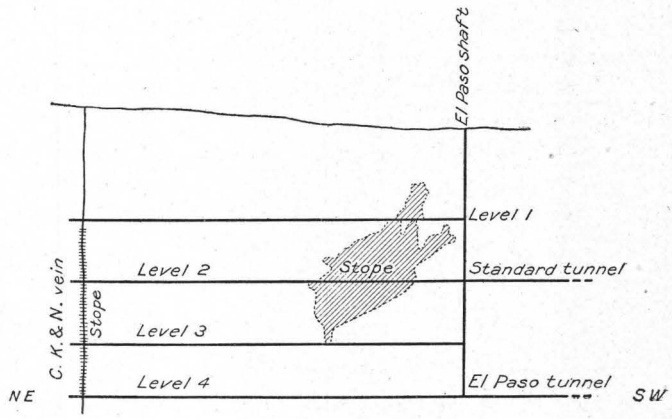


FIG. 16.—Longitudinal section of the El Paso vein, showing form of ore body at intersection with phonolite dike.

The ore body of the El Paso lode on Beacon Hill has the form of a flattened ellipsoid lying against the under side of a phonolite dike, its longest axis pitching northeast with the general line of intersection of lode and dike. In this case also the dike probably limits the ore shoot by reason of being less permeable to the solutions than the surrounding granite.

RELATION TO INTERSECTIONS.

The factor which most obviously influences the position and extent of ore shoots is the intersection of veins with one another or with "basic" or phonolite dikes. That such intersections are favorable to the development of ore shoots must be regarded as a well-established law in this district, as well as in many others. In some cases it is found that intersections of two veins have an adverse influence

on the ore shoot, locally depressing the values or wholly eliminating them. This, however, is exceptional.

Although the location of ore shoots is so strikingly dependent upon intersections of veins that it might at first glance be considered as the only factor influencing the distribution of the ore, this as will be seen further on, is by no means true. The ore shoots occur very commonly on intersections of veins, but this is observed chiefly in the case of smaller shoots and in smaller mines in which fissures intersect in various directions. The largest ore shoots in the camp can not be explained by the simple intersection of two or more fissures. In the occurrence of these smaller ore shoots along intersections the so-called "flats," or gently dipping joint planes, are of especial importance, as bodies of ore are very frequently found where they cross the vertical or steep fissures. In some cases the pay ore occurs exclusively in the "flats," but very close to the intersection, while in other cases the ore is contained chiefly in the steep veins and is suddenly cut out by gently dipping seams. Some very large bodies of ore have been found on these flat seams, which in themselves are rather inconspicuous. In the following paragraphs a few examples from among the more important mines of the district will be given in order to illustrate this remarkable dependence of shoots on intersections.

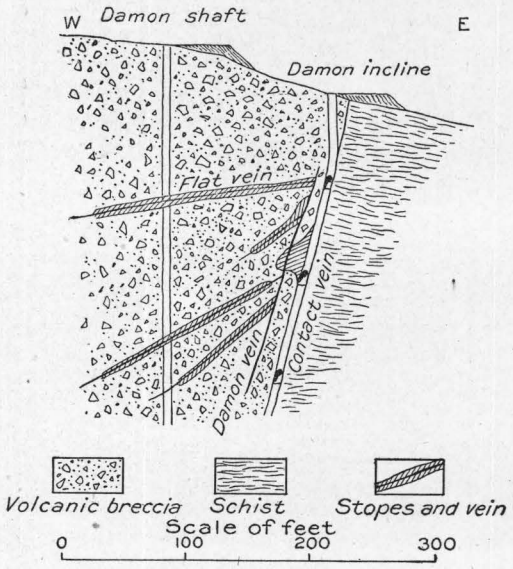


FIG. 17.—Diagram of veins and stopes in upper levels of Damon mine.

In the Abe Lincoln the pay shoots now worked occur southeast of the shaft at the intersection of two or more of the individual, indistinct, and not very persistent fissure zones in gneiss.

In the Jerry Johnson little ore was found down to the 300-foot level. At this place an ore shoot about 80 feet long occurred along the vein, but was cut off 40 feet above the level by a flat seam. A similar flat seam cut off the values in the W. P. H. vein. In other parts of the mine, however, the flat veins carry some ore. At the Damon mine (fig. 17) the principal ore bodies were found on several flat veins near the place where these intersected or joined a steep-dipping fissure.

In the Howard flat vein an ore body, in places 6 feet thick, occurred where this vein was intersected by a perpendicular fissure. In the same vicinity the Work lode contained ore where it intersected No. 2 Mary McKinney lode. On the Anaconda adit level the breccia contains many fissures of various strikes and dips. Where two or more intersect there is usually a small body of ore.

Although the main ore body of the Mary McKinney mine has no apparent connection with crossing fissures, many instances of the rule here discussed may be found in the northern part of the mine at the intersection of lodes. The Le Clair

mine contains ore at the intersection of the Peggy vein with the north-south fissure. An ore body at the intersection of a sheeted zone with a dike in the Elkton mine is shown in fig. 36 (p. 338).

Bull Hill also presents many examples. In the War Eagle mine the ore occurs in flat veins, but only along the intersection of these with the steep-dipping War Eagle vein. The Ramona vein in the same mine shows, however, an anomalous behavior; a small pay shoot occurring on it is abruptly cut off by a watercourse crossing the vein. A similar case is observed in the Sheriff mines, where small shoots are cut off by flat quartz seams.

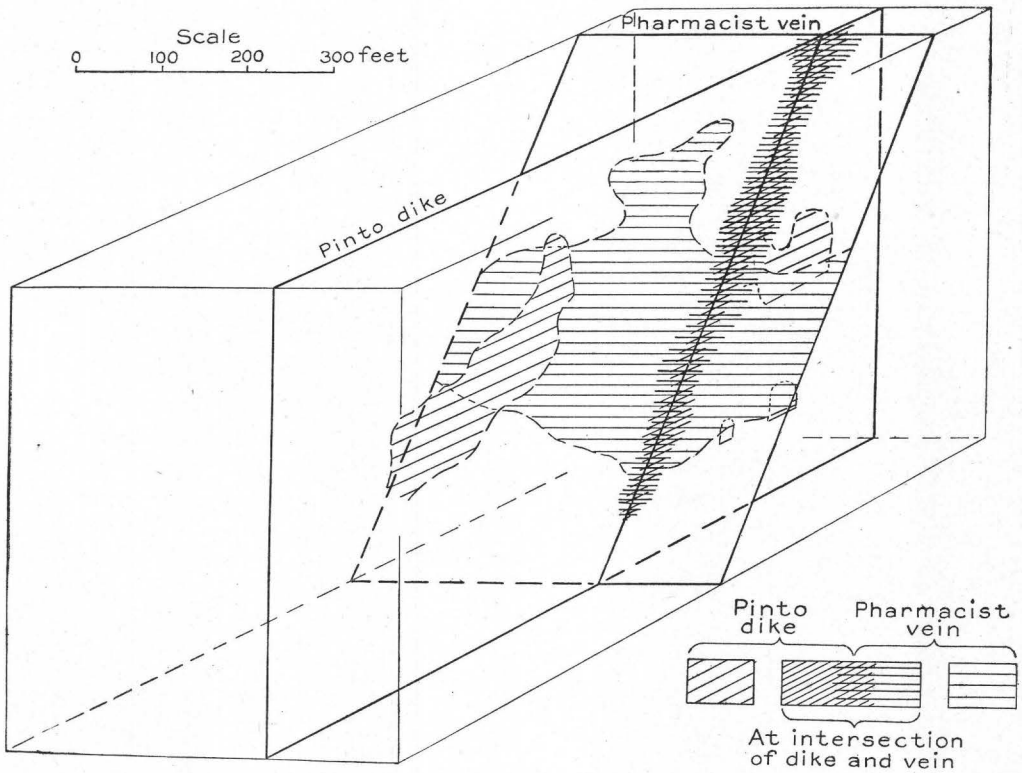


FIG. 18.—Stereogram of ore shoots on the Pinto dike and Pharmacist vein in the Pinto and Wrockloff mines.

The New Haven and Mary Ann mines show many illustrations of this principle. In the latter the intersection of flats with the north-south steep-dipping vein produces ore. Smaller bodies of ore were also found at the triple intersection of fissure systems. In the Ida May ore occurred in the basic dike, particularly where fissures came in from the walls.

The Gold Sovereign, Whisper, and Dante mines contain many small ore bodies, most of which are dependent upon intersections of the complicated system of fissures which are found in these properties. In the Trail mine close by the intersection of two veins is said to have made the best ore in the mine. In the Dexter a good body of ore occurred where the Fluorite and Manganese veins unite.

Intersection of a vein with a narrow perpendicular seam gave a couple of carloads of good ore.

The long Orpha May vein, traceable from near the American Eagle shaft for a mile southward into the Modoc property, offers perhaps the best example in the camp of the influence of cross fissures on long lodes. Penrose states that in the Orpha May mine, the most northerly on the lode, the shoots were narrow, but more likely to occur wherever cross fissures intersected the vein. In the Rubie a long, narrow shoot occurred where an east-west vein intersected the Orpha May. It is illustrated best of all in the Last Dollar mine, in which the most important shoot follows the intersection of cross veins with the main vein. In this case some ore is also contained on the former, but rarely extends more than 40 feet from the main vein. Further interest is given to this occurrence by the difference in ore carried on the two kinds of veins, the cross veins being rich in pyrite, zinc blende, and tetrahedrite, while only normal calaverite ore occurs on the main vein. Very similar conditions are observed in the Modoc mine, though the difference in ore is not so marked here.

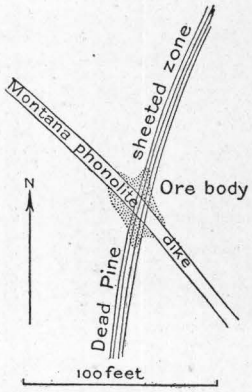


FIG. 19.—Plan showing occurrence of ore bodies at intersection of sheeted zone and phonolite dike in Dead Pine mine.

Between the Isabella lode system and that of the Vindicator lie a number of cross fissures, most of them having a northeasterly strike. In the mines located on these veins a number of interesting occurrences may be observed. In the Empire No. 2 vein one pay shoot is clearly the result of the intersection with the Buena Vista vein of the Isabella system. At the Pinto mine the intersection of the Pinto dike with the Pharmacist vein produces an important and rich shoot (fig. 18). Another on the same vein lies at the intersection of the Pharmacist and the Zenobia. In the Deadwood mine intersection of vein systems is clearly connected with the occurrence of the ore.

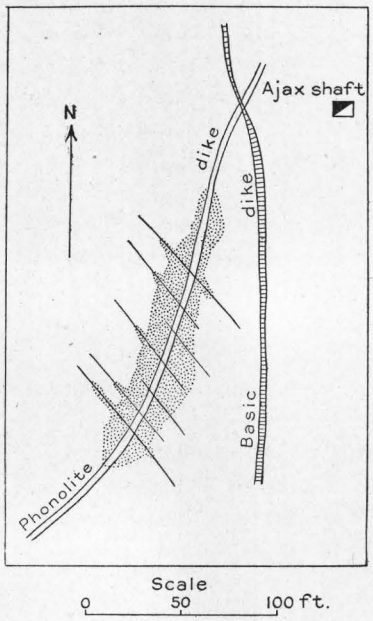


FIG. 20.—Diagrammatic plan showing occurrence of ore body in granite on level 5, Ajax mine.

As a rule no influence of cross fissures can be observed in the great pay shoots of the Vindicator system. In one case, however, at the north end of the Findley, a small but rich shoot occurred at the intersection with an east-west cross vein. Where the same vein crossed the adjoining and parallel Shurtloff vein the pay contained on the cross vein became locally impoverished.

In the Golden Cycle mine the shoots are not, as far as can be observed, dependent on crossings. Frequently, however, the richest ore occurs at splits in the principal veins. This is illustrated in both the Legal Tender and the Revenue systems.

Few examples of this rule may be derived from the Portland and Independence mines. In the latter, however, the flat ore body occurring between levels 3 and 5 may be regarded as a special case of the local expansion of ore bodies at the intersection of perpendicular veins with horizontal flats.

The description of the Granite mine shows that in all cases unusual width of ore is associated with intersections or junctions of main lode with minor fissures. In the adjoining Dillon mine ore occurs chiefly in bunches at the intersection of sheeted zones. An example from the Dead Pine mine is shown in fig. 19.

The Ajax mine is characterized by the presence of large and irregular bodies of replacement ore in granite. The occurrence of these shoots is clearly related to the intersections of the two northeast-southwest phonolite dikes with the numerous northwest-southeast fissures (figs. 20 and 21).

The Sunset-Eclipse mine, on the west side of Squaw Mountain, offers an illustration on a small scale. A body of ore occurs here at the intersection of three fissure systems.

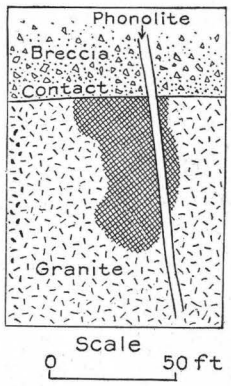


FIG. 21.—Plan of an ore body in granite, level 4, Ajax mine, showing influence of contact between granite and breccia and phonolite dike in determining the place of ore deposition.

All these examples, the number of which could be greatly increased, show clearly that deposition of tellurides is strongly and most favorably influenced by intersections of fissures. A mingling of different waters may obviously have occurred at such intersections and it is almost self-evident that such conditions might easily either excite or check the precipitation of certain compounds dissolved in the waters.[a]

The different mingling waters may well have come from one source, although by traveling separate ways for a distance their character may have been sufficiently changed to influence the precipitation of some compound.

OTHER FACTORS.

A close study will soon convince one that the ore shoots directly due to intersection are usually the smaller ones, and that although this factor is almost obtrusively present, it is by no means the only one nor the most important. Examples of ore shoots apparently entirely independent of intersections would include the largest shoots in the camp. Among them are the Mary McKinney, Elkton, Moose, Vindicator, Golden Cycle, Hull City, Findley, Isabella, Portland, Stratton's Independence, and Victor.

It might be suggested that here, too, intersections are the cause, but that they have not been observed. This, however, is improbable, for either the miner, who is very much on the alert for just such features, or the geologist should easily have recognized them. The great size of the bodies and the even distribution of the ore forms another argument against such a supposition.

We believe that in these cases other causes favoring precipitation become operative, such as decrease of pressure and temperature, and gradual change of solution by diffusion, absorption, and chemical action, rather than intermingling

[a] Regarding the influence of intersections, see, for instance, Van Hise, C. R., A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 1082, 1223.

of different waters. It is also to be remembered that a single local precipitation of tellurides will instantly act as an incentive to further precipitation and that the law of mass action is apt to produce cumulative effects.

INFLUENCE OF DEPTH.

Of the known ore bodies, as few exceed 1,000 feet in horizontal width, so very few exceed 1,000 feet in length or extend more than 1,000 feet from the surface. To speak broadly, explorations below that limit have not proved very satisfactory. With the lines drawn a little closer, it may be said that in proportion to the amount of exploration the upper 700 or 800 feet have yielded more than the interval from that limit to the lowest levels reached—about 1,500 feet. It must not be overlooked, however, that four or five mines still have good ore bodies at a depth of 1,200 to 1,400 feet from the surface. The developments of the next year or two will probably give a safer basis for generalization.

In a general way, the above-mentioned distribution holds good for any elevation within the district. In other words, the principal productive zone everywhere occupies the space from the surface down to about 1,000 feet below it, and its lower limit forms a curved surface approximately parallel to the surface of the ground. The fact that one mine situated in a low part of the district may have an ore body 2,000 feet below the shaft collar of another mine in a high part of the district is thus entirely in harmony with this statement.

The question now arises, How far does the distribution of known pay shoots represent the distribution of all the pay shoots in the district? In other words, How far has exploration been impartial in revealing ore bodies near the surface and at depths greater than 1,000 feet?

It requires but little examination to make clear the fact that ore bodies within 1,000 feet of the surface are far more likely to be discovered than those at greater depth. While shafts have been sunk for a few hundred feet without any indication of ore and have ultimately been developed into productive mines, such a procedure is considered bold prospecting, and few well-informed mining men would seriously contemplate sinking a shaft over 1,000 feet solely on the expectation of finding possible ore bodies below that depth. Most of the large mines in the district have started upon some indication of ore near the surface and have grown by the subsequent discovery of other lodes and ore bodies in the course of their underground development. As few individual ore bodies persist for more than 1,000 feet in depth, by far the greater part of the underground prospecting is at less depths, there being usually little inducement to go deeper, unless, as in the case of the Gold Coin and Portland mines, lodes are discovered in which the ore, beginning several hundred feet below the surface, extends deeper than the pay shoot upon which the mine was originally opened. Thus deep prospecting is usually confined to the vicinity of the larger and more persistent pay shoots which have been followed down from near the surface. Underground water has also proved a most serious obstacle to deep prospecting, few properties being able to develop below the 1,000-foot zone unless there is abundant and high-grade ore in sight.

It may thus be concluded, without necessarily advocating promiscuous exploration below the 1,000-foot zone, that any ore bodies existing below that depth are far less likely to be discovered than those above, where from the surface to depths of several hundred feet the rocks of the district are riddled with shafts, drifts, crosscuts, and adits. It is difficult, however, to determine the relative importance of this factor in the problem. It is probably safe to assume that the chances of discovering a given ore body within the 1,000-foot zone are at least ten times those of discovering an ore body below that zone, and the ratio may be very much greater. While it is also very probably true that there was originally more ore within the 1,000-foot zone than there is in a corresponding zone below, this disparity is not necessarily anything like so great as is indicated by the vertical distribution of known pay shoots.

Another important line of inquiry bearing upon the relations of the ore bodies to depth is concerned with the question of the relative size and abundance of the fissures near the surface and at greater depth. It has been shown that all the ore bodies are intimately connected with fissures. If such fissures are generally smaller and less abundant below the 1,000-foot zone than they are within it, obviously there is introduced a factor which diminishes the supposed importance of secondary enrichment by affording an anterior and physical explanation for the decrease of ore with increase of depth.

Detailed examination of practically all the accessible mines in the Cripple Creek district has led to the conclusion that the fissures, which ordinarily are narrow and often appear as mere cracks, do become less abundant and less conspicuous as greater depth is attained. No mine exhibits this feature better than Stratton's Independence, in which the very complex systems of productive fissures on the fifth and higher levels contrast most strikingly with the few insignificant and unproductive fractures visible on level 14. In less degree the same feature is shown in many others of the deep mines, but the rule is not without some very marked exceptions.

There are thus at least two factors to account for the smaller development of ore shoots below the 1,000-foot level: First, difficulties of development and exploration; and, second, the disappearance of many fissures in depth. These two do not, however, seem to completely explain the facts, and it is believed that there is a third cause which is related to temperature and solubility and which favored deposition near the surface rather than in depth.

The minimum depth of rock removed from the district by erosion may be estimated to be 1,000 feet in the central part and 400 or 500 feet about the periphery (p. 38). Possibly it was somewhat more. The shape and number of the ore bodies formerly existing in this eroded zone can be only conjectured, but it is probable that they were large and numerous. The veins were evidently formed shortly after the close of igneous activity, while the volcano yet possessed a greater height than at present and had a more or less pronounced conical shape.

If further development substantiates the dependence of the maximum development of the ore shoots on the depth from the surface irrespective of the elevation of the croppings, this would, according to the preceding explanation, be due partly

to the more abundant fissuring within the surface zone of a conical volcanic mountain and partly to the parallelism of the underground isothermal surfaces with the surface slopes, for these surfaces would determine the depth at which the most active precipitation took place.

It is believed that the vein-forming solutions ascended rapidly on a few dominant and very deep fissures and that they were distributed from these throughout the volcanic rocks, diminishing their velocity and gradually changing their composition. This would help to explain the scarcity of ores in depth and the frequent precipitation by mingling waters at the intersection of fissures. Decrease of temperature and retardation of water currents are regarded as the main factors favoring precipitation of the tellurides.

CHAPTER XI.—GENESIS OF THE DEPOSITS AND PRACTICAL CONCLUSIONS.

ORIGIN OF THE ORES.

COMPOSITION OF THE VEIN-FORMING WATERS.

GENERAL STATEMENT.

From the metasomatic action, from the fissure fillings, and from other data certain conclusions may be drawn, regarding the characters of the vein-forming solutions, although our imperfect knowledge of the chemical activity of thermal waters under the influence of high temperature and pressure is as yet an obstacle to the clear understanding of their work in depth. This is a field in which intelligent experimentation will yet accomplish substantial progress.

The general alkaline character of the waters with strong percentages of hydrogen sulphide, silica, alkaline carbonates, and sulphates may be considered as firmly established by the following considerations:

SILICA.

From the presence of quartz as the most abundant gangue mineral, we may safely infer that silica was present in the vein-forming solutions. Chemists generally agree that silica exists in hot mineral waters as SiO_2 rather than as an acid or as an alkaline silicate. Moreover, the substance is believed to be present in a colloid solution. Colloids are supposed to exist in solutions as suspended particles and they exhibit certain striking differences from electrolytes in solution, especially in their mode of diffusion. They do not diffuse through semipermeable membranes or walls through which electrolytes, such as ordinary salts, may freely pass; on the other hand, electrolytes freely diffuse through colloid solutions and jellies, which may be considered as concentrated solutions of colloids. These facts help to explain the rare occurrence of silicification in the wall rocks of quartz veins, the colloid solutions of silica being held by the semipermeable rock walls, while other constituents and gases in solution may more or less freely permeate them.

The derivation of the silica is a difficult matter to ascertain. One may conceive of its being dissolved by atmospheric waters from the granite, from the breccia, or from the various phonolitic rocks. The latter contain, however, extremely little free quartz, and almost the only way in which ascending waters could abstract silica from it would be by decomposition of the various silicates. Some of the silica in the waters has certainly this origin, but it by no means follows that this is the only source. It is quite possible that the phonolitic magma cooling at great depths, gave off some silica, together with some of the magmatic water, which it may have contained.

FLUORIDES.

The almost universal presence of fluorite in vein fillings and as a metasomatic product in the rocks shows that the solution contained fluorine. The general character of the solution indicates the presence either of calcic fluoride or of alkaline fluorides.

Fluorite is by no means insoluble in pure water. According to the experiments of Wilson,[a] 1 part of calcium fluoride is soluble in 26,923 parts of H_2O at 15° C. It is stated [b] that it is more soluble in waters containing CO_2, although exact figures are not given. It is thus less soluble than gypsum, of which 1 part dissolves at ordinary temperature in about 420 parts H_2O, but considerably more soluable than barium sulphate, of which, it is stated, that 1 part is soluble in 429,700 parts H_2O at +18° C.

Under the influence of solutions containing alkaline carbonates fluorite alters to calcite, and this process is believed to be more or less active in the oxidized zone wherever the absence of pyrite permits the waters to be of an alkaline character.

Fluorspar heated at 100° or 150° C. with solutions of sodium carbonate is easily converted to calcium carbonate, while sodium fluoride goes into solution (Sorby). This reaction takes place both at the elevated temperatures mentioned and at ordinary temperatures. Superheated water attacks fluorite and hydrofluoric acid is formed.

It is known that fluorine is contained in many thermal springs. The list of waters containing these constituents would no doubt be greatly extended if careful search were made for the element. Owing, however, to certain analytical difficulties it is rarely looked for. Fluorine has been shown to exist in the hot springs of Carlsbad, Plombières, Contrexeville, Chatenois (Alsace), Vichy, and Bourbon-l'Archambault. One of the waters at Vichy contains 0.00769 g. fluorine per liter, and that of Bourbon-l'Archambault 0.002689 g. per liter.[c]

The springs at Carlsbad and at Plombières are known to deposit fluorite in small quantities. The latter springs, in fact, ascended on an old system of fissure veins, the gangue of which consists chiefly of quartz and fluorite. Fluorite sometimes occurs closely associated with volcanic eruptions and is known especially from the volcanoes of Campania, Italy. The tuffs in this region are said to contain large masses of fluorite, which have probably been formed by the reaction of volcanic emanations containing fluorine upon the fragments of limestone.

The two most important reactions concerning the formation of fluorite established by Bischof[d] are (1) the above-mentioned decomposition of fluorite by alkaline carbonates with the formation of calcite and alkaline fluorides, and (2) the decomposition of sodium fluoride in solution at ordinary temperature by calcium silicate with the formation of calcium fluoride. Bischof showed that ordinary rocks like basalt or trachytes, which contain some calcium silicate, had a like effect, but in less degree than the artificial silicate of lime.

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[a] Wilson, George, On the extent to which fluoride of calcium is soluble in water at 60° F.: Rept. Twentieth Meeting Brit. Assoc. Adv. Sci., 1850, pt. 2, p. 69.

[b] Nicklés, J., Recherches sur la diffusion du fluor: Anal. de Chimie, 3d ser., vol. 53, 1858, p. 437.

[c] Daubrée, A., Les eaux souterraines à l'époque actuelle, vol. 2, Paris, 1887, p. 9.

[d] Bischof, G., Chemische Geologie, vol. 1, 2d ed., Bonn, 1863, pp. 48 and 54.

Fluorite was first proved to exist in the spring deposits at Carlsbad by Berzelius.[a] From his experiments it is clear that waters may contain SiO_2 and CaF_2, and that the two may be deposited together. Either of the two substances may be first deposited, and waters containing SiO_2 may subsequently dissolve the fluorite formed and replace it by quartz. According to Berzelius, the fluorite was dissolved as such in the waters of Carlsbad, which he says do not contain any sodium fluoride. The experiments of Bischof and Sorby would, however, show that the fluorine was present as sodium fluoride, for calcium fluoride and alkaline carbonates can not exist together in the same solution, and the Carlsbad waters contain a considerable amount of the latter salts. In mineral waters alkaline fluorides can, however, exist together with calcium bicarbonate, as the two substances do not react. The testimony is somewhat conflicting, but it seems most likely that the waters of Cripple Creek contained sodium fluoride, and that the fluorite was separated by reaction of calcium silicate on the solutions.

In tracing the origin of the fluorine we are first confronted by the fact that the Pikes Peak granite contains a certain small percentage of fluorite as a primary mineral,[b] in some cases, as in the Summit type, amounting to 0.55 per cent. In the vicinity of Cripple Creek no primary fluorite could be detected in the rock. However, if the fluorine were derived from the granite, we should expect secondary fluorite to be most common in this rock, which is certainly not the case in the district. Two or three miles south of Cripple Creek this granite does contain several small veins in which fluorite is associated with barite. The mineral is here either purple or green, the latter color never appearing in the deposits at Cripple Creek. It is very doubtful whether these veinlets really belong to the same class of deposits as those within the district proper.

Another possibility is that the fluorine is leached from the volcanic rocks. No primary fluorite has, however, been observed in these and no definite traces of fluorine have been shown by the analyses. The presence of the mineral lovenite, if substantiated, would establish the presence of fluorine, but there seems to be some doubt regarding the identification (p. 65). As a third possibility, the fluorine, together with other volatile constituents, may have been given off by the phonolitic magmas on their consolidation at higher levels of the earth's crust. We incline toward this view as the most probable explanation. There certainly exists a remarkable connection between phonolitic rocks and deposits containing fluorite and gold, exemplified not only at Cripple Creek, but also in the Black Hills, Judith Mountains, and Little Rocky Mountains.[c]

CHLORIDES.

The general distribution of sodalite in the Cripple Creek rocks indicates the presence of NaCl, and, in fact, the analyses of phonolites, latite-phonolites, and syenites show amounts of Cl up to 0.55 per cent. During the decomposition of this mineral by alkaline waters NaCl would be dissolved, and in this reaction is one

[a] Chemische Geologie, vol. 2, 2d ed., Bonn, 1864, p. 89.
[b] Mathews, E. B., The granitic rocks of the Pikes Peak quadrangle: Jour. Geol., vol. 8, No. 3, April-May 1900, p. 237.
[c] Lindgren, W., Metasomatic processes in fissure veins: Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 657.

source of chlorides in the waters. As chlorides are found among the volatile substances emitted during eruptions, it seems most probable that the magma of any rock which now contains chlorine contained more of it before the pressure in the magma was reduced by movement to a higher level in the earth's crust, and that chlorine, mingled with magmatic water, was one of the constituents which escaped.

SULPHATES.

That sulphates were present in the waters is indicated by the almost universal occurrence of celestite or sulphate of strontium in the veins (pp. 124, 125), as well as by the more sparing development of barite. Celestite is fairly soluble in water, the proportions given varying from 6,895 to 10,101 parts of water (at 15° C.) for 1 part of celestite. It is, however, much more soluble in water containing sodium chloride, 1 part of the sulphate dissolving in 457 parts of water with 15 per cent NaCl.[a] Celestite is very much more soluble than barite, of which 1 part dissolves in 429,700 parts of water.

The presence of celestite rather than barite in the veins is a very unusual occurrence in mineral veins, although known in a few cases from France and Hungary. The granites and phonolites, as well as the basic dikes of Cripple Creek, contain a very small amount of baryta, varying from a trace up to 0.18 per cent, and practically only a trace of strontia, occasionally rising to 0.07 per cent. On the other hand, the majority of the latite-phonolites and the syenite are much richer in both constituents. Six analyses of these show from 0.13 to 0.24 per cent baryta (average of the six, 0.19 per cent BaO) and from 0.03 to 0.21 per cent strontia (average of the six, 0.12 per cent SrO). Strontia is here present in much larger quantities than is usual in rocks, and the proportion is exceeded only in certain leucite and analcite rocks, monchiquites, tinguaites, and syenites from Montana and Wyoming.[b] The average percentage of baryta in rocks, as calculated by Clarke, is 0.11 per cent baryta and 0.04 per cent strontia.[c] The latter figure is probably higher than the actual average.

Strontia exists, moreover, in many thermal spring waters in amounts exceeding those of baryta. Salts of strontium are known from many spring deposits, such as Vichy, Carlsbad, and Hammam-Meskoutine, and celestite is deposited by the hot springs of Bourbon-l'Archambault.[d] From the data given there is, therefore, some reason to suppose that the strontia may have been leached from some of the intrusive rocks at Cripple Creek, but as celestite occurs in the veins throughout the district, irrespective of the particular wall rock, it follows that this leaching has probably not taken place within the zone opened by mining, but perhaps rather in intrusive latite-phonolite and syenite at greater depths.

Calcium sulphate is not found as a primary constituent of the veins, but the peculiar occurrence of large masses of gypsum associated with pyrite and fluorite at the Deerhorn mine (p. 284) leads to the belief that waters rich in sulphates of the alkaline earths appeared as one of the latest phases of thermal activity. The closest analogy

[a] See Comey's Dictionary of Solubilities.
[b] Clarke, F. W., Analyses of rocks: Bull. U. S. Geol. Survey No. 228, 1904.
[c] Op. cit., p. 17.
[d] Daubrée, A., Les eaux souterraines a l'époque actuelle, vol. 2, 1887, p. 18.

to this would perhaps be found in the hot waters of the Comstock lode, which are exceptionally rich in these constituents.

The phonolite, syenite, and latite-phonolite contain appreciable quantities of sulphuric acid combined in the mineral hauynite of those rocks. The maximum amount found is 0.37 per cent. As this mineral is very easily decomposed under the influence of vein-forming solutions with the formation of sericite, it is evident that the waters would carry away soluble sodium sulphate. This origin of a part of the sulphates in the water may be considered established, but it is probable that the magma brought up from great depths and cooling at a level still far below the present mine workings gave off part of its sulphur trioxide, which ascended, together with so much of the magmatic water as was set free.

CARBONATES.

The metasomatic processes clearly indicate that the waters contained carbon dioxide, either as dissolved gas, as bicarbonates, or as normal carbonates of the alkalies. It has been shown that an active decomposition of silicates proceeded in the rock accessible to the vein solutions. This could be explained under any of the three suppositions, but the most plausible view seems to be that bicarbonates and an excess of carbon dioxide were present. The processes outlined indicate distinctly that sodium was carried away as a carbonate and that the waters gradually became more charged with this substance on their upward journey. The metasomatic processes observed also suggest that the waters originally contained more potassium, which gradually was substituted for the sodium in the rocks.

No adequate explanation is available for the occurrence of CO_2 in the waters on the supposition that they were ascending surface waters. It can not have been leached from the volcanic rocks nor from the granitic rocks, since neither contain carbon dioxide or carbonates.[a]

Inasmuch as all cooling volcanic rocks give off carbon dioxide and as emanations of this kind are abundant in the district to-day, it appears certain to us that the carbonates in the veins and in the altered rocks of Cripple Creek were formed from the carbon dioxide exhaled by crystallizing magmas.

HYDROCARBONS.

The purple color of the fluorite of Cripple Creek is very characteristic and often very intense; in thin sections parts of a crystal may be almost opaque, but the color is very irregularly distributed. Wyrouboff and Von Lasaulx have shown that this color is due to a hydrocarbon, and thus we may conclude that the waters contained some of this substance, the derivation of which must remain problematical. Possibly it is derived from the small quantities of bituminous coal occasionally found in the breccia. Hydrocarbons are by no means entirely unknown in mineral veins, the quicksilver deposits offering one conspicuous example.

[a] The supposed derivation of carbon dioxide from fluid inclusions in the granite is altogether improbable; moreover, the explanation is quantitatively insufficient. Inclusions of carbon dioxide in granite-quartz are of comparatively rare occurrence. Aqueous solutions assuredly predominate.

HYDROGEN SULPHIDE.

The abundance of pyrite, which without notable addition of iron has been found throughout the rocks affected by the solutions, shows that hydrogen sulphide or sodium sulphide, or both, must have acted on the iron oxides and silicates. This is amply confirmed by microscopic examination. The widespread pyritization, indicating great capacity for diffusion on the part of the sulphur-bearing compound, would indicate that H_2S as a gas dissolved in water was the chief reagent. But if sodium carbonates were present sodium sulphydrate would form;[a] this, by heating or by the presence of certain metallic sulphides, may partly change to Na_2S, so that it is quite possible that both substances were active.

Neither the granitic nor the phonolitic rocks are known to contain sulphides which could have yielded the necessary sulphur. Hydrogen sulphide might, of course, have formed by the reduction of sulphates by organic matter; but very large quantities of sulphur compounds were evidently active at Cripple Creek, and here also we would attribute the sulphur to emanations from cooling intrusive magmas. This position is strengthened by the fact that sulphur in various forms is usually given off during eruptions of lavas at the surface.

IRON.

It has already been pointed out that the quantity of pyrite in the veins is very small. In the ores this mineral rarely exceeds 5 per cent. (See analyses, p. 172.) Most of this pyrite is contained in the altered country rock, which in mining can not be separated from the tellurides and quartz of the fissure filling. The iron in this pyrite is almost wholly derived from the original iron silicates in the rock. Probably less than 10 per cent of the pyrites in the ores was deposited in the filling of the fissures. We arrive thus at the conclusion that the solutions contained very little iron in a condition to form pyrite.

CALCIUM AND MAGNESIUM.

Dolomitic carbonates are of widespread occurrence in the altered rocks, but are nowhere present under conditions suggesting an introduction of either of these metals. The silicates of calcium and magnesium are simply converted into carbonates, and in some cases the percentage of the former metal is notably decreased, giving evidence of a partial leaching by the vein-forming waters. It is a noteworthy fact that the mines situated in areas of syenite and latite-phonolite, the rocks in which lime is most abundantly present, contain the largest amounts of dolomitic carbonates, both in the altered rocks and as filling of seams. There is thus strong evidence that the lime and magnesia contained in the water were, to a large extent, at least, derived from the surrounding country rock. As the waters contained carbondioxide, the metals must have been present chiefly as bicarbonates.

ALKALI METALS.

The substitution of potassium for sodium in the newly formed silicates suggests that the waters were originally richer in the former metal, but this can not be said

[a] Becker, G. F., Geology of the quicksilver deposits of the Pacific slope: Mon. U. S. Geol. Survey, vol. 13, 1888, p. 427.

to be definitely established. It is certain that sodium was extracted and that the waters must have been greatly enriched in this metal during their journey through the rocks. The alkalies were present as chlorides, carbonates, sulphates, and sulphides, as well as their several ions.

TELLURIUM AND GOLD.

If it be assumed that the ores shipped average $40 per ton, it should be remembered that the actual ore, which in the fissure deposits of Cripple Creek is formed only in the narrow seams and cracks of the lode, constitutes less than 10 per cent, perhaps only 5 per cent, of the total material extracted, and that it would thus have a value of upward of $400 per ton. For present purposes we may assume that this material consists of 60 per cent quartz, 20 per cent dolomite, and 20 per cent fluorite, to which should be added 0.1 per cent gold and 0.2 per cent tellurium, besides small amounts of iron, copper, lead, zinc, and molybdenum, each of which would on the average rarely exceed a fraction of 1 per cent. A water depositing such a product was surely of a most unusual character, compared to ordinary surface waters, and even compared to those which deposited the normal gold-quartz veins, in which the tenor of the filling is rarely higher than 1 ounce per ton.

Concerning the reactions by which the tellurides were deposited or the condition in which they existed in the solution our information is scant. The association of tellurides with fluorite is an interesting but probably not at all essential point, because, as Penrose has already emphasized, there is no quantitative relation between the two minerals. In some of the richest ores fluorite may be extremely scarce. In his great monograph on metamorphism, Van Hise[a] devotes considerable space to a discussion of the tellurides. He says:

> At first thought one might conclude that the gold, silver, and tellurium were transported as tellurides and deposited as such without chemical change, but the recent work of Lenher and Hall[b] is decidedly against this view. They have found no solvent whatever for tellurides of gold without breaking up these compounds and producing salts of tellurium, the gold usually being left in the metallic form. Moreover, as has already been noted, they have shown that metallic tellurium and seven of the more common mineral tellurides of gold and silver rapidly reduce gold from its solutions, forming metallic gold, the tellurium at the same time going into solution. Further, they have proved that the presence of any of the soluble tellurides, including hydrogen tellurides, is sufficient not only to throw the gold out of solution, but to prevent it from getting into solution. Other soluble salts, where tellurium acts as an acid, are the tellurites and tellurates. Tellurous oxide or acid is also sparingly soluble. All of these compounds, like tellurides, precipitate gold from its solutions in a metallic form, not as telluride. From the foregoing it appears that if tellurium compounds in which tellurium is a part of the acid are essential for the formation of the tellurides of gold, these tellurium salts and the gold have come into the trunk channel from separate sources. They could not have traveled together; else the gold would have been thrown from the solutions before reaching the trunk channels.
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> It may be that the key to the problem of the deposition of the tellurides lies in their association with sulphides. We have already seen that telluric salts of the type of $TeCl_4$ may travel with gold in solutions. It has already been pointed out that gold, in most cases, probably also travels as a chloride, and thus solutions of auric chloride and telluric chloride, may together enter trunk channels which contain sulphides. In such trunk channels the reaction of the sulphides might reduce both the gold and the tellurium simultaneously and thus produce tellurides of gold; or, by the reaction of the sulphides upon the telluric salts, these may

[a] Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 1119–1125, especially pp. 1120, 1121.

[b] Lenher, Victor, Naturally occuring telluride of gold: Jour. Am. Chem. Soc., vol. 24, 1902, pp. 355–360. Hall, R. D., and Lenher, Victor, Action of tellurium and selenium on gold and silver salts: Idem, pp. 918–927.

be reduced to tellurous salts, which, as already explained, would decompose into metallic tellurium and telluric salts, and the tellurium would precipitate the gold. Under these or some other conditions, the gold and tellurium go down together, with a definite composition, and thus form the tellurides.

We are not able to agree with these conclusions; on the contrary, we think the evidence from the general occurrence is very strong that gold and tellurium existed together in the solutions, and, with the assistance of Dr. W. F. Hillebrand, we have been able to show that they do so exist in a combination of two solvents which are believed to have been contained in the alkaline vein-forming solutions—i. e., sodium sulphide and sodium carbonate.

Doctor Hillebrand sums up his experiments as follows:

The first attempts with bicarbonate of soda solution at ordinary temperatures led to the erroneous conclusion that this solvent exerted an appreciable action upon the telluride. It was found, however, that the tellurium going into the solution undoubtedly came from a coating of tellurite upon the calaverite grains, for subsequent treatment of this same powder with the bicarbonate solution gave entirely negative results. That such a coating existed upon the calaverite grains was rendered further evident by the fact that a first treatment with hydrochloric acid showed tellurium in solution, while subsequent treatments of the same powder gave negative results. A further experiment with bicarbonate solution on calaverite powder thus purified was made by sealing mineral and solution in a glass tube, after expelling the air by a current of carbon dioxide. The tube was then heated to 150° for many hours. When opened and the powder separated from the solution by filtration, no tellurium whatever could be detected in the filtrate.

The case was quite different, however, if, instead of the bicarbonate solution, one saturated to a greater or less extent with hydrogen sulphide was employed. Under these conditions it was a matter of ease to detect tellurium, as well as gold, in the filtrates, even after only one or two hours' exposure at room temperature with exclusion of air. It was found possible to estimate quantitatively, with a fair approach to accuracy, both the tellurium and the gold. The amounts thus found accorded fairly well with the preparations in which these two elements combine to form the mineral calaverite. The absolute amounts were, in one case, for tellurium, 0.0011 g., for gold, 0.0008 g. The amount of calaverite which furnished the above quantities of tellurium and gold to the alkaline solution was approximately 0.4 g. in a moderately coarse state of division.

As to the actual conditions existing in these solutions of calaverite, we are still in the dark; doubtless a partial dissociation has taken place, as in most electrolytes, but we incline to the belief that the tellurides were dissolved as such and precipitated by supersaturation due to various physical changes. The synthesis of the tellurides offers a fruitful field of investigation which circumstances have not allowed us to enter.

Concerning the derivation of the gold telluride we confess to a lack of conclusive evidence. It may have been leached from the granitic rocks or from the volcanic rocks by ascending surface waters, or it may have been separated as exhalations from cooling intrusive magmas and brought up by ascending surface waters or by magmatic water. That it was leached from granitic rocks by surface waters is exceedingly improbable, for this hypothesis furnishes no explanation of the confinement of the deposits to the volcanic area. Whether the volcanic rocks now contain gold and tellurium, and if so, whether the surface waters would be able to extract them, we can not say. Determinations of gold in the volcanic rocks now accessible on the surface or in the mines would have little value, owing to the general permeation by solutions that has taken place and to the fact that an almost invisible seam in the rock might contain enough telluride to vitiate the result. Considerations concerning the quantitative relations of the sulphides and

the tellurides, as well as concerning the water circulation, make the derivation by leaching seem improbable (p. 224), and we therefore fall back upon the third alternative, namely, to consider the gold, the tellurium, and perhaps the other rarer sulphides as emanations from a cooling magma under the influence of diminishing pressure.

RELATIVE QUANTITY OF SULPHIDES.

Little is to be said of the various sulphides and sulphosalts, except that they must have been present in the water and that according to the experiments of Becker[a] and Doelter[b] they were probably dissolved as sulphides in sodium sulphide. Among them are sphalerite, galena, stibnite, tetrahedrite, and molybdenite, corresponding to zinc, lead, copper, antimony, and molybdenum. Zinc is on the whole most abundant, but the proportion does not appear to rise in many cases above 0.75 per cent and in places the metal is entirely absent. The other elements occur on the average only in minimal amounts, rarely rising above 0.1 per cent and more commonly about 0.02 per cent or 0.01 per cent. The quantity of tellurium and even of gold is often found to exceed that of these metals. A solution may of course contain sulphides and tellurides without their being precipitated. It is assumed that the precipitation is due to slowly changing physical conditions. But as the necessary requirement for precipitation is supersaturation, and as some of each sulphide has been precipitated, it is reasonable to conclude that they were precipitated in proportion as they were abundant in the solution. Such a proportion, however, if the metals have been leached from the volcanic rocks by atmospheric waters, would be highly remarkable. It would indicate that the waters contained as much molybdenum as copper and more tellurium than either. The average amount of iron deposited as sulphide in open spaces is but slightly larger than the tellurium deposited as tellurides. If these elements had been gathered by leaching we would be justified in concluding that they existed in approximately similar proportions in the rock from which they were obtained. This may be looked upon as a reductio ad absurdum.

No such difficulties appear when the metals are regarded as sulphide exhalations from cooling magmas, for here we have no separation according to solubility in water, but only according to the ability of a magma to hold certain substances in solution under rapidly changing physical conditions. That rare elements can be concentrated by this process is well shown by many pegmatite dikes.

CONCLUSIONS.

The waters which deposited the Cripple Creek veins were alkaline solutions containing the following compounds and ions, either free or in various combinations: SiO_2, CO_2, H_2S, CO_3, SO_4, S, Cl, F, Fe, Sb, Mo, V, W, Te, Au, Ag, Cu, Zn, Pb, Ba, Sr, Ca, Mg, Na, and K. We believe that at least some of the SiO_2, SO_4, Cl, Fe, Ba, Sr, Ca, Mg, Na, and K, are derived from the volcanic rocks by leaching of waters, while the remaining metals, as well as CO_2, H_2S, S, and some SiO_2, Cl, and K were more probably separated from intrusive cooling magmas at considerable depth, and brought up as solutions in magmatic water given off in the same manner.

[a] Mon. U. S. Geol. Survey, vol. 13, 1888, chap. 15. [b] Tschermaks Min. u. petrogr. Mittheilungen, vol. 2, 1889, p. 319.

DEPTH AT WHICH DEPOSITION TOOK PLACE.

The ores were deposited in the fissures of a volcanic mountain. Near its present highest point, with an elevation of 10,800 feet above the sea, the ore has been proved from the surface to a depth of 1,600 feet, and near the southern base of the volcanic hills, with an elevation of 9,700 feet, it has been followed to a depth of 1,200 feet—in each case without notable change in quality but with a distinct decrease in quantity (p. 214). From physiographic considerations (p. 38) it is probable that the volcanic mountain had an unsymmetrical conical shape and that near the highest points of the present time a minimum of 1,000 feet of rocks covered the present outcrops. It is further probable that near the southern base the vein croppings of to-day were buried at least 500 feet deep. It is concluded that the ores which we see now were deposited at moderate depths ranging from a few hundred feet below the old surface to a maximum of about 3,000 feet. The occurrence of carbonized tree trunks at many places in the breccia (p. 31) tends to confirm this conclusion.

TEMPERATURE OF THE SOLUTIONS.

As the solutions moved within a volcanic cone, shortly after the end of the eruptions, and as, being heavily charged with silica, carbon dioxide, and hydrogen sulphide, they actively deposited material and energetically altered the country rock, it follows that they were in all probability hot solutions. The similarity of the deposits to those formed by many hot springs emerging at the surface lends additional support to this conclusion. The most direct proof is furnished by aqueous inclusions in the quartz deposited. In addition to a gas bubble these very often contain solid material forming transparent adhesions to the walls of the cavity, but evidently once dissolved in the water. No inclusions of carbon dioxide have been found.

On the other hand, the temperature and pressure at which the veins were formed were not very high, as shown by the fact that carbonates crystallize freely in the rock by replacement and in the fissures by crustification and also by the general absence of minerals like biotite, garnet, and pyroxenes, which are apt to form during conditions of high temperature and pressure from aqueous solutions. The critical point of water (+364 C. and 200 atmospheres) was probably not reached. We are inclined to believe that the temperatures ranged from +100° C. to +200° C. and the hydrostatic pressure up to 100 atmospheres—that is, for the portions of the veins now accessible.

TIME OF DEPOSITION.

The ores were formed later than the latest actual eruptions; that is, later than the basic dikes. These dikes had solidified and had cooled at least to such degree that carbonates could form in them. Although the basic dikes to some degree followed the prevailing directions of the fissure system, the latter was not formed until after their intrusion. As the paths were opened they were filled by depositing solutions. The filling being in many cases only partial, we may infer that the solutions circulated for a limited time only.

That the veins are not recent is indicated by the formation of considerable placer deposits and by the depth and extent of subsequent oxidation. If we assign

a late Tertiary age to the close of direct volcanic activity, there is some reason for believing that the ore-forming epoch belonged to the close of that period.

SOURCE OF THE WATER.

The ore-depositing water was derived either from the atmosphere or from magmas under diminishing pressure and temperature or from both of these sources. In other words, it may have been a part of the ground water descending through the pores and fissures of the rocks from the surface on which it once fell as rain or snow, and possibly ascending, charged with dissolved material, from the lowest levels reached under the driving force of the volcanic heat encountered there. Or it may have formed part of the original molten phonolitic rocks and may have escaped from its bond during the ascent of this molten rock to levels of less temperature and pressure. Both hypotheses are plausible, though at first glance the former view seems much more natural and simple. Either may be difficult to prove, but it may be profitable to consider the probabilities involved.

It will be shown in Chapter XII that the conditions of underground drainage are unusual. The porous, shattered volcanic mass is deeply sunk in much more massive and impervious granite and metamorphic rocks. It therefore holds water much as would a sponge in a cup. The circulation of the ground water in this volcanic plug is exceedingly slow; in fact, the water is practically stagnant. The cold dilute sulphate solutions which constitute the ground water are evidently wholly impotent to deposit ores like those in the veins or to cause abundant pyritization of the rocks. They fill many open fissures in the rocks, but nowhere have they given the least indication of depositing telluride ores.

If surface waters were present they must have constituted currents under the influence of the heat of the volcanic rocks. This circulation was only a temporary phase, ceasing when the rocks had cooled sufficiently.

Such waters ascending vigorously throughout the volcanic mass could not reasonably have been derived from the very limited surface area of that mass itself. They must have been derived chiefly from the surrounding granitic plateau. They must have percolated through the granite to great depths near the volcanic mass, and finally have been driven up by the volcanic heat still existing in it. Considering, however, the almost impermeable character of the granite, as demonstrated by the mining operations, it becomes very difficult, if not impossible, to conceive how a sufficient amount of water could penetrate the porous volcanic mass from the surrounding granite to give rise to the strong ascending current which evidently streamed upward in every available fissure in this old volcano.

The second hypothesis of the derivation of the vein-forming waters is that they were originally an integral part of the intrusive phonolitic magmas and were given off by release of pressure or by cooling and crystallization after the magma had ascended to higher levels.

According to the general laws of solutions, pressure increases the solubility of water in magmas, and conversely, if all magmas contain more or less water which is just as much a part of them as is the silica, for instance, it follows that a portion of the water will be given off during the eruption.

The volcanic rocks of Cripple Creek are rich in combined water. The average of the analyses shows 1.62 per cent combined water given off above +110° C., and they range from 0.69 to 2.09 per cent. To a large extent this is contained in analcite, the primary nature of which is proved. Some of the phonolites contain 15 per cent of this analcite and the latite-phonolites average 4.6 per cent. To a smaller extent the water is present in kaolin or other secondary hydrous minerals. It is assuredly not an exaggeration to say that the rocks contain an average of 1 per cent of combined primary water. The presence of primary water being firmly established, it follows, if the statement in the preceding paragraph is true, that the magma contained much more of it at greater depths. The water lost as steam by the intrusive bodies under our present range of observation doubtless partly permeated the rocks and was partly dissipated in the air at the time of the eruption. But unquestionably there are large intrusive masses which did not attain the level of those now visible, though they rose to much higher levels than they originally occupied. Their water was probably partly expelled from the cooling mass, but was held in its confines under strong pressure, having abundant opportunity to dissolve the other substances which may have emanated from the magma. As the volcanic mountain settled down deep fissures were created, which reached to the levels of these stored hot waters and afforded them means of escaping toward the surface. Such is the explanation of ore deposition by "magmatic" or "juvenile" waters, to follow Suess's terminology, and to these we are inclined to attribute the largest share of ore deposition, possibly the whole. The storage reservoir was limited, and the supply of these strange solutions was soon exhausted. Surface waters followed the retreating juvenile waters and filled the "sponge in the cup" until equilibrium was established. At the present time the volcano appears extinct, and yet a few hundred or a thousand feet below the surface the faint exhalation of carbon dioxide and nitrogen are met—the last volatile products of the phonolitic magmas.

MODE OF DEPOSITION.

The laws governing the actual deposition of materials in mineral veins are little known, and it must be confessed with regret that the last ten years have not seen much direct advancement, although the foundations for it have been laid broad and deep by the development of physical chemistry. We have reached a point where further progress depends on experimental work with solutions at high temperature and pressure.

If an alkaline solution, such as is indicated above (p. 224), with an unascertained state of ionization, ascends in fissures through porous volcanic rocks, a most complicated set of reactions will follow. Pressure and temperature will constantly change, certain compounds will be precipitated, and constant changes in the composition of the solution will take place. It is further to be considered that the solutes[a] or some of them may diffuse through the walls and that different ions may diffuse at various rates. It is even possible that the walls in places may act as semipermeable membranes which will allow not any solutes to pass. There is also the chemical action of the solutions on the porous rocks, with attendant loss of

[a] Solute in physical chemistry means the substance dissolved; solvent indicates the medium in which the substance is dissolved.

some constituents and gain of new ones, and finally the mingling of the ascending solutions with the moisture already permeating the rock. The most satisfactory way of attacking such a problem is to begin by experiments in which these confusing complications are to some extent eliminated.

Simply from the results as we see them, without positive knowledge as to the composition and physical conditions of the solutions, a few conclusions may be reached. One of the most striking facts is the difference in composition between the filled veinlets and the altered country rock. The silica, the gold tellurides, and the sulphides (except pyrite) are retained in these fissures and precipitated in them. The walls are evidently not as a rule permeable for these substances. It seems to be generally true that in gold-quartz veins the silica, the gold, and some sulphides, such as galena, sphalerite, and chalcopyrite, are always deposited in open spaces, if such spaces are available. This rule, which may not be without exceptions, indicates that the wall rocks effect a separation in the solutions and that the substances mentioned penetrate them less easily than the other constituents of the solutions. For tellurides the rule is not inflexible, for it has been shown that they also occur in metasomatic form. In the "granite ore," however, which is considered one of the best examples of metasomatic deposition of tellurides, most of the latter are probably deposited in cavities created by the solutions and consequently not, strictly speaking, metasomatic. It is known that tellurides in undoubted metasomatic development occur abundantly in Kalgoorlie, Western Australia.

This question of diffusion through porous rocks in relation to veins was first suggested by a microscopic study of the quicksilver ores of California and of the altered wall rocks of gold-quartz veins in the same State.

G. F. Becker[a] first expressed the belief that a law existed governing this phenomenon and wrote as follows:

> *Osmotic hypothesis.*—These observations would be explained if it were true in general that liquids will penetrate a dense wall or septum at a sensible rate only when there is a chemico-physical reaction between the solid and the fluid. Here the term chemico-physical reaction is intended to express any chemical union or physical change attended by the evolution of heat, or rather by the degradation of energy. There is reason to think that such a law really exists, though it can not be said that it is conclusively proved. * * *
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> On this hypothesis the concentration of ores in deposits would be largely due to the fact of the *lack* of action between their solutions and the wall rocks; and the decomposition of the country rock, so often observed near veins, would be due to the absorption of solutions of gangue minerals by the walls. In short, there would be a species of concentration by dialysis.

As expressed by Becker the hypothesis is probably not true, for it is known that solutes diffuse through chemically inactive membranes or porous bodies at varying rates; some are entirely impermeable while others are partly so, and the local osmotic pressure varies according to this permeability. But it is probably true that the rate of diffusion partly depends on chemical action between membrane and solute. The silica was in all probability contained in the waters in colloidal, easily soluble form,[b] and it is at least a legitimate subject for inquiry whether or not the sulphides and tellurides were dissolved in the same manner.

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[a] Quicksilver ore deposits: Mineral Resources U. S. for 1892, U. S. Geol. Survey, 1893, p. 156.

[b] Lindgren, W., Gold-quartz veins of Nevada City and Grass Valley, Cal.: Seventeenth Ann. Rept. U. S. Geol. Survey pt. 2, 1896, p. 183.

It is well known that various sulphides of the metals, as well as some of the metals themselves—particularly gold—can exist as colloid suspensions.[a] Electric currents in acidulated water through gold electrodes easily produce red clouds of colloidal gold in the liquid.[b] Under certain conditions hydrogen sulphide may produce colloidal suspensions of sulphides instead of precipitates, and these again may be coagulated by the addition in sufficient amounts of an electrolyte, such as a chloride. On the other hand, the presence in fairly small quantity of a gelatinizing colloid in a liquid may prevent this coagulation of colloidal suspensions by salts. How far crystals can be produced from such a colloidal solution or suspension is not certain, but that quartz can and does crystallize from them seems fairly well established by observation on siliceous springs. Recent experiments also show that in a solution containing a colloid and an electrolyte, crystals can form which contain both substances.[c]

Colloid solutions diffuse with the utmost difficulty and are easily retained by porous walls or by other colloids, while crystallized substances (crystalloids) diffuse as easily through colloidal masses as through water.[d]

It is possible to separate mixtures of colloids and crystalloids by diffusion through colloidal walls. Such a separation has undoubtedly taken place in the fissures. If we suppose a concentrated solution adjoining a weak one or adjoining pure water, diffusion will take place into the latter. Should the two solutions be separated by a semipermeable wall which wholly or partly prevents the transmission of the solute, osmotic conditions will result and the surrounding water will wander into the concentrated solution and dilute the same. Such a condition of affairs might easily exist in certain veins.

Diffusion in itself is a slow process, and yet in porous rocks may well play an important rôle, especially when chemical action accompanies it. In the latter case adsorption and metasomatism cause constantly changing conditions of saturation by which the process is made enormously complicated. As an evidence of this we refer to the chapter on metasomatic action (pp. 184–195), in which it is shown that pyritization, carbonatization, and the formation of sericite and adularia often vary quantitatively in the same rocks to a degree which renders it impossible to believe that the solutions could have preserved the same composition throughout.

During the alteration of the country rock, sulphur, carbon dioxide, fluorine, and possibly also potassium, are the chief elements introduced, and in exchange sodium, with a little silica and lime, have been carried away. Quantitatively the most prominent newly formed minerals are pyrite and dolomitic carbonates, and this suggests the question whether practically all of the pyritization and carbonatization in the country rock could not have been effected by means of H_2S and CO_2, dissolved in the waters. The diffusion of dissolved gases is governed by the same laws as is that of dissolved liquids or solids. In general the diffusion constant is smaller for bodies of higher molecular weights. Consequently we should expect, for instance,

[a] Noyes, Arthur A., The preparation and properties of colloidal mixtures: Jour. Am. Chem. Soc., vol. 27, No. 2, February, 1905, pp. 85–104.

[b] Bredig, G., Anorganische Fermente: Darstellung kolloidaler Metalle auf electrische Wege und Untersuchung ihrer Katalytischen Eigenschaften, Leipzig, 1901. Cited by Noyes, loc. cit., p. 95.

[c] Van Bemmelen, J. M., Zeitschr. f. anorgan. Chemie, vol. 36, 1903, p. 393.

[d] Ostwald, W., Grundriss der allgemeinen Chemie, Leipzig, 1899, p. 197.

a solution of hydrogen sulphide to permeate the rocks with more ease than a solution of salts of the heavy metals. The same applies in a less degree to carbon dioxide and to the ordinary alkaline salts. Hydrolysis of many salts of the heavy metals has a tendency to transform the bases into colloid solutions or suspensions, and for this reason also such substances are more apt to remain in the fissures. Fluorite is common in the altered rocks, but only in very small amounts, indicating that diffusion of alkaline fluorides has taken place.

In general, then, the acids will permeate the rock more extensively than the bases and, as Van Hise says,[a] "in underground solutions the alkalies and alkaline earths, with the exception of magnesia, will largely take possession of the acids. To a less extent this is true of magnesia and to a still smaller degree of alumina and iron. Thus we have the partial explanation of the relative solubility of the bases. The alkalies are dissolved to the greatest extent; next in order comes lime, then magnesia, and finally iron and alumina."

It is not denied that solutions of heavy metals may freely permeate many porous rocks—there are, of course, many degrees of porosity—but they will not do so if open fissures are available and if there is no very strongly pronounced chemical reaction between the rock and the solution. How conditions may change in this case is well shown by the energetic metasomatic action of lead solutions on limestone.

We believe that the waters ascended in the deeper part of the volcano with comparatively great velocity on the fewer fissures and in the smaller areal space there available. Nearing the surface it spread through a much larger space in a more complicated fissure system. The speed of the current became checked; in places conditions no doubt approached stagnation; locally the solutions even became descending instead of rising; deposition and chemical action on the country rock changed their composition; and mingling with fresh ascending waters, possibly also with atmospheric waters, induced further precipitation. In this manner we would account for the smaller amount of ores deposited in depth and the richness and abundance of ore nearer to the old surface. The portion of the volcano removed by erosion may have contained still richer deposits.

FUTURE OF THE DISTRICT.

To predict the future yield of any mining district is no easy task; the conditions under which most ores are deposited are as yet too imperfectly understood and the deposits themselves are usually too erratic in form and distribution to give certitude to such predictions, even when these are based upon a careful study of the history and present condition of a district. Nevertheless, it is part of the duty of the geologists who have officially investigated the Cripple Creek district to interpret to the best of their ability the bearing of ascertained facts upon future mining development. For such a forecast of the future moderate probability is all that can be claimed.

As has been pointed out in the preceding pages, the largest known ore bodies of the district are apparently confined within a zone which extends from the surface to a depth of 1,000 feet. In general, explorations below that depth have been much less satisfactory as regards quantity of ore than explorations above. It is certainly

[a] A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, p. 92.

true that some large ore bodies as yet show no sign of depletion in depth, and that some good pay shoots have been found at a depth of 1,400 to 1,500 feet. On the other hand, the number of ore shoots that have been exhausted with increase in depth is considerable.

It is probable that the ore bodies, known or unknown, occurring below the 1,000-foot zone are neither so large nor so abundant as those nearer the surface. The discovery and exploitation of these deeper ore bodies is, moreover, beset with increasing difficulties, chief among which is the problem of dealing with the underground water. For these reasons it is unlikely that the zone between the 1,000-foot and 2,000-foot levels will yield as much as the zone between the surface and the 1,000-foot level, but it is probable that some strong fissures may carry payable ore to far greater depths than those yet attained.

As regards the zone above the 1,000-foot or 1,500-foot level, it is well to bear in mind that it still contains much ore, both as parts of known ore shoots and as yet undiscovered ore bodies. It is certain that many of these undeveloped ore bodies will be mined in the near future and that this zone will contribute the most important part of the production.

It is probable that the production of the district, while exhibiting fluctuations, will, on the whole, slowly decline. New ore bodies will undoubtedly be discovered from time to time, and individual mines may be as profitable in the future as they have been in the past, or even more so. An increased output may be expected to follow each successful step in deep drainage. But existing conditions indicate that if the maximum production of $18,000,000, in 1900, is to be surpassed, the increase will be due to the ore bodies encountered in the upper zone.

CHAPTER XII.—UNDERGROUND WATER.

INTRODUCTION.

The mode of occurrence of the underground water in the Cripple Creek district presents some unusual features, and has been the subject of special reports to the Portland company by Messrs. Victor G. Hills and Charles J. Moore and of a report to the Elkton company by Mr. Seeley W. Mudd.[a] With the common conclusion of these engineers, that the underground water of Cripple Creek is essentially stored water, we are in full accord. We are also indebted to them as well as to Messrs. Countryman & Jaquith, engineers of the El Paso tunnel, and to Mr. Sherwood Aldrich, of the Elkton Mining Company, for many facts pertaining to the water history of the mines and tunnels.

ORIGINAL WATER SURFACE.

The annual precipitation in the district is moderate. According to figures furnished by the Weather Bureau, it was 13.55 inches in 1903 and 24.01 inches in 1904 (an unusually wet year). As these are the only years during which a record has been kept, a close estimate of the average annual precipitation can not be made. The precipitation, however, is certainly less than on Pikes Peak, where observations extending over a period of fifteen years show an average of 28.65 inches. The average for Cripple Creek is probably not far from 16 inches. The slopes in the Cripple Creek district are, for the most part, bare, are frequently swept by dry winds, and are fairly steep, so that a considerable proportion of the rain and snow is evaporated or runs off without sinking into the ground. Finally, the district is deeply dissected by streams, and, as a whole, stands high above neighboring valleys. There are thus present conditions suggesting at first glance unusual depth of ground-water surface.

Such, however, is not the case. The deep shafts in the main volcanic neck, where the ground had not been previously drained by neighboring workings, encountered water at moderate depths. As the shafts of the district did not reach water simultaneously, it is evident that the record of "first water," as a means of determining the original form and position of the ground-water surface, is of unequal value in different mines. According to Mr. V. G. Hills, who has for several years carefully collected and studied the available facts bearing upon the underground water, the only mines whose records of "first water" are useful in this connection

[a] For the reports of Messrs. Hills and Moore, see Ninth Ann. Rept. Portland Gold Mining Company, 1903. See, also, Hills, V. G., Water in the mines of Cripple Creek: Eng. and Min. Jour., vol. 76, 1903, pp. 117 (table), 195-197.

are the Portland, Stratton's Independence, Gold Coin, Hull City Placer (Independence Consolidated), Isabella, Mary McKinney, Moon-Anchor, and perhaps the Victor. To this list should probably be added the C. O. D. mine. Even these records do not accurately fix the original water surface, for the Blue Bell tunnel, as will be seen, began to drain the district at a very early stage in mining development. The mine records show, however, that a former water surface, probably not very different from the original water surface, stood from 9,489 to 9,723 feet above sea level. As might be expected from the fact that the general slope and drainage of the region are westward, the higher water levels were found in the eastern part of the district, where the Hull City Placer reached water at 9,723 feet, the Victor at 9,613 feet (reported), and the Isabella at 9,550 feet, indicating a water surface at an average elevation of approximately 9,600 feet. In the southern and western parts of the district the Gold Coin reached water at a level of 9,396 feet, the Portland at 9,452 feet, Stratton's Independence at 9,569 feet, the Moon-Anchor at 9,489 feet, and the Mary McKinney at 9,498 feet. As the Gold Coin mine is entirely in the granite it may be omitted from the present comparison. The records of the other mines indicate the former presence of a water surface about 9,500 feet above sea. So far as they go, those elevations of "first water" that can be accepted as defining approximately the original water surface indicate that in the area since extensively opened by underground workings this surface sloped westward at a lower angle than the general inclination of the country. If the underground water surface had been reached by several shafts before the initiation of tunnel drainage, its angle of slope would probably have been found even lower. It may be noted in this connection that the 9,500-foot contour (Pl. I, in pocket), which corresponds to the average elevation of the ground-water surface in the southwestern part of the developed area, extends from Wilson Creek, south of Victor, around the southwest base of Squaw Mountain to the Economic mill, thence to Arequa, thence around Beacon Hill just above the El Paso mine, thence to Anaconda, and thence to the southeast corner of the town of Cripple Creek. This sinuous line lies in general outside of the main contact between the breccia and the old granites, gneiss, and schist. It enters the central breccia area, however, at Arequa and Anaconda.

The depth at which water was reached varies from 910 feet in the Isabella to 35 feet in the Mary McKinney, the latter mine being only a little over 33 feet above the 9,500-foot contour at Anaconda.

As the shafts were deepened, the ground water interfered seriously with mining development, and several mines began pumping about the year 1895. It was soon found that the cost of lowering the water in this way was a serious burden and that it fell chiefly upon a few of the deeper and wetter mines. Such individual pumping also revealed certain peculiarities of the ground water which will be referred to later. Attention was accordingly turned to tunnel drainage.

TUNNEL DRAINAGE.

Although not driven for drainage purposes, the Blue Bell tunnel, near Anaconda, is of interest as being the first of the Cripple Creek workings to encounter water. This tunnel, which enters in granite at an elevation of 9,335 feet, or about 15 feet below what seems to have been the average elevation of the original water surface in this part of the district, had a maximum flow of 200 gallons a minute. Water was issuing from this tunnel in 1894, when Penrose visited it, and the flow persisted for several years. The extent to which the Blue Bell tunnel lowered the original ground-water surface in the western part of the district, before water was reached a year or two later in shafts, can not be determined. Its effect, however, was probably slight.

The Ophelia tunnel enters the granite at the west base of Gold Hill at an elevation of 9,268 feet. In December, 1896, this tunnel was 2,600 feet in length, with a discharge estimated at from 2,000 to 2,100 gallons a minute. Practically all of this water came from the breccia, which the tunnel entered about this time, or from open fissure zones that were evidently connected with the main volcanic neck. The tunnel maintained this flow for over a year, becoming dry in 1898, when the Standard tunnel began to drain the district.

The Standard tunnel, begun in January, 1896, has its portal in the granite of Gold Run, west of Beacon Hill, at an elevation of 9,027 feet. Its objective point was not the main volcanic neck, but the phonolite plug of Beacon Hill. In February, 1896, the tunnel cut the El Paso vein, whence issued a flow of 250 gallons a minute. The water became more abundant as the contact between the granite and phonolite was approached, and in 1898, when the phonolite was reached, the flow amounted to 1,000 gallons a minute. This rapidly increased as the tunnel penetrated the phonolite and in 1899 the maximum flow of from 12,000 to 18,000 gallons a minute was attained. Work was finally abandoned in June, 1899, when the tunnel had been driven 2,800 feet. By the end of 1901 the tunnel was dry, having lowered the water levels in the Beacon Hill, Gold Hill, and Raven Hill mines, and probably also, to a less recognizable extent, those of the mines in the eastern part of the district.

The Newell tunnel enters Grouse Hill from Arequa Gulch, its portal being at an elevation of 8,930 feet. It has not reached the Beacon Hill phonolite nor the main volcanic neck, and although its face is 119 feet lower than that of the Standard tunnel, it has never encountered any important flow of water.

The El Paso tunnel, the lowest and most recent drainage tunnel in the district, has its portal at an elevation of 8,783 feet, on Cripple Creek, just below the mouth of Arequa Gulch and a little less than a mile southwest of the El Paso shaft, with which it connects. Work was begun on this tunnel in January, 1903, and on September 6 of the same year connection was completed with the lowest level of the El Paso mine.

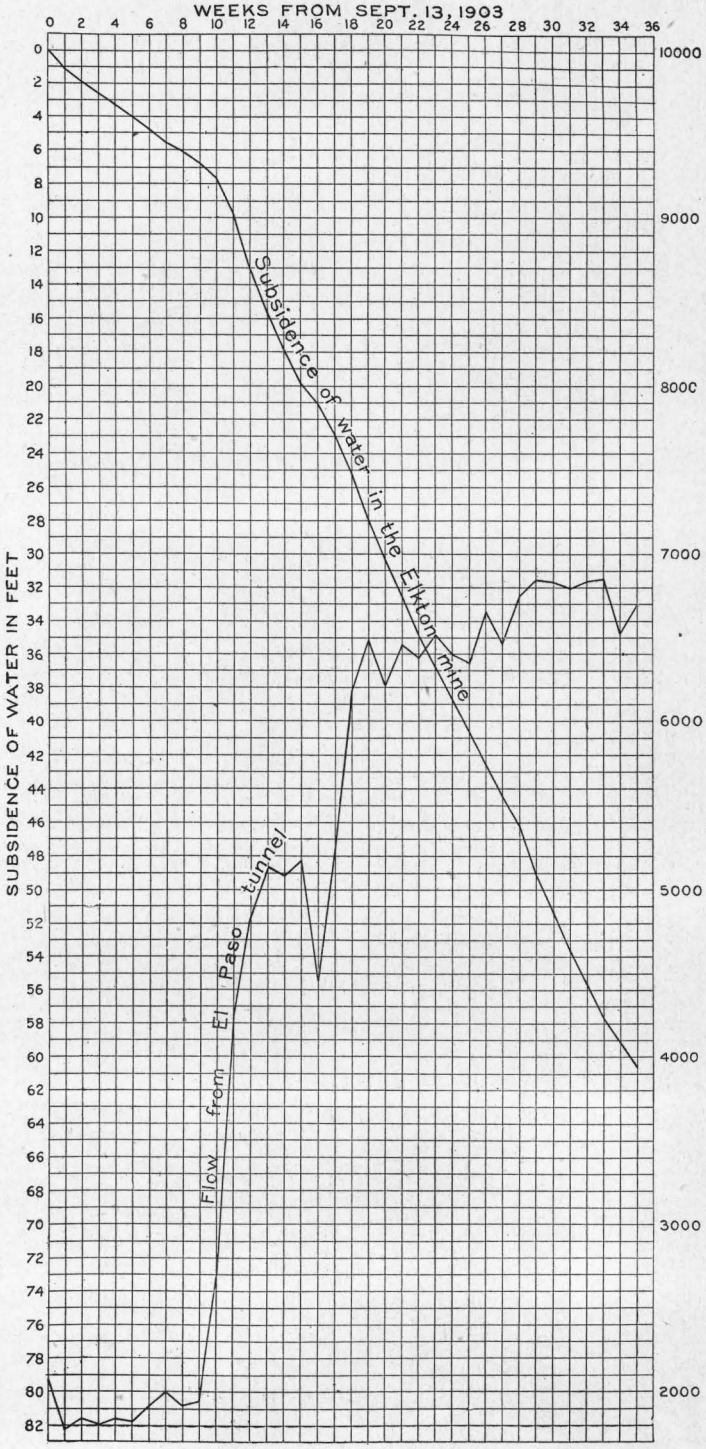


FIG. 22.—Diagram showing relation between the subsidence of the water in the Elkton mine and the outflow from the El Paso tunnel.

The weekly flow from the tunnel, as measured with a Lallie current meter by Countryman & Jaquith, the mining engineers who planned the tunnel, is as follows:

Discharge from the El Paso tunnel September 6, 1903, to December 31, 1904.

Week ending—	Gallons per minute.[a]	Gallons per week.[b]	Week ending—	Gallons per minute.[a]	Gallons per week.[b]
September 13, 1903	2,084	19,595,520	May 15, 1904	6,700	66,694,300
September 20, 1903	1,780	19,468,810	May 22, 1904		65,560,320
September 27, 1903	1,840	18,245,810	May 29, 1904		63,836,640
October 4, 1903	1,808	18,389,750	June 5, 1904		63,735,850
October 11, 1903	1,846	18,421,500	June 12, 1904		63,302,400
October 18, 1903	1,819	18,472,710	June 19, 1904		61,992,000
October 25, 1903	1,925	18,866,130	June 26, 1904		60,157,440
November 1, 1903	2,004	19,803,570	July 3, 1904		60,066,000
November 8, 1903	1,920	19,784,720	July 10, 1904		60,006,240
November 15, 1903	1,947	19,495,730	July 17, 1904		59,566,400
November 22, 1903	2,685	23,351,430	July 24, 1904		58,167,600
November 29, 1903	4,259	35,004,110	July 31, 1904		58,091,040
December 6, 1903	4,835	45,834,970	August 7, 1904		57,556,800
December 13, 1903	5,130	50,220,580	August 14, 1904		56,330,450
December 20, 1903	5,085	51,479,160	August 21, 1904		53,827,200
December 27, 1903	5,174	51,701,430	August 28, 1904		51,105,600
January 3, 1904	4,452	48,512,320	September 4, 1904		50,406,000
January 10, 1904	5,252	48,908,870	September 11, 1904		51,004,800
January 17, 1904	6,186	57,651,950	September 18, 1904		51,005,150
January 24, 1904	6,494	63,912,340	September 25, 1904		49,392,300
January 31, 1904	6,211	64,035,520	October 2, 1904		48,988,200
February 7, 1904	6,464	63,883,100	October 9, 1904		49,341,600
February 14, 1904	6,383	64,749,790	October 16, 1904		48,334,100
February 21, 1904	6,525	65,059,650	October 23, 1904		48,736,000
February 28, 1904	6,398	65,136,250	October 30, 1904		49,190,400
March 6, 1904	6,350	64,256,170	November 6, 1904		48,384,000
March 13, 1904	6,660	65,577,460	November 13, 1904		47,779,200
March 20, 1904	6,476	66,208,360	November 20, 1904		47,073,600
March 27, 1904	6,758	66,702,790	November 27, 1904		47,115,800
April 3, 1904	6,855	68,610,830	December 4, 1904		46,670,400
April 10, 1904	6,838	69,014,740	December 11, 1904		46,972,800
April 17, 1904	6,805	68,761,120	December 18, 1904		47,880,100
April 24, 1904	6,843	68,785,500	December 25, 1904		49,291,200
May 1, 1904	6,848	68,997,500	January 1, 1905		49,644,150
May 8, 1904	6,533	67,435,000			

[a] As measured weekly by Countryman & Jaquith with current meter.

[b] As estimated by Countryman & Jaquith from weekly measurements considered in relation to dates at which principal fluctuations occurred.

Messrs. Countryman & Jaquith[a] estimate the total discharge of the tunnel to January 1, 1905, at approximately 3,550,000,000 gallons, equal to about 474,695,000 cubic feet, or 10,900 "acre-feet," and weighing approximately 14,834,000 tons. The same engineers estimate the minimum cost of pumping this quantity of water, with an average lift of 500 feet, at $600,000, whereas the total cost of the El Paso tunnel was $90,000.

As was the case with the Standard tunnel, the El Paso slowly lowered the water in the Mary McKinney and Elkton mines, showing that there is a connection through

[a] Personal letter of February 13, 1905.

open fissures between the Beacon Hill phonolite and the main volcanic neck. The relation between the flow from the El Paso tunnel and the fall of the water in the Elkton mine is shown in the diagram of fig. 22.

CONDITIONS OF WATER STORAGE.

The records of the various drainage tunnels all suggest the same conclusion, namely, that the volcanic neck, filled with breccia and eruptive rocks, contains a body of water which is prevented from escaping into the streams of the region by the relatively impervious character of the older crystalline rocks of the prevolcanic plateau. The relation is suggestive of a water-soaked sponge set in a glass cup. That these granites, gneisses, and schists are not strictly impervious is shown by the evident connection between the Beacon Hill water and that in the main volcanic neck. This connection, however, is certainly due to one or more zones of persistent fissuring and not merely to passage through slightly jointed rocks. The fact that the tunnels are all comparatively dry until they penetrate the volcanic breccia or until they cut open fissures extending into the breccia and that they then receive a sudden influx of water followed by a lowering of the water level within the breccia shows that natural seepage through the prevolcanic rocks does not exceed the rate of supply to the central reservoir. The granite and related rocks undoubtedly contain water to a depth of over 2,000 feet, but this water must circulate very slowly, as shown by the absence of copious springs in the lower parts of the district, in spite of the considerable head of water formerly stored at higher levels in the breccia. For all practical purposes, therefore, the underground water of the central part of the Cripple Creek district is to be regarded, not as an underground sea extending to indefinite distances from the volcanic center, but rather as an underground lake or pond bounded by the steep walls of the old volcanic throat. In this particular pond, however, rock is far more abundant than water, and the simile should not be carried too far.

SOURCE OF THE WATER.

The question of the source of this water is of considerable scientific and practical importance. The statement is sometimes made that the water never rises after being lowered by pumping. This, of course, is not strictly true, otherwise such mines as the Gold Coin might long ago have stopped their pumps. It may be well doubted whether any wet mine has become dry by pumping alone, though after long-continued and heavy pumping, such as has been practiced in the Elkton, Stratton's Independence, and Gold Coin mines, the water seldom rises again to its original level. The drainage tunnels have been far more potent in effecting a permanent reduction of water level. The facts that these tunnels run dry in a few years and that the springs of the district have never been more than insignificant trickles show that the supply of water to this underground reservoir must be small—certainly less than 2,000 gallons a minute, the quantity which was being pumped from the mines before the completion of the El Paso tunnel. Assuming, however, the supply of water to the underground reservoir to be at the rate of 2,000 gallons a minute and conservatively estimating that the volcanic neck or reservoir has a diameter of 2½ miles, a rough calculation shows that this supply will be maintained if a sheet of water approximately

1 foot in thickness sinks into the ground annually. As the annual net supply to the reservoir is certainly much less than the 2,000 gallons a minute assumed above and may be only a small fraction of that quantity, there is evidently no need of supposing that the water is supplied from below. Samples of water collected at the bottom of the C. K. & N. shaft and from the 1,400-foot level of Stratton's Independence mine were examined by Mr. George Steiger and found to contain little but calcium and magnesium sulphates. Though the water at both places spurted from fissures in the granite, it has none of the properties of water that has come up from great depth. The underground water is invariably cold, that issuing from the El Paso tunnel in April, 1904, having a temperature of 14° C., while the temperature of the air was 16° C. Thus the behavior, character, and temperature of the underground water all indicate a meteoric origin. It is supplied by the rain and snow that fall upon the surface of the district.

EFFECT OF DRAINAGE ON WATER LEVEL.

When the underground water was first encountered its surface was more nearly level than is usual in a region so accidented as that of Cripple Creek. It is hardly probable that the coincidence of water level in the western part of the volcanic area, with the elevation of the lowest notches in the granitic rim near Arequa and Anaconda, was accidental. It may fairly be concluded that, prior to mining operations, any excess of water over that lost by slow seepage through the walls of the volcanic funnel made its escape through these notches to Cripple Creek, and thus determined the position of the general surface of permanent ground water. The lack of inequalities in the old water surface more pronounced than those indicated by the recorded elevations of "first water" suggests further that the volcanic rocks were sufficiently permeable to allow the whole water surface in the volcanic neck to very slowly adjust itself, under natural conditions, to these outlets.

When pumping began, however, this adjustment was soon found to be so slow that for practical purposes the underground water is to be regarded as occupying a number of separate basins. The different effect of the drainage tunnels in various parts of the district suggests the same conclusion. It is certain that the water does not flow with equal freedom in all directions and through all rocks of the volcanic neck. Some of the inequalities of ground-water surface developed by artificial drainage appear in the accompanying table, which is based on a similar table published by Mr. V. G. Hills,[a] supplemented by later data.

[a] Eng. and Min. Jour., vol. 76, 1903, p. 117.

Behavior of the underground water in some of the principal mines of the Cripple Creek district.

[Based in part on a similar table by V. G. Hills.]

Group.	Name of shaft or adit.	Elevation of collar or portal.	Elevation of first water.	Elevation of water.		Elevation of maximum flow.	Elevation of sump.		Depth to first water.	Depth to maximum flow.	Depth to water.		Maximum discharge.	Discharge.		Estimated elevation July, 1903, when pumping stopped.
				July, 1903.	April, 1904.		July, 1903.	April, 1904.			July, 1903.	April, 1904.		July, 1903.	April, 1904.	
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Gallons per minute.*	*Galls. per minute.*	*Galls. per minute.*	*Feet.*
Bull Hill	American Eagle	10,749.5	None.	Below sump.	Below sump.	.....	9,249	9,249	.....	.....	.....	.....	.....	.....	.....	.....
	Blue Bird	10,396.8	9,057	Below sump.	Below sump.	9,057	9,026	9,026	1,340	1,340	.....	.....	.....	.....	.....	.....
	Clyde	10,085.4	9,579	Unknown.	Unknown.	9,473	9,273	9,273	506	.....	.....	.....	150	.....	.....	.....
	Findley	10,398.5	9,119(?)	9,012(?)	9,208	.....	9,003(?)	9,003(?)	1,279(?)	1,279(?)	1,386(?)	1,190	.....	.....	.....	.....
	Golden Cycle	10,065.8	Unknown.	[a] 9,066	9,218	.....	9,036	9,036	Unknown.	9,036	1,000	848	.....	50	.....	.....
	Hull City Placer	10,279.3	[b] 9,723	[a] 9,014	9,224	9,014	9,000	9,000	556	1,265	1,265	1,055	300	300	.....	.....
	Isabella	10,460.1	[b] 9,550	9,350	9,350	9,448	9,332	9,332	910	1,012	1,100	1,100	1,300	.....	.....	.....
	John A. Logan	10,471.7	None.	Below sump.	Below sump.	.....	9,072	9,072	.....	.....	.....	.....	.....	.....	.....	.....
	Last Dollar	10,278.0	9,058	Below sump.	Below sump.	.....	9,010	.....	1,220	1,268	.....	.....	80	.....	.....	.....
	Lillie	10,222.1	[c] 9,709	[c] 9,014	[c] 9,550	.....	8,696	8,696	513	.....	1,208	672	.....	.....	.....	.....
	Orpha May	10,538.2	None.	Below sump.	Below sump.	.....	9,274	9,274	.....	.....	.....	.....	.....	.....	.....	.....
	Vindicator	10,209.3	9,709	[a] 9,012	[a] 9,198	9,012	9,010	9,010	500	1,197	1,197	1,011	800	500	180	.....
	Wild Horse	10,652.8	None.	Below sump.	Below sump.	.....	9,403	9,403	.....	.....	.....	.....	.....	.....	.....	.....
Battle Mountain.	Ajax	10,108.1	8,968	8,990	8,945	8,907	8,878	.....	1,140	1,201	1,118	1,163	22	.....	.....	.....
	Gold Coin	9,764.8	[b] 9,396	[a] 8,656	[a] 8,565	8,763	8,565	8,565	368	1,000	1,109	1,200	900	740	490	8,988
	Portland No. 1	10,082.3	[b] 9,452	9,000	8,974	9,283	8,962	8,962	630	800	1,082	1,108	3,260	.....	.....	.....
	Portland No. 2	10,244.3	.....	[c] 9,000	[c] 8,974	.....	8,962	8,962	.....	.....	1,244	.....	.....	.....	.....	.....
	Portland No. 3	10,332.5	None.	.....	.....	.....	.....	9,177(?)	.....	.....	.....	.....	.....	.....	.....	.....
	St. Patrick	9,615.3	9,372	8,973	8,973(?)	8,915	8,903	8,903	243	700	642	642(?)	30	.....	.....	.....
	Stratton's Independence	9,843.6	[b] 9,569	[a] 8,443	[a] 8,443	9,569	8,443	8,443	275	1,400	1,400	1,400	Unknown.	300	530	8,940
	Strong	9,756.0	9,055	[a] 8,872	[a] 8,872	8,855	8,852	8,852	700	900	884	884	500	200	330	8,984
	Eclipse	9,689.2	9,539	[a] 9,327	9,465	9,539	9,183	9,183	150	150	362	224	10	5	.....	9,543
Raven Hill.	Elkton	9,734.2	9,423	9,017	8,959	8,945	8,768	8,768	311	789	717	775	2,150	.....	.....	.....
	Mary McKinney	9,533.3	[b] 9,498	9,019	[a] 8,937	9,054	8,924	8,924	35	479	514	596	1,400	.....	360	.....
	Morning Glory	9,721.2	Unknown.	9,019	Unknown.	9,021	Unknown.	.....	Unknown.	700	703	.....	1,890	.....	.....	.....

[a] Pumping level. [b] Approximately original ground-water surface. [c] Drained directly by tunnel or connected mine.

Behavior of the underground water in some of the principal mines of the Cripple Creek district—Continued.

Group.	Name of shaft or adit.	Elevation of collar or portal.	Elevation of first water.	Elevation of water.		Elevation of maximum flow.	Elevation of sump.		Depth to first water.	Depth to maximum flow.	Depth to water.		Maximum discharge.	Discharge.		Estimated elevation July, 1903, when pumping stopped.
				July, 1903.	April, 1904.		July, 1903.	April, 1904.			July, 1903.	April, 1904.		July, 1903.	April, 1904.	
		Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Gallons per minute.*	*Galls. per minute.*	*Galls. per minute.*	*Feet.*
Beacon Hill.	El Paso (old shaft)[a]	9,370.4	Unknown.	[b] 8,794	[c] 8,794	8,794	8,794	8,794	9,121	576	576	576	6,805	300	6,805	9,021
Gold Hill.	Anchoria-Leland	10,139.4	9,486	Below sump.	Below sump.	9,389	9,029	9,029	653	750	.....	.....	550	.....	.....	.....
	Midget	9,796.2	.....	Below sump.	Below sump.	.....	9,030	9,030	.....	.....	.....	.....	.....	.....	.....	.....
	Moon-Anchor	9,864.7	[d] 9,489	Below sump.	.....	9,241	9,030	.....	376	624	.....	.....	1,100	.....	.....	.....
	Abe Lincoln	9,611.2	9,483	9,101	Below sump.	9,261	9,086	9,011	128	350	510	.....	500	.....	.....	.....
	Gold King	9,852.3	9,352	9,013	8,977	.....	8,944	.....	500	886	839	.....	750	.....	.....	9,006

[a] Bottom level connects with El Paso tunnel. [b] Pumping level. [c] Drained directly by tunnel or connected mine. [d] Approximately original ground-water surface.

In Pl. XX an attempt is made to show graphically the behavior of the underground water in the principal mines. A large number of facts, many of which have been collected by Messrs. Hills and Mudd, might be cited in illustration of the lack of sensitive adjustment of water surface over the district at large to changes artificially produced at any one point. A few examples only need be here adduced.

In July, 1903, the water in the Portland mine stood 557 feet above the pumping level of the adjoining Stratton's Independence, and had been stationary for several months. In April, 1904, the Portland water had fallen only 26 feet, notwithstanding the facts that pumping has been continuous in the neighboring mine and that the El Paso tunnel had been draining the district for seven months. In August, 1903, the Portland water was falling from 2 to 3 inches a week. The rate evidently increased after the completion of the El Paso tunnel, but how much of this increase is to be ascribed to the tunnel and how much to the increased pumping necessitated in Stratton's Independence mine by the development on level 14 can not be determined. It is probable, however, that the tunnel has aided in lowering the Portland water. In April, 1904, the Elkton water was 15 feet lower than the Portland water, whereas in July, 1903, it was 17 feet higher. In July, 1889, according to Mr. Mudd,[a] the Portland was pumping 1,500 gallons a minute from the 800-foot level, while the Elkton, 40 feet deeper, was dry. According to Mr. Hills,[b] the Clyde mine, on the east side of Battle Mountain, pumped water for over a year in 1900–1901, from an elevation of 9,573 feet, when the Modoc, Last Dollar, and Portland mines, its near neighbors, were dry at lower elevations. The Eclipse mine, between the Portland and Elkton, had, on April 19, 1904, a water level 491 feet above that of the Portland, 520 feet above that of the Ajax, and 506 feet above that of the Elkton. This, as Mr. Hills has pointed out, is one of the most remarkable cases of difference of water level to be found in the district. It is in a way more striking than the greater discordance between the Portland and Stratton's Independence levels, because at this time neither the Eclipse, Portland, Ajax, or Elkton were pumping, and there was supposedly some opportunity for hydrostatic adjustment.

The history of the underground water in the Elkton mine is particularly interesting from its illustration of the fact that the water circulates mainly through open fissures and not through the general mass of the country rock, and from the close connection of this mine with the drainage tunnels. The following account of the Elkton water is based upon carefully prepared data which were very kindly furnished us by Mr. Sherwood Aldrich, chairman of the executive committee of the Elkton company.

The first water encountered in the Elkton mine was on level 3, 9,423 feet above the sea. The flow ranged from 400 to 600 gallons per minute, but after a few months the level became dry, owing probably to drainage through the Ophelia tunnel. The flow on level 4 was similar to that on level 3, while successively larger amounts of water were encountered on levels 5 and 6. These levels also ultimately became dry, being probably drained by the Standard tunnel. In 1900 sinking was continued and stations cut at levels 7 and 8. Pumps were placed on level 8 and drifting was begun from both stations. In February, 1901, the south drift on

[a] Manuscript report to the Elkton company.

[b] Ninth Ann. Rept. Portland Company, 1903, p. 89.

level 7 broke into a cavity, already described, from which a large flow of water immediately rushed and, pouring down the shaft, drowned the pumps at level 8. In a comparatively short time the water rose to a point about 45 feet above level 7. Early in July, 1901, these levels were recovered by pumping and by bulkheading the south drift on level 7, whence most of the water issued. Drifting was resumed on level 8 near the end of 1901, and the water steadily increased until in July, 1902, the pumps were raising from 2,500 to 2,800 gallons per minute. Early in August the attempt at further development below the water level was temporarily abandoned, pumping was stopped, and the water rose to a point 2.5 feet below level 7. During the next thirteen months—that is, until the opening of the El Paso drainage tunnel—the water fell about a foot per month, the lowering of the water being probably due mainly to the pumping in the El Paso mine. September 6, 1903, the tunnel was completed to the El Paso mine and the restraining bulkheads blown out. September 7 the water in the Elkton stood at the shaft 29.5 feet below the floor of level 7, or 9,015.4 feet above sea level. The first rush of accumulated water from the tunnel soon subsided to the normal flow. The following table exhibits the subsequent relation of the Elkton water level to the tunnel drainage:

Relation of water level in Elkton mine to drainage through El Paso tunnel, September 13, 1903, to May 15, 1904.

Date.	Elevation above sea level of water in Elkton mine.	Flow from El Paso tunnel.	Weekly decrease in elevation of Elkton water.	Weekly variations in tunnel flow.	Date.	Elevation above sea level of water in Elkton mine.	Flow from El Paso tunnel.	Weekly decrease in elevation of Elkton water.	Weekly variations in tunnel flow.
	Feet.	*Gallons per minute.*	*Feet.*	*Gallons per minute.*		*Feet.*	*Gallons per minute.*	*Feet.*	*Gallons per minute.*
September 13, 1903	9,013.5	2,084	.....	.....	January 17, 1904	8,988.3	6,186	2.4	+934
September 20, 1903	9,012.4	1,780	1.1	− 304	January 24, 1904	8,985.4	6,494	2.9	+308
September 27, 1903	9,011.6	1,840	.8	+ 60	January 31, 1904	8,983.2	6,211	2.2	−283
October 4, 1903	9,010.9	1,808	.7	− 32	February 7, 1904	8,981.0	6,464	2.2	+253
October 11, 1903	9,010.3	1,846	.6	+ 38	February 14, 1904	8,978.7	6,383	2.3	− 81
October 18, 1903	9,009.6	1,819	.7	− 27	February 21, 1904	8,976.8	6,525	1.9	+142
October 25, 1903	9,008.8	1,925	.8	+ 106	February 28, 1904	8,974.8	6,398	2.0	−127
November 1, 1903	9,008.0	2,004	.8	+ 79	March 6, 1904	8,972.9	6,350	1.9	− 48
November 8, 1903	9,007.5	1,920	.5	− 84	March 13, 1904	8,971.0	6,660	1.9	+310
November 15, 1903	9,006.8	1,947	.7	+ 27	March 20, 1904	8,969.0	6,476	2.0	−184
November 22, 1903	9,005.9	2,685	.9	+ 738	March 27, 1904	8,967.3	6,758	1.7	+282
November 29, 1903	9,003.7	4,259	2.2	+1,574	April 3, 1904	8,964.3	6,855	3.0	+ 97
December 6, 1903	9,000.4	4,835	3.3	+ 576	April 10, 1904	8,962.2	6,838	2.1	− 17
December 13, 1903	8,997.9	5,130	2.5	+ 295	April 17, 1904	8,959.8	6,805	2.4	− 33
December 20, 1903	8,995.8	5,085	2.1	− 45	April 24, 1904	8,957.8	6,843	2.0	+ 38
December 27, 1903	8,993.7	5,174	2.1	+ 89	May 1, 1904	8,955.8	6,848	2.0	+ 5
January 3, 1904	8,992.5	4,452	1.2	− 722	May 8, 1904	8,954.4	6,533	1.4	−315
January 10, 1904	8,990.7	5,252	1.8	+ 800	May 15, 1904	8,952.9	6,700	1.5	+167

The data in the foregoing table are graphically shown in fig. 22 (p. 236). It there appears that a few days after the El Paso tunnel cut into the great watercourse that raised the flow from 2,000 to over 5,000 gallons the water in the Elkton began to fall with comparative rapidity. The line in the diagram representing this fall is nearly straight and strikingly independent of the subsequent fluctuations in the flow from the tunnel, indicating that the rate of fall of the Elkton water is practically limited by the flowage capacity of the natural fissure which afforded the first

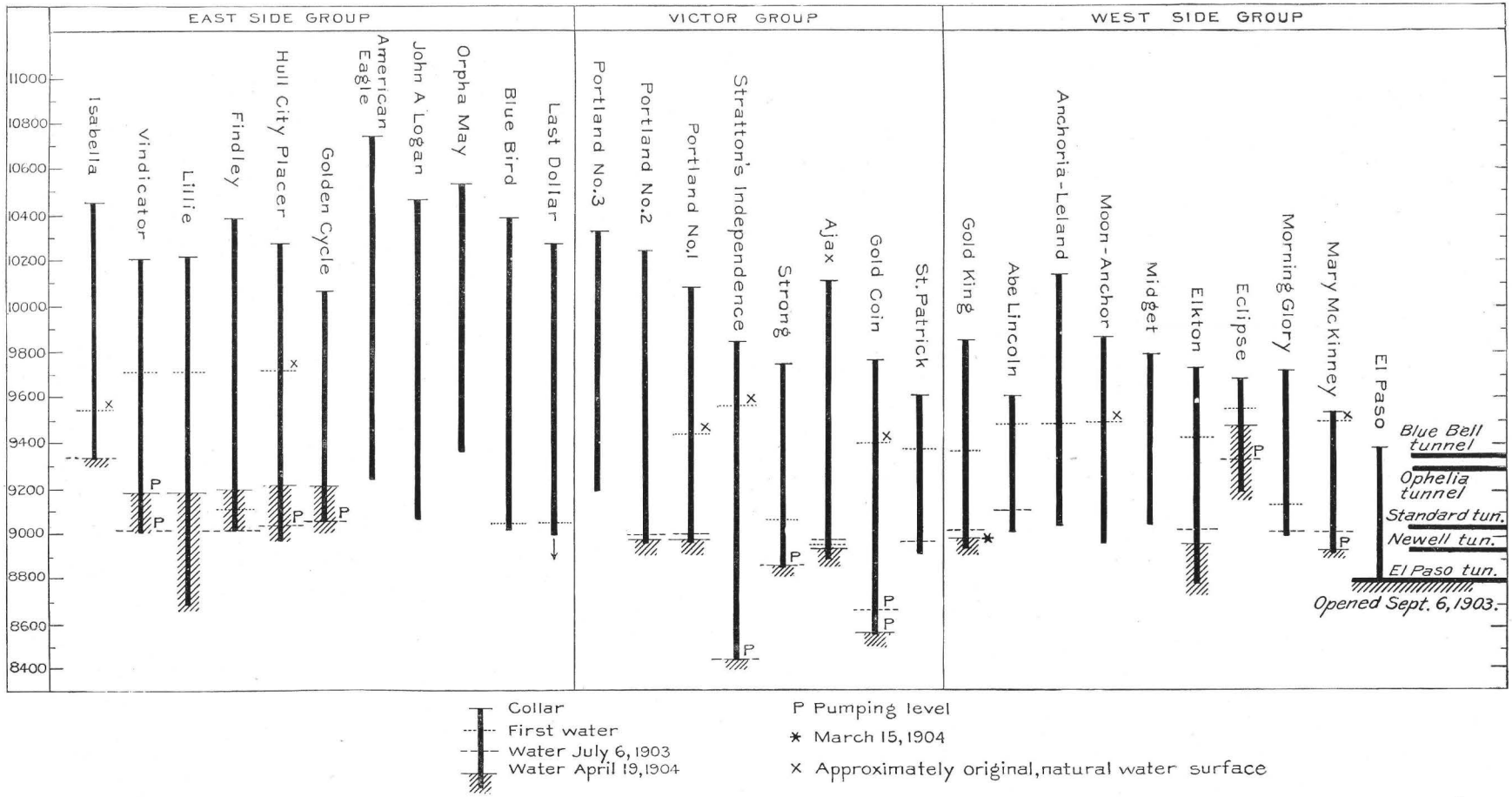
great flow in the tunnel. The water later encountered in the tunnel is apparently not connected with the Elkton mine by any important open channels.

The history of the water of the Elkton mine thus well illustrates the fact that the portion of the underground water which need be considered in mining operations is confined to fissures. It also explains the frequent difference in water level in neighboring mines. The few springs in the district appear in some cases to be unaffected by the unwatering of deep mines in their vicinity, showing that they are not necessarily supplied from a general body of underground water. At Arequa, for example, is a spring that has not disappeared in spite of the deep workings at Elkton and under Beacon Hill.

All of the existing drainage tunnels have tapped the breccia-filled volcanic neck from the west or southwest, and it is from the latter quarter that future tunnels, in all probability, will be driven. The effect of each tunnel has naturally been most quickly and decisively apparent in what may be called the west-side group of mines (Pl. XX, p. 242). That the Ophelia tunnel, driven far into the breccia and through a number of previously known fissure zones, would drain the mines of Raven and Gold hills approximately to its level was almost a foregone conclusion. But in the case of the Standard tunnel, directed not for the breccia but for the phonolite plug of Beacon Hill, no such result could confidently be predicted. Fortunately the phonolite proved to be connected by open fissures with the main volcanic neck, and there can be no question that it lowered the water levels of most of the west-side mines. The Eclipse seems to have been the only wet mine not clearly affected. The peculiar behavior of the water in this mine, which should perhaps be grouped with the Battle Mountain or Victor mines, has already been pointed out and is shown diagrammatically in Pl. XX (p. 242). The Eclipse water seems to occupy an impervious pocket in the breccia, for which no geological explanation has been found. The Standard tunnel undoubtedly drained the Gold Hill and Poverty Gulch mines.

The effect of the Standard tunnel on the mines of the Victor group is not clear. It is supposed to have lowered their water surfaces to some extent, but the continuous pumping of the Stratton's Independence, Gold Coin, and Strong mines has probably been the dominant factor in lowering the water in this part of the district. At all events, the effect of the tunnel drainage is not clearly distinguishable from that of pumping. As may be seen from Pl. XX (p. 242), the pumping levels of the Gold Coin and Stratton's Independence mines are far below the flow gradient of the tunnel.

As regards underground water, the east-side group of mines is divisible into two subgroups. One of these includes the mines lying on the western and southwestern slopes of Bull Hill, particularly the American Eagle, John A. Logan, Orpha May, Blue Bird, and Last Dollar mines. The shafts of these mines are among the deepest in the district, the American Eagle shaft being second only to the Lillie (see Pl. XI, p. 148), though its sump is 806 feet above that of the Stratton's Independence shaft. Notwithstanding their depth, these shafts have had little trouble with underground water. This is due to the fact that they were not sunk to their present depth until this part of Bull Hill had been drained by the mines and tunnels to the west. The American Eagle, John A. Logan, and Orpha May



WATER LEVEL AT VARIOUS DATES IN THE PRINCIPAL MINES OF CRIPPLE CREEK.

shafts have always been dry. The Blue Bird reached water in March, 1902, at an elevation of 9,057 feet, or 30 feet above the portal of the Standard tunnel, which had been dry since the preceding year. This water slowly receded, and in August, 1902, the sump, elevation 9,026 feet, was dry. The Last Dollar first reached water at the same elevation as did the Blue Bird. This soon receded. It was again reached at 9,010 feet, but disappeared after a short period of pumping. After the completion of the El Paso tunnel sinking was resumed and no water had been encountered up to April, 1904. These facts indicate that the mines of the western and southwestern slopes of Bull Hill are effectively drained by the El Paso tunnel.

The mines of the second subgroup lie on the eastern slopes of Bull Hill and on Bull Cliff. They include the Isabella, Victor, Vindicator, Lillie, Findley, Hull City Placer, Golden Cycle, and a number of other mines of less depth. These mines have all had to contend with water, the burden of pumping falling in recent years most heavily upon the Vindicator, which in 1903 was draining the Findley, Hull City Placer, and probably the Golden Cycle. Whether the Isabella belongs to the same drainage basin is doubtful.

In the early part of the year 1903 the Vindicator kept down its water to the lowest level, 9,012 feet above sea, by pumping from 300 to 550 gallons a minute. Under these conditions the Findley, with its sump at 9,103 feet, was dry. The Findley sank another hundred feet, and in June, 1903, there was a little water on this bottom level, apparently corresponding in elevation to the pumping level of the Vindicator sump at that time. The water in the Hull City Placer then stood at 9,052 feet above sea, the pumps discharging 70 gallons a minute. The Golden Cycle, with its sump at 9,066 feet above sea, was kept free of water by pumping 50 gallons a minute. During the labor strike in the autumn of 1903 the pumps were stopped and the water rose at least 200 feet in the Vindicator, Lillie, and Findley mines. The rise in the Hull City Placer and Golden Cycle mines appears to have been slightly less. The position of the water on April 19, 1904, when the Vindicator had resumed pumping and was discharging 180 gallons a minute, is shown in Pl. XX (p. 242). At the date of writing (February 1, 1905) it is reported that the Golden Cycle mine is holding the water at an elevation of 9,066 feet by pumping 300 gallons a minute and that the Vindicator has stopped pumping, with its water at approximately 9,200 feet. The Golden Cycle is thus discharging nearly the same quantity of water that the Vindicator was raising in July, 1903, before the opening of the El Paso tunnel. In other words, the burden of drainage has been shifted to the Golden Cycle mine, and that burden has not been perceptibly lightened, although nearly a year and a half has elapsed since the opening of the tunnel.

The behavior of the water in these five mines shows that they have a common water basin, an artificial change in the water level of any one mine being followed in reasonable time by adjustment in the others. The fact that on the cessation of pumping in 1903 the water in this basin rose only to a level 500 feet below the original water surface indicates a considerable permanent reduction of the water. How much of this is due to the pumping of the Victor and west side groups of mines and to the drainage tunnels and how much to the persistent pumping of the Vindicator and near-by mines can not be determined. The water of the Vindicator stood, in

April, 1904, 171 feet above the portal of the Standard tunnel. This gives a flow gradient, to the mouth of the tunnel, of about 1 to 82, which, in view of the conditions of flowage through the rocks, does not preclude the possibility that the Standard tunnel has aided in lowering the water in these mines. On the other hand, during the seventeen months ending December 31, 1904, the El Paso tunnel discharged 3,550,000,000 gallons of water without perceptibly relieving the mines at Altman and Independence. We are forced to conclude that from a practical standpoint the existing tunnels do not aid the Vindicator, Lillie, Hull City, Findley, and Golden Cycle mines. The same statement probably applies to the Isabella mine, which may occupy a local water basin having only imperfect flowage connection with that of the Vindicator mine. The long idleness of this mine and the relatively high level of its sump (Pl. XX, p. 242) leave us somewhat in doubt as to the recent behavior of its water. The portion of the district probably drained to a practical extent by the El Paso tunnel is shown in fig. 23 (p. 250).

The isolation of the Vindicator water basin from those of the west side and Victor groups is apparently not due to the intervention of any continuous zone of massive rock, such as a phonolite or basic dike. The fissure systems of the Vindicator, Gold Cycle, and other mines in the vicinity traverse breccia as well as syenite and latite-phonolite, and were the breccia generally permeable there is no reason why the water should not drain westward. But the experience gained in underground workings, notably in the Elkton mine, shows that unfissured breccia may be practically impervious. The fissure systems of the Altman and Independence mines have a general northwest-southeast trend. Between these fissures and those those of the west and southwest slopes of Bull Hill is a zone of breccia with intrusive masses of syenite and latite-phonolite, which contains, so far as known, no important cross fissures that might serve as water channels. In the absence of notable east-west or northeast-southwest fissures in this zone is probably to be found the chief explanation for the failure of existing tunnels to drain the mines near the eastern side of the volcanic neck.

FUTURE DRAINAGE.

Mr. Hills has shown[a] that it is practicable to tap the Cripple Creek volcanic neck from the southwest by tunnels at various altitudes down to 6,600 feet. Taking the Blue Bird shaft as an objective point, he estimates the lengths of some of the possible tunnels as follows:

Estimated length of possible tunnels in Cripple Creek district.

Elevation of portal above sea.	Length of tunnel.
Feet.	*Feet.*
8,600	16,000
8,400	18,400
8,200	19,600
8,000	21,000
7,500	23,900
7,000	29,000
6,600	36,000

[a] Ninth Ann. Rept. Portland Gold Mining Company, 1903.

A tunnel at 6,600 feet elevation would enter the breccia about 2,000 feet below the portal of the El Paso tunnel, would be approximately 7 miles long, and is regarded from the engineer's standpoint as the lowest tunnel practicable. At the present stage of mining development in the district, however, it seems inadvisable to seriously consider any proposed tunnels below an elevation of 7,500 feet. A tunnel at that elevation would be about 4½ miles long and would have its face about 1,200 feet below the portal of the El Paso tunnel. Its cost in round figures would probably be from $400,000 to $500,000. Whether such a tunnel will be justified depends primarily upon the outlook for extensive ore bodies below the El Paso tunnel. Even if this outlook should prove encouraging, the wisdom of tunneling at an elevation of 7,500 feet rather than at 8,000 feet or higher might well be doubted. The justification for deep tunneling depends further upon the question whether water is as abundant at greater depth as it is above the El Paso tunnel and whether it can pass with sufficient freedom through the rocks to insure effective drainage of the major part of the district.

Knowledge of the number of gallons of water corresponding to a fall of 1 foot in the general reservoir would be of great use in planning future drainage operations. This problem, however, presents two serious difficulties—(1) the data regarding the quantities of water pumped and drained from the district since operations began are very incomplete, and (2) it is impossible to determine with accuracy the average level of the water at any one time. Mr. S. W. Mudd, in connection with his report to the Elkton Company, collected all the available data and calculated that from January 1, 1896, to December 31, 1901, the total quantity of water discharged from the mines and tunnels amounted to 20,005,405,000 gallons. He estimated the general lowering of the water within the same period to be 300 feet, giving an average discharge of 66,684,683 gallons for each foot of subsidence. The semiannual relations of subsidence and discharge and the pumping data from which they are derived are shown in the following table taken from Mr. Mudd's report:

Quantity of water pumped from the Cripple Creek mines from January 1, 1896, to July 1, 1902.

[Compiled by Seeley W. Mudd for a report to the Elkton Company.]

Period.	Elkton.	Mary. McKinney.	Portland.	Standard. tunnel.	Morning Glory.
	Gallons.	*Gallons.*	*Gallons.*	*Gallons.*	*Gallons.*
Jan. 1, 1896, to July 1, 1896	.....	.....	.....	.....	.....
July 1, 1896, to Jan. 1, 1897	43,200,000	.....	52,876,200	.....	.....
Jan. 1, 1897, to July 1, 1897	105,753,600	8,304,400	83,635,200	.....	.....
July 1, 1897, to Jan. 1, 1898	180,403,200	108,172,800	103,680,000	.....	.....
Jan. 1, 1898, to July 1, 1898	33,868,800	158,284,800	156,556,800	115,960,000	.....
July 1, 1898, to Jan. 1, 1899	97,436,800	140,313,600	274,742,000	485,568,000	.....
Jan. 1, 1899, to July 1, 1899	79,120,000	48,729,600	357,686,000	3,810,240,000	.....
July 1, 1899, to Jan. 1, 1900	114,356,800	174,528,000	145,152,000	3,246,912,000	.....
Jan. 1, 1900, to July 1, 1900	123,624,800	6,912,000	67,046,400	2,547,072,000	.....
July 1, 1900, to Jan. 1, 1901	173,836,800	232,257,600	129,600,000	2,004,480,000	.....
Jan. 1, 1901, to July 1, 1901	277,516,800	360,115,200	71,539,200	1,137,024,000	45,964,800
July 1, 1901, to Jan. 1, 1902	302,054,400	94,003,200	77,414,400	107,136,000	328,220,000
Jan. 1, 1902, to July 1, 1902	503,884,800	67,046,400	150,681,600	.....	262,656,000
Total	2,035,056,800	1,398,667,600	1,670,609,800	13,454,392,000	636,840,800

Quantity of water pumped from the Cripple Creek mines from January 1, 1896, to July 1, 1902—Continued.

Period.	Moon-Anchor.	Total.	Elevation of water level.	Drop in water level.	Amount pumped per foot of drop in water level.
	Gallons.	*Gallons.*	*Feet.*	*Feet.*	*Gallons.*
Jan. 1, 1896, to July 1, 1896	13,132,800	13,132,800			
July 1, 1896, to Jan. 1, 1897	40,780,800	136,857,000			
Jan. 1, 1897, to July 1, 1897	181,735,600	379,428,800			
July 1, 1897, to Jan. 1, 1898		392,256,000	9,335		
Jan. 1, 1898, to July 1, 1898	52,876,800	517,547,200	9,305	30	17,251,573
July 1, 1898, to Jan. 1, 1899	236,192,000	1,234,252,400	9,285	20	61,712,620
Jan. 1, 1899, to July 1, 1899	285,120,000	4,580,895,600	9,242½	42½	107,785,779
July 1, 1899, to Jan. 1, 1900		3,680,948,800	9,172½	70	52,584,983
Jan. 1, 1900, to July 1, 1900		2,744,655,200	9,137½	35	78,418,720
July 1, 1900, to Jan. 1, 1901		2,540,174,400	9,102½	35	72,576,411
Jan. 1, 1901, to July 1, 1901		1,892,160,000	9,082½	20	94,608,000
July 1, 1901, to Jan. 1, 1902		908,828,000	9,057	25½	35,640,313
Jan. 1, 1902, to July 1, 1902		984,268,800	9,035	22	44,739,491
Total	809,838,000	20,005,405,000		300	[a] 66,684,683

[a] Average.

Mr. Mudd was compelled by lack of data to disregard the considerable flow from the Ophelia tunnel. He also omits from his calculations the probably small quantity of water that sinks into the ground each year and the water pumped from the Gold Coin and Stratton's Independence mines, probably because he considered these mines as outside of the area affected by the drainage tunnels. His general conclusion was that the quantity of stored water decreases as greater depth is attained.

Recently Mr. A. C. Jaquith[a] has estimated that during the four weeks ending April 10, 1904, the average discharge necessary to lower the water in the Elkton mine 1 foot was 34,839,775 gallons. This, taken in connection with Mr. Mudd's figures, indicates that there is less water in the lower part of the subterranean reservoir than above. It is certain, however, that the water in the Elkton and Mary McKinney mines is lowered more rapidly by the tunnels than in other mines less favorably situated, so that a fall of 1 foot in the Elkton does not mean that the entire surface of the reservoir has subsided to the same extent. These estimates, in short, are at best very rough approximations to the truth.

The volumetric ratio of the water-bearing spaces to the rock mass as a whole can not be determined from existing data. It has been shown that in the spring of 1904 a discharge of approximately 35,000,000 gallons corresponded to a fall of 1 foot in the Elkton and Mary McKinney mines. If the entire volcanic neck were affected, if the volcanic rocks everywhere permitted the free passage of water, and if the inclosing granite, gneiss, and schist were quite impervious, it would be a comparatively simple matter to estimate the approximate area of any given horizontal section of the neck and then to calculate the percentage of water-bearing spaces. These conditions, however, do not obtain. The rocks are practically impermeable except where fissured, and the eastern part of the volcanic neck is but slowly affected by the drainage of the western part. The rock mass drained by lowering the water

[a] Oral communication.

1 foot near Beacon Hill may be compared to part of an exceedingly irregular horizontal lens 1 foot thick near Beacon Hill and thinning to an edge in the northern and central parts of the productive area. Within such a mass, however, would be pockets of water undrained because not connected by fissures with the artificial channel of discharge. Furthermore, certain persistent fissures would probably contribute water from points outside of the recognized limit of general drainage. It is thus impossible to determine with any approach to accuracy what area a plate of rock 1 foot thick and possessing the same water-bearing capacity as the Cripple Creek rocks should have in order to contain the quantity of water removed from the district when the water in the Elkton is lowered 1 foot. It may be assumed that the area of such a plate is equal to that part of the volcanic neck lying south of Globe Hill and west of Bull Hill, plus a projecting area to include the phonolite plug of Beacon Hill. (See fig. 23.) In such case the volume of rock drained is approximately 80,000,000 cubic feet. If the water discharged for each foot of subsidence is taken at 35,000,000 gallons, the drained water-bearing cavities in the rock constitute about 6 per cent of the whole. If Mr. Mudd's estimate of approximately 66,700,000 gallons be accepted as the average discharge per foot of drop above the level of the Standard tunnel, then the water-bearing cavities, on the same assumption as before with regard to the area drained, constitute about 13 per cent of the rock volume. These rough estimates, it should be observed, relate merely to spaces of visible size, due chiefly to fracture, but probably in some cases, as in the Elkton mine, enlarged by solution. If the assumption as to area drained is anywhere near the truth, even the lower figure of 6 per cent indicates that the aggregate water capacity of the fissured rock of the volcanic neck is unusually large for texturally nonporous rocks. Similar or more accurate estimates for other regions are lacking, so that no close comparisons are possible. The original pore space in coarse assorted gravel probably ranges, according to Van Hise,[a] from 32 to 40 per cent. The water-bearing spaces in some of the shattered rock in the Moose, Midget, Moon-Anchor, and Conundrum mines are probably nearly as porous as coarse gravel, and the large water capacity or such portions of the volcanic neck considered in connection with the remarkably abundant fissures suggests that the assumed area of the hypothetical plate 1 foot in thickness is not excessive.

It is probable that at a depth of 1,000 to 1,500 feet below the El Paso tunnel open fissures and shattered zones in the breccia will still be sufficiently abundant to contain in the aggregate a large body of water, though the amount is likely to be smaller than that at the El Paso level. It is probable, also, that the greater part of this water can be drawn off by a tunnel, provided that the main tunnel or crosscuts are run through fissure zones known to carry abundant water at higher levels.[b] From a tunnel driven to a point under the Blue Bird shaft it would not be difficult to crosscut into the water basin of the Vindicator and Golden Cycle mines. The valuable bearing on this problem of the careful record that has been kept of the El Paso water can hardly be overestimated.

[a] A treatise on metamorphism: Mon. U. S. Geol. Survey, vol. 47, 1904, p. 127.

[b] Press dispatches from Cripple Creek, dated March 27, 1906, bring news that the El Paso mine, which has been opened to the 1,000-foot level, or 400 feet below the drainage tunnel, has been flooded. On breaking through the El Paso phonolite dike (see fig. 39, p. 350) the miners encountered an unexpected flow of water, estimated at from 5,000 to 7,000 gallons per minute, which drowned the pumps and in six hours filled the mine to the 600-foot level. This event shows that the fissuring along the C. K. & N. vein constitutes an open and effective waterway to a depth of at least 400 feet below the present drainage tunnel.

Since the completion of the geological work in the district the El Paso, Elkton, and other mines have stoped down to the water level established by the El Paso tunnel. A new tunnel is now under consideration and a report on the subject of

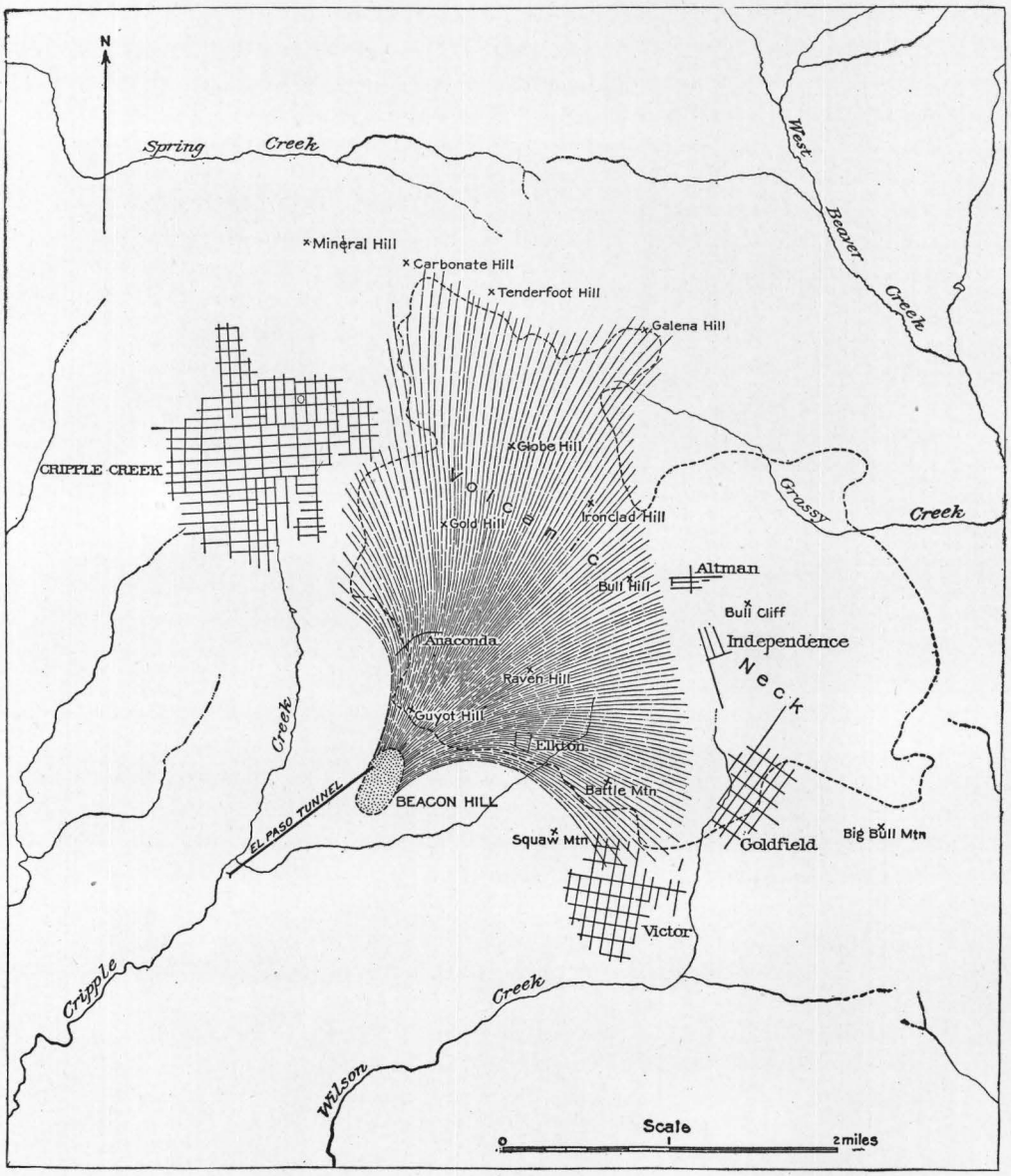


FIG. 23.—Diagram showing probable extent of area practically affected by drainage tunnels into Beacon Hill.

deeper drainage has been prepared by Mr. D. W. Brunton[a] for the Cripple Creek Mine Owners' Association. He shows that the three most feasible sites for the portal of the proposed tunnel are Cape Horn, Gatch Park, and Window Rock, all in the

[a] Drainage of the Cripple Creek district: Eng. and Min. Jour., vol. 80, 1905, pp. 818–821.

canyon of Cripple Creek. The relative advantages of the three sites are compared by him in the following table:

Comparison of three sites for portal of new tunnel.

Location of portal.	Elevation of portal.	Depth below El Paso 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 foot of depth drained.
	Feet.	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Feet.*	*Years.*		*Feet.*	
Cape Horn	8,160	630	12,840	13,840	8,840	650	1.97	$380,000	605	$628
Gatch Park	8,020	770	14,550	15,550	10,570	880	2.1	430,000	740	581
Window Rock	7,660	1,130	17,200	18,200	12,690	1,140	2.5	510,000	1,090	468

Mr. Brunton recommends a tunnel having its portal at Window Rock, though he states that either of the other sites would give the district adequate drainage for many years. Whichever site be chosen, the new tunnel will probably pass under Beacon Hill, tapping the open fissures that have proved so useful in the Standard and El Paso drainage projects. From Beacon Hill a branch of the tunnel will in all probability be driven east until the east side group of mines are effectively drained.

According to the latest advices (March, 1906), received during the final revision of this report, differences of opinion on the part of the mine owners with regard to the most desirable course for the tunnel and the equitable assessment of the cost are delaying the initiation of the project.

CHAPTER XIII.—UNDERGROUND GASES AND TEMPERATURE.

SUBTERRANEAN GASES.

GENERAL STATEMENT.

During the earlier years of development in the Cripple Creek district no unusual mine gases were observed, but as the shafts were deepened and the workings extended several properties began to experience much annoyance and even serious interference with the work, often in spite of vigorous measures to insure ventilation. At least one mine has been forced to close down, largely on account of this subtle and insidious enemy, and several miners have perished by it. The trouble appears to increase as depth is gained, though at what rate can not as yet be ascertained. Certain localities are almost exempt, while in other mines not far distant the gas issues in large quantities. The gas has proved to be a mixture of nitrogen and carbon dioxide, with some oxygen.

The subject seemed of sufficient importance to warrant a careful investigation. Such facts as have been ascertained are set forth in the following paragraphs.

COMPOSITION OF AIR.

Normal air should have the composition shown in the following table:

Composition of normal air.

	Dry air.		Average air (volumes).
	Volumes.	Weight.	
Oxygen	20.92	23.10	20.6
Nitrogen	78.10 } 79.04	75.55 } 76.85	78.5
Argon	.94	1.30	
Carbon dioxide	.04	.....	.04
Water	.....	.....	.86
	100.00	100.00	100.00

Comparative specific gravity of air and various gases.

Air	1.0000
Oxygen	1.1056
Nitrogen	.9713
Carbon dioxide	1.5290

The amount of water gas naturally varies and may reach 3 per cent by volume. In moist climates it would perhaps average 1.3 per cent by volume or 0.84 per cent by weight. The air at Cripple Creek is ordinarily dry, and the elevation above sea level is without influence on its percentage composition.[a]

[a] Erdmann, H., Lehrbuch der anorganischen Chemie, Braunschweig, 1902, p. 223.

A loss of oxygen by oxidation of pyrite or organic matter, for instance, soon makes air unfit for respiration. Air having but 15 per cent of oxygen is dangerous or even fatal.[a]

The percentage of carbon dioxide given in the table is often exceeded. According to Cl. Winkler, the exhaust air in the Saxon coal mines averages 0.7 per cent CO_2, but with such an amount the air is still respirable. At 1 per cent the presence of CO_2 may produce no special discomfort. With 2 to 2.5 per cent CO_2 the candles are extinguished,[b] but, as all miners know, the air can then still be breathed without much inconvenience. At 5 or 6 per cent the condition is very dangerous, and any excess of CO_2 above this amount is soon fatal.

The per cent of carbon dioxide may be easily determined in the mine by the little portable apparatus devised by Lunge, by which the volume of air which will neutralize a given amount of lime water is ascertained, the end of the reaction being indicated by the discoloration of a solution of phenol-phthalein. Such an apparatus is in regular use by the mine inspectors in the alluvial mines of Victoria, Australia, and one of these was obtained through the kindness of Mr. Wykeham Bayley of the government laboratories in Melbourne. It was soon found to be useless, however, for in the Cripple Creek mines the excess of nitrogen may be as dangerous as that of carbon dioxide. Unfortunately no methods for the direct determination of oxygen are suitable for a compact portable apparatus, and thus physiological effects, together with candles and lamps, afford the only easy and safe method of ascertaining the deficiency in oxygen. It was found that the small portable acetylene lamp now in common use among mine superintendents and engineers offers a fairly safe indication. This lamp will burn long after the candles are extinguished, but when it refuses to burn the air is very dangerous. This probably indicates about 15 per cent of oxygen.

Neither nitrogen nor carbon dioxide is directly poisonous, and the effect is in both cases due to suffocation. But there is reason to believe that the heavy carbon dioxide produces the worse effect by interfering more actively with the diffusion of gases in the lungs. It is difficult to say just what deficiency in oxygen may be permissible in spaces where men are working continuously. It assuredly should not exceed 1 per cent. The air may, of course, be entirely unfit for long-continued use while candles are still burning. In general the workings of the Cripple Creek mines are well ventilated and contain a very small percentage of carbon dioxide.

DISTRIBUTION AND MODE OF OCCURRENCE.

The gas appears chiefly in the western part of the district, where few of the deep mines are entirely free from it. It rarely occurs in the eastern part, including the mines of Victor and Battle Mountain and the Vindicator and Isabella vein systems, although these mines are among the deepest in the district. A little gas may occur sporadically in long crosscuts, or small pockets of it may be struck (as in the Hull City mine), but as a whole this vicinity is remarkably exempt from it. In this connection it is worthy of note that the veins mentioned form a separate drainage sys-

[a] Kohler, G., Lehrbuch der Bergbaukunde, Leipzig, 1900, p. 674.

[b] Smith, A. M., Report on the foul air in the Allendale mines: Special Rept., Dept. of Mines, Melbourne, 1892.

tem which does not freely communicate with the more open rocks and fissures of the western half of the district, as is shown by the failure of the drainage tunnels to rapidly unwater them.

In the western part of the district, extending as far east as Eclipse Gulch and Bull Hill, gas began to be encountered as depth was attained. In the Wild Horse mine it was found at a depth of 1,200 feet, in others at from 500 to 800 feet below the surface. It may issue uniformly from the country rock, chiefly from a porous and fractured breccia, as in the Ophelia tunnel, or directly from partly open vein fissures, as in the Elkton. In many cases, as at the Moose and Conundrum mines, it pours out along basic dikes in more or less shattered rocks. Again it may locally issue from fractured granite near the contact with the igneous rocks, as in the El Paso mine. In places, at periods of low barometer, it will break out and possibly entirely fill a mine which at other times is free from it. It may issue almost continuously from a certain place in a drift, even with good ventilation, producing a local barrier of bad air.

PHYSICAL CHARACTERISTICS AND COMPOSITION.

The gas is colorless and without noticeable taste or odor. It is stated, however, that it sometimes, when very strong, appears as a bluish haze. If this is correct, it is no doubt due to its being saturated with water gas, as is the usual case with the carbon dioxide of the Victorian deep alluvial mines. It is a heavy gas, normally filling the lower part of winzes and drifts up to a horizontal plane defined by the sudden extinction of the candles. Apparently, however, its weight is not an unfailing characteristic, for it is reported from some places—the Last Dollar mine, for instance—as accumulating in the roof of the crosscuts. When the breast of the Ophelia tunnel was examined (p. 269) the acetylene lamps barely burned, but no difference whatever was noticeable in the amount present on the floor and in the back of the tunnel, which is 8 feet high. The percentage of carbon dioxide measured was only 0.68. The temperature of the gas is without doubt higher than the normal temperature of the mines. This is well shown by the fact that in the nonventilated breast of the Ophelia tunnel the temperature is +58° F. when gas issues, and only +54 F. on days when gas is absent. In the Conundrum mine the temperature on the 600-foot level was +62° F. when the drift was filled with gas, and only +53° F. when, with a higher barometer, the gas had subsided to a point where it filled only the winzes. As shown on page 270, the normal increment of temperature in the district as measured in gas-free mines is 1° F. in 60 feet. This corresponds to the lower temperatures given above, while the higher figures would give an abnormally rapid increment.

Where no determination of moisture is required, the gas can be collected in a large bottle, say an acid bottle holding about 2 or 3 liters, simply by filling it with water and emptying it in the locality to be sampled. The two samples from the Conundrum mine were collected in this manner. A more accurate apparatus was used in the Elkton mine, where the gas issued from a fissure in the roof of the drift. It consisted of two 2-liter bottles, stoppered and connected by a rubber tube provided with pinchcocks. A long rubber tube reached up from the dry gas bottle to the fissure and was inserted in it as far as possible. The other bottle was filled

with water and its repeated filling and emptying by siphon insured a corresponding quantity of dry and pure gas in the dry bottle.

The two samples from the Conundrum mine, collected under the conditions explained on page 262, were analyzed by the department of chemistry of Cornell University through the kindness of Prof. L. M. Dennis, the analyst being Mr. L. F. Hawley.

Volumetric analysis of gas from Conundrum mine.

	1.	2.
Carbon dioxide	10.2	8.3
Oxygen	5.7	10.2
Nitrogen (by difference)	84.1	81.5
	100.0	100.0

No methane or other hydrocarbons were found, nor was there any carbon monoxide or hydrogen.

One sample from the Elkton mine, level 7, south, collected by Mr. L. C. Graton on April 15, 1904, under conditions explained above, was also forwarded to Professor Dennis, who reports on it as follows:

The gas was received in a 2-liter glass-stoppered bottle, stopper tied in and protected with paraffin-coated canvas.

The analysis was made by Dr. Arthur W. Browne, of the department of chemistry, Cornell University. All determinations of absorbable constituents were made over mercury in a Hempel burette provided with a water jacket. The absorbents were contained in mercury pipettes that were charged with not more than from 15 to 25 cc. of the absorbent. In the absorption analysis the first series of results was rejected to avoid errors due to incomplete saturation of the reagents with the nonabsorbable constituents. The percentage of water vapor was determined in two fresh samples of the gas by absorption with concentrated sulphuric acid, the acid being of course saturated with the other constituents of the gas. Nitrogen was determined by sparking the unabsorbed residue with an excess of oxygen over a solution of potassium hydroxide. This was first carried on in a Winkler-Dennis combustion pipette fitted with an adjustable spark-gap in place of the spiral coil. The final experiments, looking to the removal of nitrogen, were made in a Hempel explosion pipette with the spark gap slightly widened. When the residue was sparked in this manner with oxygen, contraction took place and continued for about forty hours. The mixture was sparkled for several hours after contraction had ceased. The spectrum was then observed and nitrogen lines were found to be absent. The excess of oxygen was then removed and the inert residue was measured. Spectroscopic examination of this residue revealed the presence of argon only. This result was confirmed by comparison (by superposition) with the spectrum of an argon tube. The results of the analysis are as follows:

Volumetric analysis of gas from the Elkton mine.

Water vapor	1.4	Hydrogen	0.0
Hydrocarbon vapors	0.0	Methane, etc	0.0
Carbon dioxide	14.7	Nitrogen	76.8
Heavy hydrocarbons	0.0	Argon	1.5
Oxygen	5.6		
Carbon monoxide	0.0		100.0

This gas may be considered as a mixture of about 25 per cent air, 59 per cent nitrogen and argon, 15 per cent carbon dioxide, and 1 per cent water vapor. There is considerably more argon present than in normal air. If the air be regarded as an accidental admixture the pure gas would consist of about 20 per cent carbon dioxide and 80 per cent nitrogen and argon.

PHYSIOLOGICAL EFFECTS.

The gas produces the usual effects of suffocation. When present in small quantities a feeling of oppression and heaviness, with headache, is noted. In larger amounts the breathing and the pulse become rapid. If no fresh air is obtained collapse follows, often very suddenly and before the full extent of the danger is realized. The deaths due to gas have generally occurred in this way and not because the escape had been cut off. Nausea, vomiting, and pains in the back are common after-effects of a short visit to a gas-filled drift or winze. In some cases men have worked one or two days by electric light in places where candles would not burn; but in such cases utter exhaustion and possibly permanent injury followed.

CONDITIONS OF OCCURRENCE.

The miners soon ascertained that in the places affected the bad air was present and absent at intervals. The reason commonly assigned was the change of direction of the wind, high southwesterly winds being generally supposed to bring out the gas. In no mine were barometric observations carried on. While a local influence of winds on conditions of ventilation can not be denied, the relations of mine gases to barometric fluctuations, as established by investigations elsewhere, suggested an inquiry along these lines. A few observations in the Ophelia tunnel and in the Conundrum mine soon confirmed the hypothesis that the influx of gas takes place during low barometer and that the air is good during periods of high pressure. A series of observations extending over eight months was kindly and most efficiently carried out for us by Mr. B. F. Tipton, of the Conundrum mine, as recorded on page 264. In conjunction with our own data these records prove fairly well that the gases are subject to Kohler's laws, primarily formulated for coal mines, which may be expressed as follows:[a]

1. The influx of gas increases with falling barometer and decreases with rising barometer.

2. The rapidity of the influx of gas is, roughly, proportional to the rate of decrease of pressure, and, conversely, the more rapidly the pressure increases the more rapidly the gas disappears.

3. If a sudden fall of the barometer is followed by a longer period of low pressure the gas decreases slowly. If a sudden rise of the barometer is followed by a less rapid increase, or if the pressure remains constantly high, the quantity of gas will slowly increase. The largest or smallest amount of gas present does not, therefore, always correspond to the minimum or maximum of pressure.

The records kept by Mr. Tipton show that in April and May, as well as in November and December, 1904, a great number of sharp fluctuations took place, the aneroid varying from 20.1 to 20.7 inches. One or two remarkable exceptions were noted. The gas was bad on April 23, with the high stand of 20.6 and a strong southwest wind.

During the summer and fall, from June 9 to October 29, the barometer remained steadily at 20.4 to 20.5. During this period slow and curious fluctuations took place. From June 9 to August 4 the gas was continuously very troublesome.

[a] Kohler, G., Lehrbuch der Bergbaukunde, 5th ed., Leipzig, 1900, p. 682.

On August 5, without change in barometer, the gas disappeared, and conditions continued good until August 24, the barometer remaining steady. From August 25 to October 29 the barometer remained at 20.4 to 20.5, and some gas was present at intervals. On October 29, for the first time since July 13, the barometer sank to 20.3 and more gas appeared. On December 15, 23, and 24 the aneroid indicated the low pressure of 20 inches, and the whole mine was filled with gas.

Imperfect as they are, these data seem to indicate that the gas is influenced to a lesser degree by some factor besides the atmospheric pressure. If, as seems probable, the gases are of volcanic origin and given off by a cooling magma, the supposition that their pressure is subject to some such fluctuations as appear when the barometer is steady, as during the summer months, is not unreasonable. It is to be hoped that long-continued and more detailed records, which no doubt will be kept in the future at the mines where gas appears, will throw more light upon these important questions.

ORIGIN OF THE GAS.

Although carbon dioxide may be introduced in mines locally by many natural and artificial processes, and although the proportion of nitrogen likewise may be increased in places by some such chemical reactions as oxidation of pyrite or combustion of powder, it seems entirely out of the question to account for the mine gases at Cripple Creek by such explanations. There is very little timbering used from which carbon dioxide could form by decay; there is only a small proportion of carbonates and pyrite present in the ores and rocks compared to that in many other mines entirely free from gas. Moreover, the fact that practically no gas was encountered in the oxidized zone shows that oxidation can not have anything to do with its origin. The sudden influx of large volumes in some mines at periods of low barometer clearly shows that vast amounts of this dangerous gas are stored in the rocks; and as the evil in general increases with depth, it is evidently accumulated mainly below the present workings in the porous volcanic rocks, a conclusion also borne out by the fact that the gas has a higher temperature than the normal mine air.

Considering further that exhalations of gases composed of carbon dioxide, oxygen, nitrogen, and sometimes also sulphureted hydrogen always take place after volcanic eruptions,[a] and that they frequently continue for a long time after the cessation of the igneous outbursts, we believe that the mine gases of Cripple Creek represent the last exhalations of the extinct Cripple Creek volcano. If this is true, and the evidence in favor of it seems to be strong, the next question is to what extent the gases have a magmatic origin, or whether a part of them, at least, can be included air. That the carbon dioxide has the former origin will doubtless be admitted. That the mine gases collected contain a considerable amount of diffused air obtained during their ascent or in the workings is also probable. The question whether some of the nitrogen is of magmatic origin is more difficult to answer. If the breccia was formed by explosive action, as seems likely, and then consolidated in the large vent of the volcano, it is reasonable to suppose that much

[a] Henri Moissan analyzed the gases in one of the fumaroles of Guadeloupe, West Indies, with the following result (Comtes Rendus, vol. 138, 1904, pp. 936–938): Sulphureted hydrogen, 2.7 per cent; carbon dioxide, 52.8 per cent; oxygen, 7.5 per cent; nitrogen, 36.07 per cent; argon, 0.73 per cent.

air might have been included in it and that a gradual absorption of oxygen might have taken place. On the other hand, it might be contended that the continued exhalations of the volcano would long ago have driven out any included air. If this is true, the larger part of the nitrogen must be of magmatic origin.

REMEDIAL MEASURES.

In many mines no particular inconvenience is experienced by these gases, owing to the fact that they issue in relatively small amounts or to exceptional facilities for ventilation. At other places the gas has proved a most difficult problem. At the Moose mine strong blowers were used with indifferent effect; experiments were made both by exhausting the gas and by forcing in fresh air. At times of low barometer all measures fail at this and other mines, as the gas pours out in irresistible volumes. The very next day the mine may be free from it.

Many different remedies have been suggested. Where carbon dioxide is the only gas to contend with, chemical means, such as absorption by lime, have been proposed, but these may without hesitation be put aside as impracticable. No doubt powerful blowers would in many cases dilute the air sufficiently, but the expense would be a serious matter for many mines. Exhaust fans would appear to be less suitable. In the Conundrum mine and in some mines in Gilpin County steam pipes have been introduced in the workings, and the condensing steam is said to have given considerable relief at times. The only way in which the steam acts is probably by promoting a circulation of the air. A blower should give better results. In some cases particularly bad places in the drifts have been cemented or lined with sheet metal. This is no doubt an excellent remedy as far as it goes. It would seem that the only really effective way of combating the evil would be to maintain, in emergencies, by means of powerful blowers and properly arranged air curtains, a pressure in the workings which would slightly exceed the normal atmospheric pressure. This is called the "plenum" system of ventilation, and has been successfully applied in coal mines and in the alluvial mines of Victoria, the objectionable gas being carbon dioxide in the latter case. At least this method could be applied to certain parts of the workings. Considerable expense and some difficulties would no doubt be connected with it. In case of failure of the blowers it would no doubt also increase the danger of the men working in the mine, but in some cases it would seem to be the only possible remedy.

CARBON DIOXIDE AND NITROGEN IN OTHER MINING DISTRICTS.

Carbon dioxide (carbonic acid) is known to occur at many places, although in metal mines it is somewhat rare. In coal mines it may develop by explosion of fire damp or by exudation from coal seams; in metal mines the explosives used generate a slight amount; locally it may be due to the action of oxidizing sulphides on carbonates. The lead mines of Pontgibaud, France, contained much of this gas; also those of Alston Moor and Foxdale, England. Carbon dioxide is frequently present in the Thames district on the Hauraki Peninsula, on the north island of New Zealand, and here often interferes with the working, especially during periods of low barometer.[a] The Hauraki veins intersect late Tertiary andesite.

[a] Park, James, The geology and veins of the Hauraki gold fields: Trans. N. Z. Inst. Min. Eng., vol. 1, 1897, p. 23.

Carbon dioxide is often very troublesome in some of the deep alluvial mines at Creswick, just north of Ballarat, Victoria. In these mines the gravels of Tertiary river channels are extracted by means of shafts from 300 to 500 feet deep. The gravels are covered by thick basalt floors which have been erupted from many points in the district. As a rule these gravels contain only a small amount of organic matter. The occurrence of these gases has been carefully examined by Prof. A. Mica Smith, of the Ballarat School of Mines, who[a] finds that they issue most abundantly during periods of low barometer, that the gases are warmer than the normal air of the mine, and that they are heavily charged with moisture. The maximum amount of carbon dioxide found was 4.05 per cent, the highest nitrogen 81.47 per cent, the minimum of oxygen 14.72 per cent. A typical analysis follows:

Analysis of gas in mines at Creswick, Victoria.

Carbon dioxide	3.20
Oxygen	14.72
Nitrogen	78.78
Water	3.30
	100.00

A similar gas appears to be abundant in a great number of mines in the southeast section of the main Gilpin County district of gold-silver veins.[b] The deposits occur in pre-Cambrian gneiss with dikes and masses of andesitic rocks. The gas, which is partly, at least, composed of carbon dioxide, issues suddenly in great volumes during periods of low barometer and especially following a sudden decrease in the barometric pressure. Several fatal accidents are due to the presence of this gas. It is heavy and fills shafts and winzes up to a sharply defined line.

Mr. J. E. Spurr states[c] that pockets of a gas which evidently consisted of carbon dioxide were opened in the Tonopah mines at relatively shallow depths. The deposits consist of gold- and silver-bearing fissure veins in andesite rocks.

A heavy gas, probably chiefly carbon dioxide, is very abundant and troublesome in the shafts near Rico, Colo.[d]

There are few accounts of the presence of nitrogen gas in mines. Only one occurrence is quoted in the general literature; it is at the Strinesdale tunnel near Stockport, England.[e] It consisted of 92 volumes of nitrogen, 8 volumes of oxygen, and a trace of carbon dioxide. An important occurrence has lately been described by Mr. Harry A. Lee, of Denver.[f] The locality is Creede, a mining district in Colorado containing silver veins in Tertiary volcanic rocks. The Happy Thought mine is working on a great fault fissure on which a number of other well-known mines are also located. The shaft is 1,400 feet deep and the natural ventilation excellent. The gas at times issues in great abundance from the vein; the changes appear to accord with barometric variations. Nitrogen being slightly lighter than

[a] Smith, A. Mica, Report on the foul air of the Allendale mines: Special Rept. Dept. of Mines, Melbourne 1892, p. 24.

[b] Collins, Arthur L., Note on the occurrence of carbonic-acid gas in certain veins of Gilpin County, Colo.: Proc. Colorado Sci. Soc., vol. 6, 1897–1900, pp. 120–123.

[c] Oral communication.

[d] Ransome, F. L., Ore deposits of the Rico Mountains, Colorado: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, pp. 304, 305.

[e] Foster, C. Le Neve, Ore and Stone Mining, 2d ed., London, 1897, p. 479.

[f] Gases in metalliferous mines: Proc. Colorado Sci. Soc., vol. 7, 1897–1900, pp. 163–192.

the air the gas accumulates in raises and in the backs of the drifts. According to analysis by Mr. W. F. Edwards the gas contains 96.08 volumes nitrogen (by difference) and 3.92 volumes oxygen. No carbon dioxide is present.

In the cases of the Colorado and New Zealand mines mentioned it seems most probable that the carbon dioxide and the excess of nitrogen are exhalations from cooling magmas, as they are believed to be at Cripple Creek.

DETAILED OBSERVATIONS AT CRIPPLE CREEK MINES.

Eastern part of the district.—The large mines in the immediate vicinity of Victor, including the Portland, Stratton's Independence, and adjacent properties, also the Golden Cycle, Vindicator, Hull City, Findley, Isabella, and Victor mines, are all practically free from the exhalations which in other parts of the district often cause inconvenience. In the Isabella mine the gas accumulated near the end of a long crosscut east on level 11. The same is true of a long crosscut toward the east on level 11 of the Findley mine; also, in the Golden Cycle, of a crosscut 900 feet long, which, near its breast, enters a particularly loose and open mass of breccia. The Hull City mine contained a few indications of gas. With these insignificant exceptions, no inconvenience has been caused by subterranean gases in the mines mentioned.

Eclipse mine.—The Eclipse mine, situated immediately east of the Elkton, contains some gas. At the time of examination the shaft was filled with water to a point 224 feet below the collar. Above this the shaft was filled with gas, rendering the first level inaccessible.

Elkton mine.—In the Elkton mine serious inconvenience is often experienced from gases which issue from fissures following the basic dike which traverses the property. At times the northern portion of the mine is almost filled with gas, especially in the lower levels. It is sometimes necessary to suspend work on this account. No gas was known above level 6 and until recently the work was not really interrupted by it. In the southern part of the mine, on level 7, gases issued in considerable quantities from an open crevice in the vein, which is here contained in granite, just outside of the boundary line of the breccia. A candle held up to this crevice in the roof of the drift would be immediately extinguished, and at times this vicinity is entirely inaccessible. A sample of the dry gas as it issues from the crevice was collected according to the method indicated on page 254 and an analysis gave the result shown on page 255.

Moose mine.—A heavy gas is exceedingly troublesome in the Moose mine, particularly on the levels below 6, which communicate with the surface only through the main shaft. It issues copiously from the fissures in the breccia, particularly from the shattered breccia on the 1,050-foot level, and it was only by lining the north drift of this level with sheet tin for a distance of over 600 feet that work in the north end was made possible. Powerful suction blowers were used to draw out the gas from the bottom level; but on stormy days, presumably at times when the barometric pressure is low, the gas pours into the mine, and the miners in several instances narrowly escaped suffocation. It is said that at such times, in spite of the adit connection in level 6, the gas has issued from the collar of the shaft in such abundance as to at once extinguish a candle. The gas collects

in winzes, from which it can be bailed or sucked out when the barometer is high, but when the barometer is low the gas enters more rapidly than it can be removed. The presence of a moderate amount of the gas in the mine atmosphere is said to produce irregular heart action, sweating, and weakness. If these warning symptoms are not heeded, asphyxia may suddenly follow. The mine was closed in March, 1904, partly on account of the difficulty of working in the lowest levels.

Last Dollar mine.—This mine was not troubled by gas until level 10 was developed. On this level, at the breasts of certain long crosscuts, a considerable amount accumulates at times. The gas does not interfere with the ordinary working of the mine. It is stated that it sometimes accumulates in the back of the drifts instead of on the floor; if correct, this would indicate that it is largely composed of nitrogen. Miners have worked in the gas for one or two days by electric lights when the candles would not burn, but were unable to continue longer, as great lassitude and pains in the back developed.

Modoc mine.—The upper workings do not contain gas, but a 400-foot winze in the lower part of the workings always contains some gas and is sometimes entirely filled.

Blue Bird mine.—Gas enters the mine in all levels below 4 on certain days. At these times the lower part of the mine is frequently inaccessible.

Wild Horse mine.—The depth of the Wild Horse mine is 1,250 feet, the elevation of the collar being 10,653 feet. Complete oxidation extended down to a depth of 1,150 feet. There was no gas until the 1,250-foot level was opened, when it issued in large volumes from the porous pyritic granite-breccia which constitutes the country rock. The gas interfered greatly with the work and is said to have sometimes filled the mine almost to the collar of the shaft for several days in succession, especially at periods of low barometer.

Logan and Orpha May mines.—A few records from these mines, which were closed in 1904, were secured from Mr. Fred Johnson, formerly in charge of the properties. He states that gas was very troublesome in a crosscut east on level 13 in the Orpha May. It also issued in large amounts from a certain place in a crosscut on level 12 of the Logan mine, about 500 feet northwest of the shaft. Ventilation had no effect, and the place was ordinarily inaccessible, so that the drift was temporarily barred. It is stated that the gas had the appearance of a "bluish haze" and that it was unusually concentrated and poisonous. Two men were suffocated at this place trying to make their way through it.

Doctor-Jackpot mine.—Gas enters this mine at nearly all points where there are open fissures and accumulates wherever the ventilation is defective. Owing to the closing of the Doctor shaft, the levels above 10 are filled with the gas, which flows down the shaft to level 10. Here, however, it is carried out by ventilation through the stopes and the Advance No. 2 shaft. The 550-foot Morning Glory level was so filled with gas beyond the Doctor shaft as to be inaccessible at the time of visit. The gas appears to be chiefly carbon dioxide, probably mixed with nitrogen. It is said to be particularly troublesome on days when the barometer is low.

The neighboring Mary McKinney mine is practically free from gas.

El Paso and C. K. & N. mines.—An abundant flow of gas, in part carbon dioxide, issues from some of the fissures of the C. K. & N. lode, at a depth of 300 feet, so that a candle held to such an opening is immediately extinguished. Owing to the connections with the El Paso and Old Glory shafts, the mine was well ventilated and the gas was causing no particular inconvenience.

In the El Paso tunnel, a few hundred feet from the regular El Paso workings, gas sometimes issues from granite near the phonolite in such volumes that the rapidly flowing stream of water coming from the heading of the tunnel and the resulting brisk circulation of air in the drift are insufficient to carry it away. At such times candles, torches, and acetylene lamps are extinguished. While no actual fissures were found from which the gas issued, the zone from which gas comes is narrow and well defined.

Pointer and Mint mines.—The Mint shaft is 750 feet deep and is sunk in breccia, while that of the Pointer is 530 feet deep, latite-phonolite being the country rock. Both mines contain much gas, which often seriously interferes with their operation. This gas collects in nearly all crosscuts and drifts not in the direct line of ventilation between the two shafts. A considerable part of the workings was found to be inaccessible from this cause at the time of visit.

Poverty Gulch.—Of the mines in this vicinity the Abe Lincoln contains a small amount of gas in the winze below the Cripple Creek and Chicago drainage tunnel, close to the Half Moon vein. There is also a little gas in the winze below the 500-foot level.

In the Mollie Kathleen the air on the 700-foot level is often so bad that candles fail to burn, especially when a brisk southwest wind is blowing.

In the C. O. D. mine, the lower levels of which are not worked at present, gas stands several feet deep above the bottom level, 800 feet below the surface.

Conundrum mine.—This mine, which is situated on the eastern slope of Gold Hill, contains at times a large amount of gas, which interferes very seriously with the working of the property. The deposit consists of a basic dike in a very much shattered gneiss, whence the gas escapes in large quantities. The workings consist of an adit 300 feet long with an incline shaft at the end. The lowest (sixth) level is 625 feet below the adit, and the workings where most of the gas issues are approximately 725 feet below the surface. The workings, as shown in fig. 24, partly connect with those of the adjoining Midget mine, which is also much troubled by gas. The ventilation is not perfect, the air current entering an old incline near the mouth of the adit; thence descending through the workings and winzes to level 6, from which point it ascends through the incline and leaves the mine through the adit. The connection with the Midget mine on level 6 is closed by an air curtain. It will be seen that there is practically no difference in level between the intake and the upcast current. An attempt is made to increase the ventilation by a sail stretched above the winze at the mouth of the adit so as to catch the prevailing southerly or southwesterly winds. On days of low barometer gas enters the mine from practically all points on level 6, and when the barometer is exceptionally low it may fill the whole mine. Work is frequently impossible for many days in succession. On March 20, 1904, when the barometer stood at 19.9 inches at the portal, the mine was visited. Candles would burn at the shaft station on level 6,

but immediately north of the shaft even acetylene lamps were at once extinguished. Breathing was very difficult and a feeling of great distress was produced by remaining for only a few minutes in the drift just north of the shaft. It was possible, however, to penetrate to a winze 12 feet deep and 100 feet north of the shaft, at

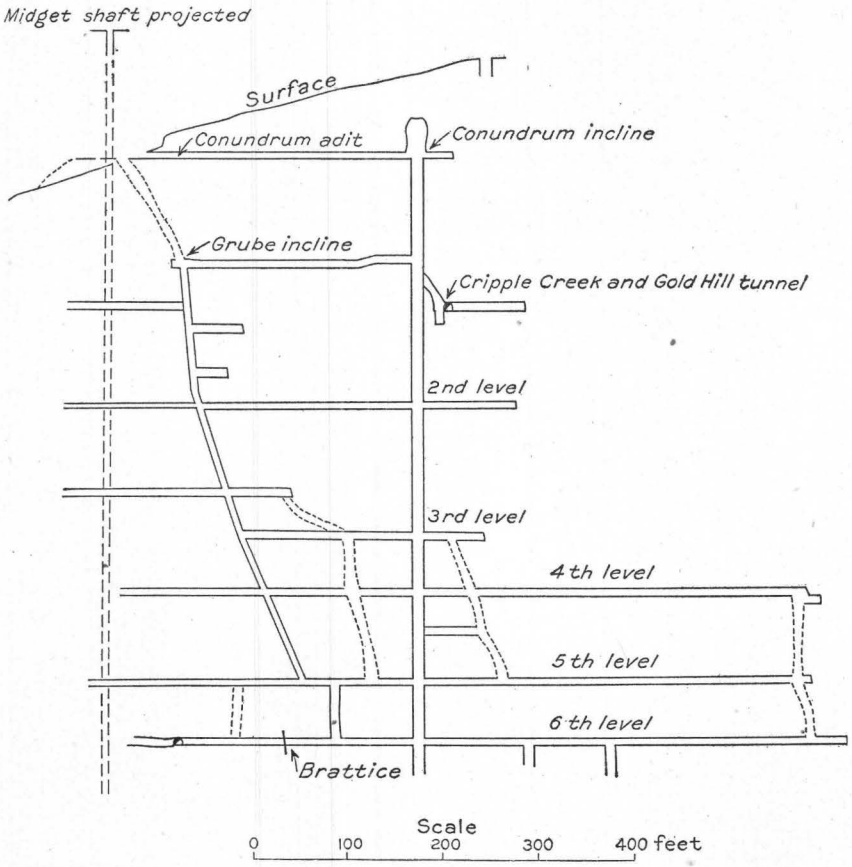


FIG. 24.—Longitudinal section showing ventilation in the Conundrum and Midget mines.

which point a sample of gas was collected by lowering and emptying a bottle filled with water. The temperature at this point was +16.7° C. (+62° F.). This sample of gas was analyzed by Mr. L. F. Hawley, of Cornell University, with the following result:

Analysis of gas from Conundrum mine, March 20, 1904.

Carbon dioxide	10.2
Oxygen	5.7
Nitrogen (by difference)	84.1
	100.0

On March 21 the mine was again visited. The temperature at the mouth of the adit was −2° C. (+28° F.), while the barometer stood at 20.2 inches. Work was in progress on level 6, but a winze 50 feet deep and 185 feet north of the shaft was found to be completely filled with a heavy gas, practically to the level of the

rail. An acetylene lamp lowered into it was immediately extinguished at a certain sharply defined line. The temperature at this place was +11.5° C. (+53° F.). A sample of the gas contained in the winze was collected by the same method as before, and as analyzed by Mr. Hawley contained the following proportions:

Analysis of gas from Conundrum mine, March 21, 1904.

Carbon dioxide	8.3
Oxygen	10.2
Nitrogen (by difference)	81.5
	100.0

A short distance north of the winze the air in the drift was examined and found to contain 0.11 per cent carbon dioxide. Near this point a crosscut several hundred feet long extends in a northeast direction into the Moon-Anchor ground. This crosscut was found to be full of gas, and could be traversed only to a point 150 feet northeast of the junction. Here the temperature was +15° C. (+59° F.), or 6° warmer than at the winze, which was only 200 feet distant. The air at this place contained 1.3 per cent dioxide. The acetylene lamps barely burned, and the atmosphere was exceedingly oppressive and distressing.

The conditions described continued during the remainder of the year 1904. In addition to the natural circulation indicated above, a steam pipe was carried down into the workings, and some benefit is said to have been derived from forcing steam into the drift. During the last days of December a man was suffocated on level 6 while attempting to enter this bottom level alone during a time of low barometer. His body was recovered in twenty minutes, but it was found impossible to resuscitate him even by the immediate use of oxygen.

Since March, 1904, Mr. B. F. Tipton, superintendent of the Conundrum mine, has kept a complete record of barometer readings in order to ascertain the connection between the influx of gas and the atmospheric pressure. This important record follows, copied in full. It is to be hoped that at other mines where gas is known to exist a barometer will always be kept and records preserved.

Record of barometric stand and gas conditions in the Conundrum mine, Cripple Creek, on 600-foot level.

Date.	Barometer at portal of adit.	Air conditions in mine.	Weather conditions.
1904.			
April 21	20.3	Very bad; candles will not burn	Sunny; cloudy and snow.
April 22	20.4	Good	Sunny.
April 23	20.4	Gas rising; candles will just burn	Sunny; high southwest wind.
April 24	20.6	First-class	Snow; high wind.
April 25	20.7	Good	Sunny; no wind.
April 26	20.5	A little gas, but lights will burn	Sunny.
April 27	20.5	No gas on levels; winzes are full	Do.
April 28	20.3	Gas very bad; lights will not burn	Sunny and high southwest wind.
April 29	20.3	Gas 2 feet in bottom of levels; lights burn well in back of levels.	Cloudy; north wind.
April 30	20.7	First-class	Snow.
May 1	20.4	Gas rising, but candles will burn	Cloudy.
May 2	20.2	Candles will not burn	Snow.
May 3	20.3	Good	Sunny.
May 4	20.3	do	Do.

Record of barometric stand and gas conditions in the Conundrum mine, Cripple Creek, on 600-foot level—Continued.

Date.	Barometer at portal of adit.	Air conditions in mine.	Weather conditions.
1904.			
May 5	20.4	Good	Sunny.
May 6	20.4	do	Do.
May 7	20.3	Bad	Snow.
May 8	20.7	Good	Sunny.
May 9	20.5	do	Do.
May 10	20.4	Gas rising	Do.
May 11	20.5	First-class	Do.
May 12	20.4	Good	Do.
May 13	20.5	First-class	Do.
May 14	20.5	Good	Cloudy.
May 15	20.3	Gas rising; candles just burn	Do.
May 16	20.4	Good	Snow.
May 17	20.5	Good on levels; gas in winzes and shaft	Sunny.
May 18	20.4	Bad	Cloudy.
May 19	20.3	Bad; candles will not burn	Sunny.
May 20	20.4	Good	Do.
May 21	20.5	First-class	Sunny; snowfall.
May 22	20.4	Good on levels, winzes, and shafts	(?)
May 23	20.6	Candles will not burn	Sunny and high southwest wind.
May 24	20.2	Very bad	Sunny.
May 25	20.2	do	Cloudy and rain.
May 26	20.4	Good	Cloudy.
May 27	20.4	Gas rising, but candles burn	Sunny.
May 28	20.4	Good	Cloudy.
May 29	20.4	do	Sunny.
May 30	20.4	Candles will not burn	Do.
May 31	20.3	do	Do.
June 1	20.3	do	Do.
June 2	20.2	do	Cloudy.
June 3	20.1	do	Snow.
June 4	20.3	Good	Do.
June 5	20.4	do	Cloudy and cold.
June 6	20.4	do	Do.
June 7	20.5	do	Sunny.
June 8	20.4	do	Rain.
June 9	20.4	A little gas	Cloudy and rain.
June 10	20.5	do	Do.
June 11	20.5	do	Do.
June 12	20.5	do	Do.
June 13	20.5	do	Do.
June 14	20.5	Candles will not burn	Sunny.
June 15	20.5	do	Do.
June 16	20.5	do	Rain.
June 17	20.5	Good	Cloudy and cold.
June 18	20.5	Candles will not burn	Cloudy and rain.
June 19	20.5	do	Sunny.
June 20	20.5	do	Do.
June 21	20.5	do	Do.
June 22	20.5	do	Do.
June 23	20.5	do	Do.
June 24	20.5	do	Rain.
June 25	20.5	do	Do.
June 26	20.5	do	Hard rain.
June 27	20.5	do	Sunny.

Record of barometric stand and gas conditions in the Conundrum mine, Cripple Creek, on 600-foot level—Continued.

Date.	Barometer at portal of adit.	Air conditions in mine.	Weather conditions.
1904.			
June 28	20.5	Candles will not burn	Sunny.
June 29	20.5	do	Do.
June 30	20.5	do	Hard rain.
July 1	20.5	do	Hail and rain.
July 2	20.4	do	Sunny.
July 3	20.5	do	Rain.
July 4	20.4	do	Sunny.
July 5	20.3	do	Clear.
July 6	20.4	do	Foggy and showers.
July 7	20.4	do	Do.
July 8	20.4	do	Clear.
July 9	20.6	do	Do.
July 10	20.5	do	Cloudy.
July 11	20.5	do	Clear.
July 12	20.4	do	Cloudy and rain.
July 13	20.3	do	Clear.
July 14	20.4	do	Do.
July 15	20.4	do	Do.
July 16	20.4	do	Do.
July 17	20.4	do	Clear and hot.
July 18	20.6	do	Do.
July 19	20.6	do	Rain and hail.
July 20	20.5	do	Do.
July 21	20.5	do	Do.
July 22	20.5	do	Do.
July 23	20.5	do	Do.
July 24	20.5	do	Do.
July 25	20.5	do	Do.
July 26	20.5	do	Do.
July 27	20.5	Candles will not burn, but gas lower	Heavy rain and hail.
July 28	20.4	Candles will not burn below level 5	Heavy rain and lightning.
July 29	20.3	Gas rising	Cloudy; no rain.
July 30	20.4	Gas the same	Rain; sunny.
July 31	20.4	Air good on level 4	Do.
August 1	20.5	Gas lower in the morning	Heavy rain.
August 2	20.5	Gas rising	Sunny.
August 3	20.5	Reached station at level 6	Cloudy; clear.
August 4	20.4	Good above level 6	Do.
August 5	20.5	Air good	Rain and hail.
August 6	20.5	do	Rain; sunny.
August 7	20.5	do	Do.
August 8	20.5	do	Cloudy; sunny.
August 9	20.5	do	Do.
August 10	20.5	do	Clear.
August 11	20.5	do	Do.
August 12	20.5	do	Clear; cloudy.
August 13	20.5	do	Do.
August 14	20.5	do	Do.
August 15	20.5	do	Rain and hail.
August 16	20.5	do	Do.
August 17	20.4	do	Rain.
August 18	20.4	do	Do.
August 19	20.4	do	Clear.
August 20	20.4	do	Do.

Record of barometric stand and gas conditions in the Conundrum mine, Cripple Creek, on 600-foot level—Continued.

Date.	Barometer at portal of adit.	Air conditions in mine.	Weather conditions.
1904.			
August 21	20.4	Air good	Rain.
August 22	20.5	do	Clear.
August 23	20.5	do	Do.
August 24	20.5	Candles will burn	Do.
August 25	20.6	do	Cloudy.
August 25	20.5	do	Rain.
August 27	20.5	do	Clear.
August 28	20.5	do	Cloudy.
August 29	20.5	do	Rain.
August 30	20.5	do	Do.
August 31	20.4	Some gas after noon	Clear.
September 1	20.4	Candles will burn	Rain.
September 2	20.5	do	Cloudy.
September 3	20.5	Air good	Clear.
September 4	20.4	do	Do.
September 5	20.4	do	Do.
September 6	20.5	do	Do.
September 7	20.4	do	Do.
September 8	20.4	Some gas to-day	Do.
September 9	20.4	Mine closed	Do.
September 10	20.4	Air fairly good	Do.
September 11	20.4	Bad	Do.
September 12	20.4	Air fairly good	Do.
September 13	20.5	do	Do.
September 14	20.5	do	Do.
September 15	20.4	do	Cloudy.
September 16	20.4	do	Do.
September 17	20.5	do	Clear.
September 18	20.5	do	Do.
September 19	20.5	do	Do.
September 20	20.4	do	Rain.
September 21	20.5	do	Do.
September 22	20.4	do	Cloudy.
September 23	20.4	do	Do.
September 24	20.4	do	Clear.
September 25	20.5	do	Do.
September 26	20.5	do	Do.
September 27	20.4	do	Cloudy.
September 28	20.5	do	Do.
September 29	20.4	do	Clear.
September 30	20.4	do	Do.
October 28	20.4	A little gas; candle will burn	Clear and warm.
October 29	20.3	do	Do.
October 30	20.3	Gas bad after noon	Do.
October 31	20.3	Some gas in winze	Do.
November 1	20.3	do	Do.
November 2	20.3	do	Do.
November 3	20.3	do	Do.
November 4	20.3	do	Do.
November 5	20.3	do	Do.
November 6	20.3	do	Do.
November 7	20.4	Good air	Do.
November 8	20.4	do	Do.
November 9	20.3	Ran men out at 2 p. m	Snowing.
November 10	20.3	Candle will not burn; gas very bad	Do.

Report of barometric stand and gas conditions in the Conundrum mine, Cripple Creek, on 600-foot level—Continued.

Date.	Barometer at portal of adit.	Air conditions in mine.	Weather conditions.
1904.			
November 11	20.4	Good	Clear.
November 12	20.3	Good on levels, bad in winzes	Do.
November 13	20.3	.....do	Do.
November 14	20.3	.....do	Clear and warm.
November 15	20.3	Very bad	Do.
November 16	20.4	Good air	Do.
November 17	20.4	.....do	Do.
November 18	20.2	Candle will not burn	Warm and high wind.
November 19	20.3	Candle will just burn	Warm.
November 20	20.3	.....do	Do.
November 21	20.4	Good air	Clear and warm.
November 22	20.4	Some gas	Cloudy.
November 23	20.4	.....do	Clear and warm.
November 24	20.3	Candle will not burn	Do.
November 25	20.3	.....do	Do.
November 26	20.4	Air good	Do.
November 27	20.3	Candle will not burn	Do.
November 28	20.2	Candle will not burn; gas very bad	Warm.
November 29	20.3	Some gas	Sunny and cold.
November 30	20.3	.....do	Do.
December 1	20.2	Air bad	Sunny and warm.
December 2	20.2	.....do	Sunny and cold.
December 3	20.4	No gas	Do.
December 4	20.4	.....do	Do.
December 5	20.5	.....do	Sunny and warm.
December 6	20.5	.....do	Do.
December 7	20.4	.....do	Do.
December 8	20.3	A little gas	Do.
December 9	20.2	Gas on levels and very bad in winzes	Do.
December 10	20.2	Candle will not burn	Snow at night.
December 11	20.3	Good air	Clear and cold.
December 12	20.1	Gas very bad	Cloudy.
December 13	20.2	No gas	Clear and cold.
December 14	20.2	.....do	Do.
December 15	20	Mine full of gas	Cloudy and windy.
December 16	20.4	Air first class	Clear and cold.
December 17	20.3	.....do	Do.
December 18	20.4	.....do	Do.
December 19	20.4	.....do	Do.
December 20	20.4	.....do	Do.
December 21	20.2	Gas very bad	Clear and warm.
December 22	20.1	.....do	Cloudy and cold.
December 23	20	Mine full of gas	Snow.
December 24	20	.....do	Sunny.
December 25	(a)		Snow.
December 26	20	Gas in mine	Cold and snowy.
December 27	20.2	Air first class	Clear and cold.
December 28	20.3	.....do	Do.
December 29	20.2	Good on levels	Clear and warm.
December 30	20.2	Some gas	Do.
December 31	20.2	.....do	Do.

a Nobody at mine

Ophelia tunnel.—The portal of the Ophelia tunnel is located on the east side of Cripple Creek, about half a mile south of the town. The elevation is 9,268 feet. The tunnel starting in granite soon penetrates the breccia and continues in this rock to the end, the breast being somewhat over 7,000 feet distant and almost due east of the portal. Considerable difficulty was experienced with the gas when the tunnel was driven, especially in the last 700 feet beyond the surface connections through the Mary McKinney and Callie workings. At times work had to be suspended and frequently, it is said, gas issued from every new bore hole drilled in the breast. In March, 1904, work had been stopped for some time owing to other reasons. During a visit on March 5, 1904, the temperature at the portal was −3° C. (+26° F.) and the barometer stood at 20.5 inches. At the World's Fair drift, 300 feet south of the main tunnel, the temperature was +48° F. Near the caved end of the drift on the Howard flat vein, 4,605 feet from the portal, the temperature was 50.5° F. At 6,610 feet from the portal the temperature was 58° F. and candles burned with difficulty, though the percentage of carbon dioxide was only 0.25, and 2 per cent is usually considered necessary to extinguish them. This seemed to point clearly to the presence of some other gas besides carbon dioxide. At 6,870 feet from the portal the temperature was 58° F., the candles were extinguished, and the percentage of carbon dioxide in the air was 0.47. At the breast of the tunnel, about 7,000 feet from the portal, acetylene lamps barely burned, the temperature was 58° F., and the percentage of carbon dioxide was 0.68.

At a subsequent visit, on March 18, the temperature at the portal was 45° F., and the barometer indicated 20.7 inches. The temperature at the breast was 54° F. The air was good, and candles burned brightly up to the breast.

Copper Mountain.—The only record of gas conditions in outlying districts was obtained from the Fluorine mine, on Copper Mountain. Tunnels were driven in granite extending underneath the workings of the Fluorine mine, and much gas was said to have issued from the surrounding rocks in these workings.

UNDERGROUND TEMPERATURE.

No accurate measurements have been undertaken to ascertain the exact increment of temperature with depth in the Cripple Creek district. A few observations are, however, available which may serve to attain at least an approximate result.

Concerning the mean annual temperature at Cripple Creek, which should be approximately identical with the rock temperature at the depth of, say, 50 feet, it should be stated that the only data available are incomplete records at Cripple Creek extending over a period of three years. By estimating temperatures for those months which are lacking the figure of +42° F. is obtained for Cripple Creek, the probable error being about +2°. The mean annual temperature at Colorado Springs is +47° F., while that of the summit of Pikes Peak is 19.4°. The determination for Colorado Springs is based on the average for twenty-six years and that for Pikes Peak on records for fifteen years.

Cripple Creek has an elevation of about 9,000 feet, while the elevation of Colorado Springs approximates 6,000 and that of Pikes Peak 14,000 feet. At the elevation of 10,250 feet in the vicinity of Cripple Creek a mean annual temperature of +41° F. has been assumed.

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The Last Dollar mine is 1,200 feet deep, the shaft having a surface elevation of 10,278 feet. In a long crosscut on the 1,200-foot level, under the Modoc vein, a temperature of +16° C. (+60.8° F.) was measured at the breast. This figure is doubtless not far removed from the actual temperature of the surrounding rock. On the assumption that the mean surface temperature is 41° F., this will correspond to an increment of 1° F. per 58 feet. In the same mine and on the same level the temperature in the stopes 40 feet above the rail was found to be +17.5° C. (+63.5° F.), which is probably higher than the normal temperature. At the shaft on the same level the temperature was +13° C.

The next observations were taken in the Vindicator mine, at the breast of the Christmas crosscut, 800 feet below the surface, the elevation of the collar of the shaft being 10,209 feet. The temperature obtained at the breast of the crosscut was +12° C. (+53.6° F.). Again assuming that the mean surface temperature is 41° F. and that the temperature of the crosscut does not differ materially from that of the surrounding rock, we obtain an increment of 1° F. per 63.5 feet.

The Ophelia tunnel extends for over 7,000 feet westward from Cripple Creek into the heart of the district. At the time of visit work had been discontinued at the breast for several months. Connection with the surface was established through the Callie shaft, 1,800 feet back from the breast. No artificial ventilation was resorted to, and it may again be assumed that the temperature at the breast does not differ more than 1° or 2° at most from the temperature of the surrounding rocks. On March 18, 1904, the temperature at the breast was +12° C. (+54° F.). The vertical distance to the surface being 700 feet, and a mean annual temperature of 41.3° F. being assumed for that surface elevation, an increment of 1° F. per 55 feet is obtained.

At the Conundrum mine, in the workings on level 6, 750 feet below the surface, a temperature of +53° F. was measured on March 21, 1904. There was some ventilation at the time, and it is possible that the figures may be somewhat too low to represent the actual rock temperature. If we assume that it is approximately correct, however, the increment is calculated to be 1° F. per 60 feet.

This is in some measure confirmed by the observed temperature of the water where it issues from the El Paso drainage tunnel, the portal of which has an elevation of 8,783 feet. This temperature was found to be +14° C. (+57.2° F.). Assuming that this water is drained from an average level of 1,000 feet below the surface throughout the large area affected by the tunnel and further that the mean annual temperature is +41° F., we obtain an increment of 1° F. per 62 feet.

Although these observations are not accurate, they may be depended on as showing that the average increment of temperature in the Cripple Creek district approximates 1° F. per 60 feet. This is very nearly the normal figure usually given for the increase of temperature in depth and indicates that there is no special source of heat present which would interfere with mining at depths much greater that those attained at present. At the depth of 2,400 feet a temperature of +81° F. might be expected if the rate is maintained. At 3,600 feet the temperature should rise to 101° F.

As has been explained in more detail in the paragraphs devoted to subterranean gases, a higher temperature obtains at places where mine gases are especially abundant.

PART II.—DETAILED DESCRIPTIONS OF MINES.

CHAPTER I.—MINES NORTH AND EAST OF THE TOWN OF CRIPPLE CREEK.

MINERAL HILL.

The southern slope of Mineral Hill contains a great number of prospects, on some of which much work has been done, though all operations were suspended in 1903. These prospects are almost wholly confined to the area covered by breccia. The rock shows strong evidence of mineralization in places, being bleached and impregnated by carbonates and pyrite. The Roanoke shaft is located on the reservoir ridge immediately north of the town, and sunk to a depth of 375 feet, water now standing 308 feet below the collar. It is reported that a well-defined north-south vein was encountered, containing some ore. A little higher up are the Sunflower shafts, each 100 feet deep, with about 800 feet of drifts.[a] Still farther north and about 200 feet vertically below the summit are the Laura Lee and Addie C. shafts, the former 100 feet, the latter considerably deeper—458 feet, according to report. Some quartz containing native gold is said to have been found in the Laura Lee.

CARBONATE HILL.

Carbonate Hill rises a short distance east of Mineral Hill. Its summit is made up of granite, while volcanic breccia covers its southwestern slopes. Like Mineral Hill, its slopes are dotted with prospect holes, but thus far little of permanent value has resulted. Near the summit is a phonolite dike, in and near which some oxidized ore has been found. On the southwestern slope the Elkhorn mine is located, in breccia. High-grade ore has been shipped from this property at intervals. The shaft is 450 feet deep. Toward the east the breccia extends across the gulch and covers the western and southern parts of Tenderfoot Hill, but the productive area is not encountered until the slopes of Poverty Gulch are reached.

POVERTY GULCH.

Poverty Gulch, heading at Hoosier Pass, separates Tenderfoot and Globe hills and extends down into the town of Cripple Creek. Its upper course lies over breccia containing some dikes of phonolite, latite-phonolite, and basalt, but a short distance below the C. O. D. mine it enters the schist and gneiss areas. Dikes and principal veins trend north-northeast or northwest, the former system being the most productive. The Gold King basic dike is of remarkable length and evidently

[a] Hills, Fred, Official Manual of the Cripple Creek District, 1900.

somewhat mineralized throughout. Many of the lodes are of short horizontal extent and not always persistent in depth. The three most important mines are the Abe Lincoln, C. O. D., and Gold King. The latter was the first regularly producing mine in Cripple Creek. In 1904 only the first-named was actively worked.

C. O. D. MINE.

The C. O. D. mine, operated by the Rebecca Gold Mining Company, is one of the oldest mines of the district. In 1894, when Penrose examined it, the depth attained was 220 feet. At the present time the shaft is 800 feet deep, ten levels are turned, and the total developments consist of about 4,000 feet of drifts, extending chiefly northward; level 8 attaining a distance of 600 feet from the shaft. The elevation of the collar is 9,821 feet. Except in a very limited way by lessees, the mine was not worked in 1903 or 1904. The bottom was dry in the latter year. The total production is given as $594,000, and the dividends amount to about $150,000. The C. O. D. vein is contained in normal fine-grained breccia, with a moderate amount of disseminated pyrite and carbonates. Level 7 is said to run out in schist 130 feet south of the shaft. A crosscut, 300 feet long, toward the east on level 8, remains throughout in breccia. The vein is a sharply defined fissure striking about N. 10° E., and dipping about 84° in an east by south direction. The Gold King vein is said to have been cut in a crosscut on level 5 about 200 feet west of the shaft. The crosscut east on level 8 cuts two veins 200 and 300 feet distant from the C. O. D. and approximately parallel to it. Both are oxidized and show no pay ore. One of them is believed to represent the extension of the Proper vein. The ore in the C. O. D. is of the usual type, with calaverite, quartz, and fluorite. Fresh tellurides were found close to the surface. Much of the ore averaged 5 ounces per ton. A small cross seam containing tetrahedrite was struck on level 10 and is reported to have yielded assays of 850 ounces silver and 5 ounces gold per ton.

Penrose says of the upper levels that the vein is a well-defined fault fissure, with grooves and slickensides, and with numerous subordinate cracks on either side of the main fissure. On level 8, where seen in 1904, the vein is marked by several narrow fissures and has the ordinary appearance of the sheeted zones characteristic of Cripple Creek veins. In one place the vein is slightly faulted by cross seams. From the discovery shaft to level 6 the ore shoot pitched southward toward the main shaft at an angle of 40°. Its length along the levels was about 100 feet. Below this point its pitch became reversed toward the north, but at the same time became much poorer. Near the main shaft ore was stoped from level 8 to level 6, but the ore seams are said to have been narrow, at the same time spreading over a wider space. On levels 9 and 10 little if any ore has been stoped.

PROSPECTS NEAR THE C. O. D.

The partly oxidized breccia near the C. O. D. and close to the contact with the schist contains many little seams of fluorite and quartz. Much of the surface material is rich enough for shipment, but none of these deposits has proved to be of great extent.

The Proper vein cuts through breccia about 200 feet above the C. O. D. on the south side of Poverty Gulch, and is developed by an incline shaft with a vertical depth of 100 feet. A dike of latite-phonolite about 30 feet wide is exposed on two levels apparently trending southwesterly toward the Gold King mine. The vein strikes northeastward and dips to the southeast. A small shoot from which a carload of 2-ounce ore has been shipped outcrops near the shaft. Stringers of galena and zinc blende occur in the ore.

GOLD KING MINE.

The Gold King mine, also known as the El Paso Gold King, operated by the Gold King Gold Mining Company, is situated a few hundred feet north of the C. O. D., on the northwest side of Poverty Gulch. It was the earliest regular producer and has been actively worked up to a recent date. In 1904 it was idle and not accessible, but a reopening of the mine was under consideration. The dividends distributed up to July, 1901, are given in Hill's Manual as $262,000. The ground owned comprises 40 acres.

The mine is developed by a vertical shaft 1,007 feet deep; the elevation of the collar is 9,852 feet. Nine levels are turned and extend chiefly northward from the shaft. The total length of drifts and crosscuts is about 2 miles. Level 9 (the deepest) is 840 feet below the collar. Water has been a great source of trouble and expense. The operations have been suspended until the El Paso tunnel (elevation 8,790 feet) shall have drained level 9. The water level stood 875 feet below the collar in March, 1904.

The country rock is normal fine-grained breccia, with some disseminated pyrite and carbonate (ankerite). The main vein is said to follow a phonolite dike trending N. 10° E. A very persistent basic dike, probably a monchiquite, also exposed in the Abe Lincoln workings, lies 250 feet west of the shaft and has been drifted on for several hundred feet on levels 3, 5, and 8. It is 3 to 5 feet wide. Three ore-bearing veins are known on the property. The first and most important trends N. 10° E. from the shaft and has a very steep east-southeast dip. Drifts are extended on it on all levels for about 400 feet north of the shaft; south of it some exploration has been done on levels 1, 5, and 8. A second nearly vertical vein, trending north-northwest from near the shaft and intersecting the first just south of it, has been developed on the adit and first levels for a distance of 300 feet, but has not been found productive. Four hundred feet north of the shaft it would intersect the third vein, which follows the basaltic dike mentioned above. Like the dike it strikes N. 30° E. and dips 70° west-northwest. Some fluorite and calaverite ore occurred on it, but the vein proved productive only down to level 5. It has been opened on levels 3, 5, and 8.

The ore is of the usual kind, the calaverite being accompanied by quartz and fluorite in all of the veins. There is little oxidation, unaltered tellurides being found close to the surface. Galena, zinc blende, and tetrahedrite are reported absent. A small vein in the northern part of the mine, 40 feet east of the basalt dike, contained much galena, but no work was done on it.

The pay shoot on the main vein, from which the largest part of the production has been derived, has a maximum horizontal length of 300 feet and from the vicinity of the shaft pitches steeply north on the plane of the vein. The width of ore is very variable, ranging on level 8, for instance, from 1 to 28 feet. The ore is reported to continue down to the deepest (ninth) level. The pay shoot on the vein following the basic dike is situated about 400 feet north of the main shaft; it seems to pitch steeply northward, but, as stated, proved productive only down to level 5.

MOLLIE KATHLEEN MINE.

The Mollie Kathleen mine is situated on the south spur of Tenderfoot Hill, just north of the El Paso Gold King mine. It is owned by Mr. M. C. Gortner, of Cripple Creek, and is at present being operated under lease by the Creston Big Eight Mining Company. The total production is estimated at $200,000. The underground developments consist of a shaft 700 feet deep, with stations cut at 100-foot intervals and levels at 200 and 700 feet.

The main shaft and the greater portion of the workings are in a dense breccia, considerably pyritized and in places partially oxidized. On the 700-foot level, however, the workings to the northwest, beginning at a point about 75 feet from the shaft, are in a pyritized massive rock which proves to be a syenite. The contact could not be located exactly, but rock is probably of intrusive character. On the 200-foot level a phonolite dike 10 feet wide, striking about N. 25° E. and approximately vertical, occurs 50 feet northeast of the shaft. It was not observed on the lower level, but a dike of phonolite apparently vertical and about parallel with the drift to the northwest occurs near the shaft on the 700-foot level.

The Gold King basalt dike, striking on the average about N. 35° E. and dipping 75° NW., is cut on the 200-foot level about 150 feet northwest of the shaft. On the 700-foot level the dip has carried it about 250 feet from the shaft. The dike is somewhat irregular in dip and strike, and varies in width from 3 to 5 feet. About 150 feet northwest of the shaft, on the 200-foot level, the dike is faulted about 1 foot by a fissure running N. 40° W. and dipping about 65° SW. Neither the fault nor any well-defined fissure which might represent it was observed on the 700-foot level. On the upper level the dike is considerably decomposed, but shows the characteristic longitudinal parting or jointing and the narrow seams of carbonates as distinctly as on the level below.

A number of more or less persistent veins have been found belonging to two systems, one of them with a northeasterly, the other with a northwesterly strike. The main vein of the Gold King, striking about N. 10° E., has not been encountered in this mine. The most important vein apparently follows the basic dike of the Gold King, which has been cut and drifted on at both levels.

On the 200-foot level a zone of fissuring is encountered about 150 feet northwest of the shaft. It strikes N. 60° E. and dips 75° to 80° NW. The lode ranges from 4 to 7 feet in width and consists of very many narrow fissures or cracks approximately parallel, but of little persistence. The breccia immediately about the fissures is oxidized. The lode carries values, but in most places they are too low to permit of profitable working. Tellurides are said to occur both in the seams and, more sparingly, in the rock between them.

The lode is crossed, northeast of the shaft, by the Gold King basalt dike. On this level the course of the dike is about N. 50° E., so that here the dike and lode intersect at an acute angle. The lode, in fact, seems to follow the dike for 20 feet or more. Sixty or seventy feet southwest of this junction the lode and dike approach again. At both points good ore occurs.

On the 700-foot level the course of the basalt dike is N. 30° E. It is somewhat fresher than above. Low values are said to occur all along the dike at this level, but no stoping has been done. Nothing was seen which corresponded to the northeast lode on the upper level. About 150 feet northwest of the shaft on the 700-foot level a narrow vein running northeast and dipping steeply northwest has been cut at two points. The vein is characterized by a quartz filling with vugs, carrying in places considerable quantities of pyrite, with sphalerite and a little galena, also low values in gold and silver. It evidently corresponds to the vein containing galena described from the Gold King mine.

A number of northwesterly trending fissures have been found, but they seem to carry small values. On the 200-foot level a lode has been cut about 100 feet northeast of the shaft and drifted on for 400 feet. It strikes N. 55° W., dips 75° NE., consists of a number of narrow, rudely parallel fissures in breccia. This lode has furnished a small pocket of ore. It was not found on the 700-foot level. Three hundred feet northeast of the shaft on the bottom level a similar fissure zone was encountered and drifted upon. It contained a small bunch of ore.

Two parallel fissures 3 to 12 inches wide and about 8 feet apart, running northwest and dipping about 80° NE., are cut 200 and again 250 feet west-northwest of the shaft. They are partly filled with large and small loose fragments, mostly oxidized, and appear to be old watercourses. They are barren.

Just west of the shaft on this level a short drift has been run on a narrow northwest seam carrying soft, clay-like matter, considerable pyrite, a little galena, and very small quantities of gold.

The greatest amount of ore was shipped from shallow workings on the Gold King basalt dike. This was stoped for practically the whole width of the claim down to a depth of about 75 feet, a point where at that time (1894–95) water interfered. Although the hill has since been drained to a lower level, mining has not been resumed in these upper workings

The junction of the basalt dike and the northeast lode on the 200-foot level made ore which has been stoped 20 to 30 feet high, about 60 feet long, and 4 to 6 feet wide. Values did not warrant further stoping. To the south of the junction, where the lode and dike approach, a stope had only been begun at time of visit, so that the form and extent of that ore shoot could not be determined.

GOLD PASS DIKE.

The narrow, irregular, and sometimes interrupted Gold Pass dike is cut by the Chicago and Cripple Creek tunnel 1,300 feet from its portal, and has been followed 500 feet toward the northwest and 700 feet in a southeasterly direction. It seems to be slightly mineralized throughout, but on the tunnel level the only stopes opened are at the end of the north drift and at the intersection with a vein supposed to be the Half Moon, 500 feet southeast of the tunnel. The Nolan shaft connects the

tunnel level with the surface, 400 feet above. At a height of 140 feet above the tunnel some ore is stoped at present along this dike. A small vein with a northwesterly course is traceable for a distance of 400 feet on the surface, but the basaltic dike does not show very clearly. The ore consists of thin quartz seams with calaverite contained in breccia or basaltic rock. The property belongs to the Stratton estate.

ABE LINCOLN MINE.

INTRODUCTION.

The Abe Lincoln claim in Poverty Gulch, near the eastern edge of the town of Cripple Creek, was located in April, 1895, and the mine began to ship ore the same year. The property is now part of the Stratton estate and is worked under lease. The total production is unknown. In 1903 and 1904 the mine was actively worked and shipped about 30 tons per day.

UNDERGROUND DEVELOPMENT.

The Abe Lincoln is operated through a vertical shaft, 600 feet in depth, with three levels, 360, 500, and 596 feet, respectively, below the collar. The collar of the shaft is 9,611 feet above sea level. There are some smaller shafts on the property, of which the most important is the Arcadia, 160 feet west-southwest of the Abe Lincoln shaft. The Arcadia has three small levels, all above the 360-foot Abe Lincoln level. A large amount of horizontal development work has been done on levels 1 and 2. On level 1 a north crosscut extends for 750 feet from the shaft, well under Womack Hill. Another crosscut extends northeast of the shaft for 900 feet to a point nearly under the portal of the Chicago tunnel, where it connects with a long northwest-southeast drift. Level 1 also extends about 1,000 feet southwest of the shaft, partly as drift and partly as crosscut. On level 2 are a number of drifts and crosscuts extending for about 500 feet southwest of the shaft, a northeast crosscut of about 400 feet to the May Queen lode, and an east crosscut about 2,000 feet in length toward the Gold Pass shaft. The development on level 3 is less extensive than on the others and is entirely to the southwest of the shaft.

GEOLOGICAL FEATURES.

The workings of the Abe Lincoln are partly in the granite, gneiss, and schist complex underlying the town of Cripple Creek and partly in the breccia. The productive part of the mine, however, is entirely in the older rocks. The contact between the gneiss and breccia is usually fairly well defined, though the gneiss shows more or less local brecciation and the breccia near the contact contains abundant gneiss fragments. The contact exhibits some pyritic mineralization, but no ore, and has not been much explored. The general dip of the contact is southeasterly. From the surface to level 1 the angle of dip appears to be 80° or 85°. Below this the dip is evidently lower, the relative positions of the contact on the two levels indicating an angle of about 30°. Most of the ore occurs in a fine-grained granitic gneiss such as is exposed at the surface near the Midland station, in many of the street cuts in Cripple Creek, and on the dump of the Cripple Creek Enterprise shaft, opposite the hotel. The gneissic structure, however, is somewhat less

conspicuous in the Abe Lincoln mine than elsewhere. This gneiss is cut by irregular dikes of reddish granite, such as may be seen in the cut at the Short Line station in Cripple Creek, and by dikes of phonolite. So far as known these dikes have exerted no particular influence on ore deposition. The schist encountered in the mine is a fibrolitic schist similar to that exposed in the Short Line cut near the Poverty Gulch trestle, containing large scales of muscovite. It is often intimately mingled with the gneiss, and like the latter is cut by dikes of red granite. The long east crosscut on level 2, after passing through breccia, continues for about 250 feet in shattered schist, which contains much pyrite in veinlets and in disseminated crystals. This schist is part of the same mass that is exposed at the surface near Fairview and that is reached also by the Chicago and Anaconda adits.

In nearly all the breccia seen in the Abe Lincoln mine granitic or gneissic fragments predominate over those of other rocks. In a few places, however, fragments of schist are the most abundant. Recognizable fragments of phonolite or andesite are extremely rare. The breccia usually contains much pyrite as finely disseminated crystals and in irregular bunches and veinlets.

There are at least two important basic dikes in the Abe Lincoln mine. One of these, called the Gold King dike, is supposed to be the dike known in the Gold King mine in Poverty Gulch and exposed beside the Short Line track just southwest of that mine. It has been followed for 500 feet in the Chicago tunnel, for about 70 feet on level 1 of the Abe Lincoln, and for 600 feet on level 2, where it lies about 1,000 feet east of the Abe Lincoln shaft. Its general course is N. 10° E. and it dips west at from 60° to 75°. This dike is crossed by a second basic dike which strikes generally N. 75° W. and dips southwest at varying angles, ranging from about 60° to 75°. This second dike has been followed for about 700 feet on level 1 of the Abe Lincoln, in a drift which is under and has nearly the same course as the initial portion of the Chicago tunnel. Both dikes appear to have been intruded at the same time and there is no appreciable faulting at the junction. The second dike, known as the Gold Pass dike, is supposed to be identical with the basic dike which has been drifted on for over 1,300 feet in the Chicago tunnel near the Gold Pass shaft. The general strike of the dike, as shown by this Gold Pass drift, is northwest. But as its course is very irregular and as it frequently branches and pinches out it may be that the two dikes, or rather dike zones, are really continuous.

LODE SYSTEMS.

Most of the ore in the Abe Lincoln mine occurs in a network of narrow and not very persistent lodes in gneiss, southwest of the main shaft. The most prominent of these lodes strike northwest or notheast, but they are intimately associated with other fissure zones running more nearly north and south. Few of the individual fissure zones have been followed for more than 400 feet. The most persistent productive lode is the Lillie, which strikes N. 20° E. and has been stoped for a length of 300 feet on level 1. On level 2, however, the Lillie fissure zone has not been found. The Abe Lincoln lode is a sheeted zone of rather indefinite width, striking N. 50° or 60° W. and dipping southwest. The name is used to designate one or more fissures of a general zone of approximately parallel fissures. The total width of this zone is probably 150 or 200 feet. The portion known as the Abe

Lincoln vein varies, according to circumstances, from a few inches to 30 feet in width.

The gneiss is cut also by a number of nearly horizontal fissures with generally southerly dip. These fissures, as well as the more nearly vertical lodes, have influenced the deposition of ore, as will presently be shown.

CHARACTER OF ORE.

The essential constituent of the Abe Lincoln ore is calaverite, which occurs with quartz in little vuggy fissures in the gneiss. Fluorite occurs occasionally with the quartz. Some of the veinlets on level 3 contain galena, pyrite, and tetrahedrite intimately associated with the pyrite. As a rule pyrite formed first, then tetrahedrite (when present), and finally quartz and calaverite. The galena apparently formed at about the same time as the quartz and calaverite, but is of sporadic occurrence. The ore on levels 1 and 2 is said to have contained very little silver, but on level 3 ore containing 6 or 7 ounces of gold per ton carries as much as 2 ounces of silver. No ore was seen at the time of visit on levels 1 and 2, but it is said to have been practically unoxidized. No oxidation was observed on level 3. The ore on levels 2 and 3 as mined in 1903 and 1904 is of medium grade.

PAY SHOOTS AND LODE STRUCTURE.

Some ore occurred in the Gold Pass basalt dike above level 1. It is said to have been rich, but was found in small isolated shoots of an aggregate length of about 500 feet. None of this ore was seen at the time of visit and its mineralogical character is not accurately known. It was probably partly oxidized. The Lillie lode contained a pay shoot which just above level 1 was about 300 feet in length. The ore occurred in the veinlets of a narrow sheeted zone in gneiss. So far as known, this pay shoot does not extend for more than a few feet below level 1, crosscuts on the lower levels having failed to find even a distinct continuation of the fissuring.

The pay shoots visible at the time of visit all occur southeast of the shaft, at the intersection of two or more of the fissures in the gneiss, which are individually rather indistinct and seldom very persistent. Although the ore bodies at these intersections are of irregular form, yet the ore is confined to the actual fissures and to the accompanying irregular fractures, and does not, as in the Ajax, Thompson, and some other mines, permeate the granitic rock. These fissures are as a rule only a fraction of an inch in width. For a distance of half an inch or so from the fissure the gneiss contains disseminated pyrite and is greenish yellow in color. Beyond this narrow zone the gneiss is normally fresh and unaltered. The walls of the fissures are usually lined with a film of pyrite and upon this are deposited the quartz and calaverite, sometimes with tetrahedrite and galena. The fissures are in some cases of microscopic width and can be traced only by the narrow zone of greenish alteration in the gneiss, which is always an indication of the presence of ore. A typical ore body being opened at the time of visit on level 3 occurs at the intersection of at least three distinct sets of fissures. One set strikes nearly north and dips east at about 75°. It forms a well-defined zone of sheeting from 6 to 20 feet in width. Another set strikes northwest and dips southwest at about 45°. The

fissures of this zone are more widely spaced than the other, the whole zone being at least 30 feet in width. The ore occurs in the vicinity of the intersection of these two sets of fissures with a so-called "flat vein" striking northwest and dipping northeast at 45° or 50°. This flat vein is about 4 inches wide and consists of quartz, valencianite, and pyrite, these minerals apparently being a product of replacement of the surrounding rock. The pay shoot, so far as developed at the time of visit, follows this "flat vein," though the latter itself does not contain ore. The ore body as stoped in January, 1904, was about 60 feet long and from 6 to 20 feet wide.

About 150 feet southwest of this place, or 200 feet southwest of the shaft, is another pay shoot known as the Arcadia shoot. This is an irregular chimney-like body of ore which has been stoped on all the levels. It occurs at the intersection of at least three nearly vertical fissure zones—one striking northwest, another north-northwest, and another northeast. According to the manager, Mr. Walter Swanson, these vertical fissures are crossed by a number of nearly horizontal fissures. The best ore occurs near these horizontal fissures. This ore body was lately reached by crosscutting on level 3.

UNDERGROUND WATER.

Water was first encountered in the Abe Lincoln shaft at a depth of 128 feet, or about 9,483 feet above sea level. The maximum flow of 500 gallons per minute was reached at a depth of 350 feet, but the Ophelia and Standard tunnels ultimately drained the mine. In sinking the shaft to level 3, in the winter of 1903, a little water was encountered near the new level, but this soon disappeared, probably as a result of the drainage by the El Paso tunnel.

RHYOLITE MOUNTAIN.

GEOLOGICAL FEATURES.

Rhyolite Mountain, with an elevation of 10,771 feet, lies 2½ miles north of Cripple Creek and is separated from Mineral Hill by the deep trench of Spring Creek On its eastern side the Pikes Peak granite reaches nearly to the summit, but the western and northern slopes are covered by a volcanic breccia, with usually coarse fragments of brownish or dark-gray color. As a rule, it contains but little pyrite. A smaller area of breccia covers the southern slope of the adjacent Copper Mountain. It is similar in character, but contains many large fragments of granite. There is some evidence that the breccia of Rhyolite Mountain is of local origin and formed in a volcanic neck underneath the summit. Several large and irregular areas of normal phonolite cover the southern slope of the hills and also occupy their summits. These masses of phonolite are in most places bordered by intrusive contacts.

PROSPECTS ON RHYOLITE MOUNTAIN.

At the eastern foot of the steep granitic slope of Rhyolite Mountain the Pay Rock claim is located. A shaft 80 feet deep was here sunk on a seam trending northwest and containing a little calaverite. The shaft was deepened to 300 feet, but, it is stated, without results.

About 150 feet below the summit are the prospecting shafts of the Rhyolite Beacon Gold Mining Company, from many of which good assays are reported. In

one place the granite contains disseminated secondary fluorite. The overlying breccia is locally converted to a soft yellowish-white kaolin rock. The principal shaft is 200 feet deep and sunk through 150 feet of dark-brown, fresh breccia. At that depth the granite was met, the sharp contact dipping 45° W. and showing a hummocky surface covered with clay. Near the contact the breccia contains seams and disseminated grains of calcite. Some good assays are reported from the upper part of the shaft.

The Metallic tunnel is located at an elevation of 9,250 feet on the western slope of Rhyolite Mountain. It is 1,000 feet long and reported to be entirely in granite. Farther north, on Bernhard Creek, some prospecting operations have been carried on along phonolite dikes in granite.

FLUORINE MINE.

The Fluorine mine, owned by the Montreal Gold Mining and Milling Company, is situated halfway up the southern slope of Copper Mountain. It is now leased by the Sioux Falls and Cripple Creek Gold Mining Company, who have recently built a 100-ton cyanide mill to treat the ore. The mine is of interest as being the northernmost producer of the camp. The total production could not be definitely learned, but it is probably near $160,000. The workings consist of several shallow shafts and a tunnel 200 feet in length. The stoping from the tunnel reached nearly to the surface, and the roof has recently caved in, leaving a large open chamber.

The mine is situated practically on the contact of phonolite, breccia, and granite. The phonolite overlies the breccia, which in turn lies flatly on the granite. The breccia is not extensive just at this point, however, and pinches out in the farthest workings, leaving the phonolite resting on the granite. The different rocks in the mine appear to have contained much pyrite, but are now completely oxidized. The breccia is rather granitic and contains numerous large granite fragments.

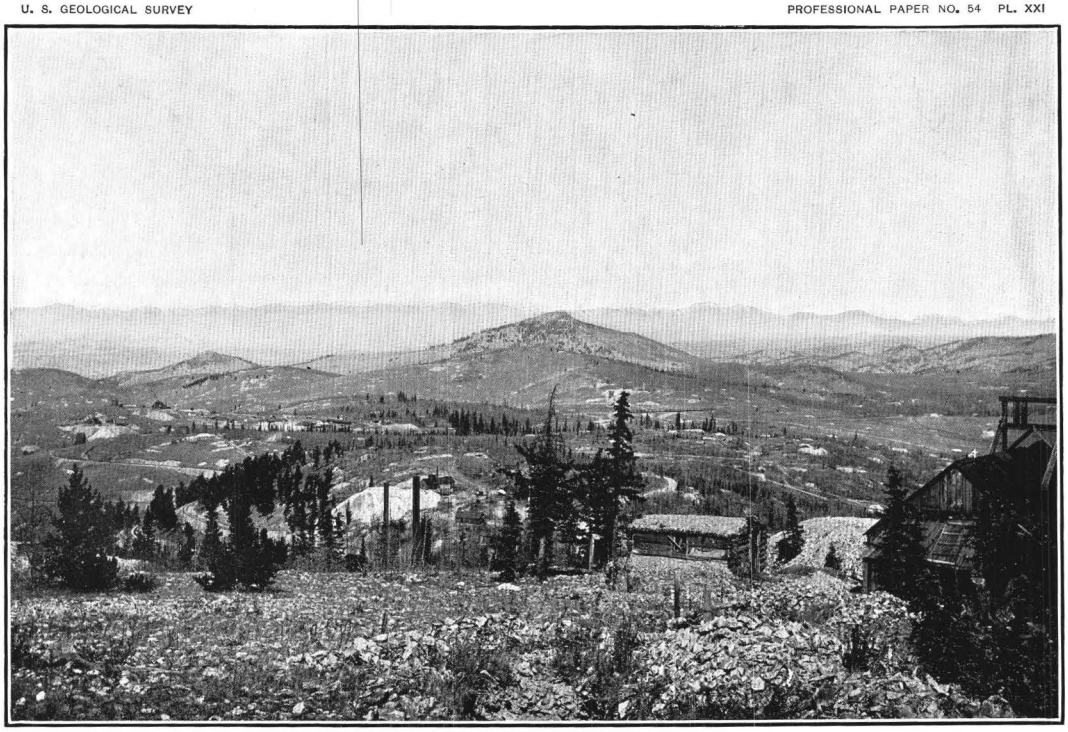
Rich pockets were found in the breccia, and were mined out. At the present time practically the whole of the breccia and some of the granite in the mine is being taken out and treated by cyaniding without roasting. The value of the ore now mined ranges from $4 per ton up. In a pit on the eastern part of the claim some rhodochrosite with argentiferous galena and zinc blende was found in spaces of dissolution in the granite. A tunnel driven underneath the Fluorine mine is entirely in granite and failed to find ore.

The Copper Mountain mine, situated just east of the Fluorine, shipped some ore in 1898, but the amount was not ascertained. It is developed by a shaft 200 feet deep and drifts extending in a northwesterly direction on a vein in phonolite containing pyrite, galena, and zinc blende, with fluorite gangue.

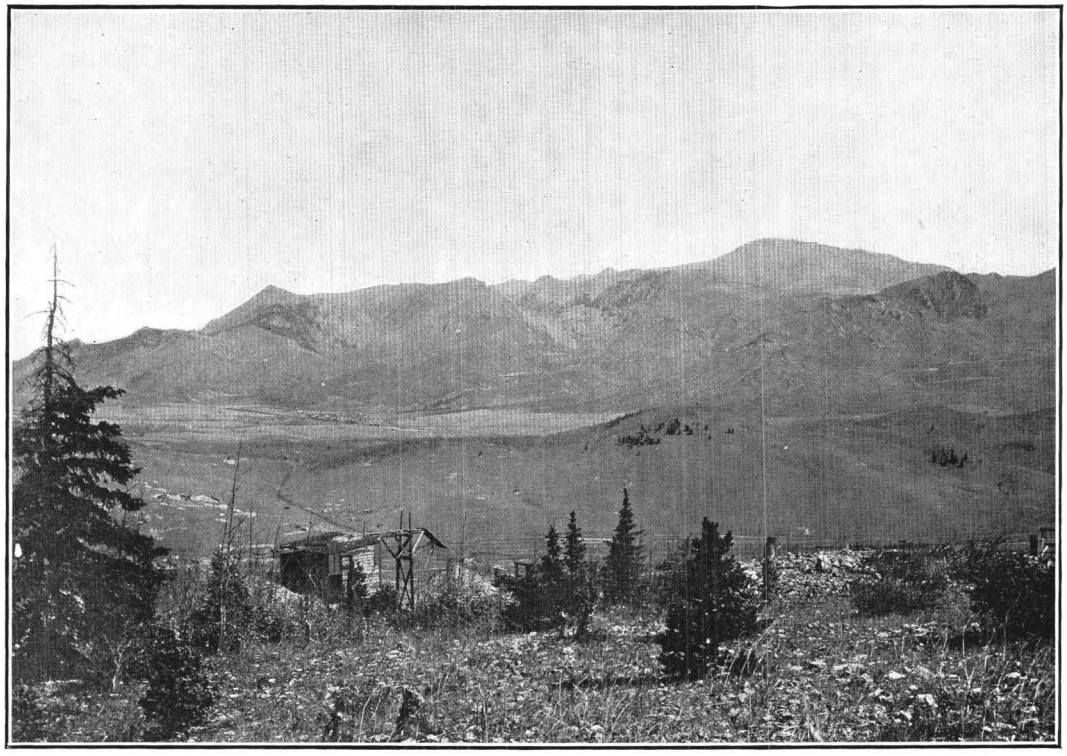
RED MOUNTAIN.

GALENA MINE.

The Galena mine, located on the slope of Red Mountain toward Spring Creek, is the only place in the area west and northwest of Cripple Creek where any notable amount of ore has been found. The mine is owned by the Iron Mountain Mining and Milling Company and is developed by an incline shaft 560 feet deep, extending



A. RHYOLITE MOUNTAIN, FROM SUMMIT OF BULL HILL.



B. PIKES PEAK, FROM SUMMIT OF BULL HILL.

Town of Gillett in left middle-ground.

from the croppings down to the level of a tunnel 1,000 feet long, near the level of Spring Creek. The total production is reported to have amounted to $12,000. Hill's Manual gives $6,000 up to 1900. Little work was being done in 1904.

The vein is contained in Pikes Peak granite, near the northwesterly trending contact of the Spring Creek granite. Its continuation across Spring Creek would carry it into the area of olivine syenite. The vein follows in part a phonolite dike which at the croppings is only 4 inches wide and is said to carry values up to $20. The general strike is northwest and the dip is 35° NE. In depth the vein straightens and in the tunnel dips 50°, appearing here as a dark streak, 8 to 10 inches wide, of crushed and partly replaced granite containing fluorite with some pyrite. The assay values are low. The present workings are in a winze 165 feet above the tunnel level. The vein is here 10 inches wide and distinctly crustified, consisting of quartz, fluorite, manganiferous dolomite, galena, zinc blende, and pyrite. This ore is said to contain 8 to 10 ounces silver and 2 to 3 ounces gold per ton. The gold values are probably in calaverite, though this mineral was not positively identified. The pay shoot which was found at the croppings appears to pitch southeasterly on the plane of the vein, and it is hoped that a further extension of the tunnel will intersect it.

AREA BETWEEN CAMERON AND GILLETT.

GEOLOGICAL FEATURES.

The little town of Cameron is situated at the northern base of Bull Hill, near the head of Grassy Creek. The low hills north of the town consist of schist, gneiss, and the two principal varieties of granite, in irregular areas. A small outlier of the main breccia area covers Galena Hill. Near its contact the granite is often brecciated or shattered. North of this extends a rolling granite plateau on which, 2 miles farther north, the town of Gillett is located. Trachyte and Cow mountains rise southeast of Gillett to an elevation of 1,000 feet above the plateau. A series of more or less continuous phonolite dikes with a general northerly trend traverse the granite between Cameron and a point 1 mile west of Gillett. A number of prospects and one or two mines are contained within this belt.

SUNSHINE MINE.

Situated on the southeastern slope of Galena Hill the Sunshine is of interest as being farther to the northeast than any of the mines in the main volcanic area. It is owned by the Fort Pitt Mining Company, of Pittsburg, Pa. The total production, including the ore taken from the Sunshine vein in Sedan ground, was estimated at $25,000 in January, 1904.

The developments consist of an incline shaft following the vein for about 400 feet, and four levels, representing perhaps 2,000 feet of drifting, besides a number of shallow shafts on the apex of the vein. The Sedan shaft, which connects with levels 2 and 4, is 250 feet deep and vertical. The elevation of the collar of the incline shaft is 10,180 feet.

Examined underground, the country rock appears to be a coarsely brecciated mass of granite and schist, both of which are oxidized and kaolinized. A 15-foot phonolite dike crosses the property from northwest to southeast, and dips southwest at about 45°.

A vein follows the foot-wall side of the phonolite dike. On level 2 the vein is a shattered zone varying from a few inches to 2 or 3 feet in width and sometimes contracting to a narrow seam. In general the ore is oxidized and contains much kaolin, but pyrite occurs in some places. Toward the north end of this level cross seams are numerous and ordinarily strike north-northeast. So far as known they they contain no values. About 125 feet southeast of the shaft on level 2 the vein becomes obscure and can not be traced farther. A north-northeast seam is drifted on and is said to connect about 25 feet to the south with a vein parallel and similar in character to the vein above described. Whether these two veins are one and the same with an intervening jog or two separate veins connected by a cross fissure the evidence was not sufficient to determine. Level 3 shows the vein with much the same character as above. In the fourth (bottom) level the vein is less oxidized and contains kaolin and quartz in places, also much pyrite.

To the south the phonolite dike forms the hanging wall of the vein, and about 50 feet south of the shaft the vein seems to break up, sending a number of pyritized stringers into the dike. It is as yet uncertain whether these stringers were mere spurs from a continuous vein or whether they eventually carried the vein through the dike.

Down to level 3 the ore is oxidized. Assays alone distinguish that which is workable. There seems to be a fairly distinct separation in the range of values, however, and ore containing 1½ ounces per ton is about the poorest that has been mined. Between levels 3 and 4, where the vein is more quartzose, some of the ore is unoxidized, and where sufficiently rich, tellurides can be seen in little veinlets and seams, along with oxidized material.

From the surface south of the shaft down to level 2 a pay shoot has been stoped 2 to 4 feet wide and 30 to 60 feet long, being widest near the surface. The stope continues for a short distance below level 2, but the vein soon touches the under surface of the dike, and this is said to limit the pay ore. The shoot pitches to the northwest, and is said to have furnished good ore.

Another shoot, also pitching to the northwest, occurs about 35 feet south of the shaft on level 3. A stope 3 feet wide and 20 feet long is being carried upward. The values do not appear to extend below the level. When the shaft had reached a depth of about 30 feet below level 3 a small bunch of ore was found and seemingly corresponded in position to a partly interrupted continuation of the ore shoot on level 3. The bottom level is being driven to the north in hope of cutting this ore shoot, the supposition being that it pitches to the northwest, as do the others. No conditions decidedly influencing the position of the ore shoots could be ascertained.

DEPOSITS NEAR GILLETT.

A number of prospects have been opened on small phonolite dikes north of the Sunshine mine. One of these, called the "E. F. C.," is located on a hill just south of the main road between Cripple Creek and Gillett, 1¼ miles south-southwest of the latter town. The ore, which contains much galena and zinc blende with adularia, is found in the granite close to the wall of a phonolite dike, and is said to contain up to $40 per ton.

A little farther north, on the main road, is the Mayflower, the vein of which follows an east-west dike, and is said to have produced some good ore. The Bolivar, about 1 mile west of Gillett, is located on one of the principal phonolite dikes. Here, too, galena is said to occur.

One mile west of Gillett a number of northwesterly trending flat phonolite dikes cut the granite. The property of the Lincoln Mines Mining and Milling Company is located here. Small shipments amounting to about $4,000 have been made. The mine is developed by a vertical shaft 300 feet deep, and three levels, 75, 160, and 300 feet below the collar, have been turned. The ore shipped is said to have been extracted from a northeast vein dipping steeply northwest; on the lowest level this vein does not appear, and it has possibly been deviated by a phonolite dike dipping 30° SW. A short distance westward is the Normandy shaft, 200 feet deep, intersecting a phonolite dike, and the Hawkeye, sunk on a brecciated dike containing much fluorite. Close by the Hawkeye a narrow basic dike of doubtful original character is met trending southwesterly, and is said to contain some values.

About half a mile east of Gillett, at the Great Western claim, a northeasterly trending zone with small seams of fluorite has been opened, and is said to contain low-grade ore. Some prospecting has been done on phonolite dikes at the southern point of Trachyte Mountain. A long tunnel is being driven under the summit of this mountain through granite in the hope of striking the supposedly mineralized vent connected with the mass of phonolite which covers its top.

A number of small shafts and tunnels are located on the western slope of Cow Mountain, east of Trachyte Mountain, and low-grade ore is reported from some of these places.

GLOBE HILL.

GEOLOGICAL FEATURES.

Globe Hill rises on the southeast side of Poverty Gulch to an elevation of about 10,450 feet, and its broad, gently rounded summit overlooks the town of Cripple Creek. It is composed of volcanic breccia of normal type, but throughout very much oxidized and containing much limonite and kaolin. Dikes are notably absent. The rock is extremely shattered by seams and short veins, having many different directions and dips and often filled with quartz. The adjoining western part of Ironclad Hill is geologically similar to Globe Hill, but contains a number of strong veins with northeasterly trend and characterized by well-crystallized smoky comb quartz. Here, too, the breccia is thoroughly oxidized over a considerable space, and this oxidation descends at least 700 feet to the level of the Chicago drainage tunnel. Nothing similar to this deep and extensive oxidation of the rock occurs in any other part of the district. It has been assumed by Penrose and Rickard, who have described these occurrences, that they are due to the decomposing action of thermal waters. In a general way this is probably correct. (See p. 284.) Ironclad Hill, like Globe Hill, is characterized rather by irregular masses of low-grade ore chiefly confined to the surface than by large ore shoots following the veins.

DEERHORN MINE.

The Deerhorn mine, which occupies the summit of Globe Hill, is owned by the Stratton estate. A considerable quantity of ore has been extracted from the property, chiefly from the open cuts, but no exact figures could be obtained. The developments comprise several large open cuts underneath which the Globe tunnel (elevation of portal about 10,325 feet) extends in many ramifications. The deeper developments start from the Deerhorn shaft (elevation of collar about 10,425 feet), which is 575 feet deep. Six levels are turned and exploratory drifts extend 600 or 700 feet in various directions, chiefly north, south, and west. Level 6, 565 feet below the collar, has several long crosscuts in various directions and connects with the Plymouth Rock shaft, 650 feet to the southwest; the various drifts and crosscuts will aggregate nearly 2 miles.

The soft oxidized breccia on top of Globe Hill contains small values throughout and many smaller shoots and pockets of richer ore. Values of about $5 per ton are said to be widely distributed, and parts of the oxidized material would probably be suitable for the direct cyanide process without roasting. In the Globe tunnel, which throughout traverses the oxidized breccia filled with kaolin and limonite, the first 300 feet are reliably reported to average $3 per ton. Some of the seams carry up to $15. A few hundred feet from the portal are old workings, the ore of which is said to average $8 across a width of 100 feet, while along some fissures it will average $30. There are few quartz veins; the numerous seams and veinlets appear nonpersistent; occasionally they contain partly decomposed fluorite. Much ore was extracted from the large pit 200 feet north of the shaft. The breccia is ordinarily entirely decomposed, but a few masses of bluish, less oxidized, rock occur; these, however, are said to contain very low values. Seams cut the mass in many directions; one system dips 10° to 40° S.; another north-south system is vertical. A large mass of this rock is said to average $25 to $30, and connects with a smaller shoot on the Globe tunnel level, forming a large body which dips south or southwest. The flat seams sometimes cut off the ore.

The lower levels were not accessible, and no work was being done on them. On level 6 a drift running out west-northwest is said to follow a "soft fluorite vein 20 feet wide." On the whole the results of the extensive underground exploration are said to have been disappointing, though some rich seams are reported from various places. The oxidation extends to the bottom level, and is said to be as well marked here as near the surface.

The large masses of gypsum found near the shaft are of particular interest. They are mentioned by Penrose in his report and more fully described by T. A. Rickard,[a] who says that at a depth of 240 feet the shaft cuts into a mass of gypsum, which continues for about 300 feet to the bottom level. There are at least three of these chimneys, ending with narrow points a short distance above level 3; the largest is at least 75 feet in diameter near the bottom of the shaft. The gypsum is compact, white, and crystalline; it contains grains of pyrites and a little disseminated fluorite, as is well shown on the dump of the shaft. Mr. Rickard says that "The surrounding breccia is everywhere traversed by color bands due to

[a] Trans. Am. Inst. Min. Eng., vol. 30, 1900, p. 399.

layers of gypsum, manganese, oxide, and iron ocher. Scattered through the vicinity but parallel to the group of columns of gypsum there are patches as well as seams of fluorite sand, consisting of particles of crystalline silica, stained purple by admixture with fluor-spar. The upper levels also show bands of * * * pure kaolin." For further discussion in regard to this occurrence see page 220.

PLYMOUTH ROCK MINE.

The Plymouth Rock property, likewise owned by the Stratton estate, is located on the west side of Ironclad Hill, about 600 feet southwest of the Deerhorn shaft. The production is not known. Developments consist of a shaft between 800 and 900 feet deep, the principal workings being on a northeasterly trending vein, possibly the same as the Ironclad. From the lowest (ninth) level drifts extend for a couple of hundred feet west, northeast, and southeast. The shaft and workings, which were inaccessible in 1904, are reported to be throughout in thoroughly oxidized breccia. The deep exploration is said to have failed to develop any ore bodies, though much of the soft rock gives traces or very low assay values in gold.

The Chicago tunnel, the elevation of which is about 9,700 feet, extends from Poverty Gulch to the Plymouth Rock shaft, with which it connects about 700 feet below the surface. The tunnel extends for 2,000 feet in an east-southeast direction, and then changes to a few degrees north of east and continues for about 2,200 feet farther, to the connection with the shaft. From its portal to the end the tunnel traverses normal breccia and aside from the few basalt dikes cut in the first 1,200 feet there are no intrusive masses present. The breccia is in general not oxidized and contains a little pyrite. A specimen from a point 1,200 feet from the shaft consists of normal fine-grained breccia of phonolite and granite, with much finely distributed pyrite. The ferromagnesian silicates have been converted to chloritic material. Otherwise there is little alteration. About 1,000 feet from the end the rock within a short space becomes entirely oxidized and softened; it is filled with kaolin, limonite, and oxides of manganese; sometimes it also contains gypsum. At the end the rock is extremely soft, and close timbering is necessary. There are no distinct veins, but seams, usually with much kaolin, run in various directions. The rock is said to contain small assay values throughout, ranging up to $1.50 per ton in gold. Branch drifts from the main tunnel enter schist.

A thousand feet east-northeast of Plymouth Rock shaft is the World's Fair claim, also belonging to the Stratton estate. A shaft about 200 feet deep has been sunk on it and some drifting has been done on a northerly trending vein. A little ore is said to have been shipped.

IRONCLAD MINE.

The Ironclad mine is situated a few hundred feet southwest of the Plymouth Rock and is operated at present by the Cripple Creek Homestake Mining and Reduction Company. The total production is stated to be $225,000. A considerable amount of low-grade oxidized ore has lately been encountered on the claims adjoining the Ironclad on the southeast; this ore is at present mined and milled by the same company, the process employed being that of simple cyaniding without

roasting. In 1904 a 150-ton mill was in operation, but a much larger one is now (1905) in course of construction. The Ironclad mine is developed by a vertical shaft 690 feet deep, with seven levels, and at least 1,500 feet of drifts and crosscuts. The elevation of the collar is about 10,425 feet. Level 7 is 660 feet below the collar.

The country rock consists throughout of thoroughly oxidized breccia of normal type. Above level 4 the ore bodies consist of irregular masses of soft, oxidized breccia, with many small seams of comb quartz showing radial structure. On level 4 a well-defined vein begins to appear, striking northeasterly and dipping about 70° SE.; the same vein has been reached by crosscuts on all of the lower levels; it is from 1 to 6 feet wide and consists chiefly of soft, brown, clayey vein matter, with seams of comb quartz. No tellurides remain; copper stains are often found, and a specimen from between levels 6 and 7 contained a little tetrahedrite, with chrysocolla, the former inclosed in quartz. Fluorite seems to be absent or entirely decomposed in the main vein, but near the end of the crosscut on level 7 a parallel northeasterly seam, with crushed fluorite, was cut. Fifty feet south of the shaft on level 7 another northeasterly vein was cut, dipping 50° SE.; this is said to contain some lead. It shows a streaky mass 1 foot wide mingled with clay and limonite, but consisting chiefly of celestite or sulphate of strontium, in part crystallized.

The pay shoot on the Ironclad vein dips southwest on the plane of the vein at an angle of about 70°. Its greatest horizontal length is 75 feet. The shoot is continuous from level 3 almost down to level 7, but on the latter contains only low-grade ore. A fair amount of low-grade ore is claimed to exist on levels 5, 6, and 7 outside of the richer pay shoot.

A thick, well-defined quartz vein, with northeast trend, and containing much smoky comb quartz, is encountered between the surface pits on the Magna Charta claim and the Ironclad shaft; it has been traced for several hundred feet up toward the summit of Ironclad Hill. This same vein is cut by a tunnel from the Magna Charta claim, and by a crosscut from a shaft 150 feet deep on the same property. It is said to contain only low-grade ore.

The shaft just mentioned enters hard pyritic breccia a short distance below the surface and evidently marks the southeasterly limit of that area of very deep oxidation which characterizes Ironclad and Globe hills. The oxidized ore milled in the cyanide works of the Homestake Mining Company has thus far been extracted from the surface between this shaft and the prominent vein mentioned in the preceding paragraph. It is reported to average $4 to $5. The South Park shaft was sunk in breccia near the Ironclad some years ago to a depth of nearly a thousand feet. Little exploratory work was done and it is stated that nothing of value was found.

HOOSIER MINE.

The Hoosier mine is situated just north of Hoosier Pass and about half a mile north of Globe Hill. It is the property of the Grafton Gold Mining Company. The total production of the mine is estimated at $360,000. Dividends have been paid from the royalties received from lessees. The workings consist of an incline shaft 300 feet deep and a vertical shaft about 600 feet deep, in which sinking is in progress. The drifts and crosscuts probably aggregate 2,000 feet in length. The elevation of the shaft collar is about 10,335 feet.

The vertical shaft begins in breccia about 250 feet south of the granite contact. Nothing but breccia is disclosed in the mine workings, and the granite-breccia contact must therefore be steep. The breccia is in general rather fine grained and contains much pyrite.

Three veins are encountered in the mine. On the Discovery, or Hoosier, vein the incline shaft was sunk. The vein has a northwesterly strike and dips 65° to 80° NE. The second vein, called the Ore vein, strikes about 15° more to the north and is nearly vertical. The third is a flat vein, dipping slightly to the south, and crosses both the others at a depth of about 250 feet.

Good ore occurred along the Ore vein, but near the intersection with the Hoosier vein the grade was lower; rich ore was, however, found below this intersection. The Ore vein is a sheeted zone in breccia, much oxidized toward the top, and carries streaks of quartz and kaolin. The upper part of the vein contained oxidized ore with free gold. The values are said to have been largely in the kaolin. Below the 200-foot level oxidation was slight and fluorite with tellurides made their appearance. A 1-inch seam of manganese oxide, probably psilomelane, is seen in the vein on level 5 of the vertical shaft. The values of the ore mined averaged about $60.

A shoot pitching to the southeast and averaging 70 feet in horizontal length extended from near the surface down to about 350 feet on the Ore vein. Two hundred and fifty feet below the surface, at the intersection with the flat vein, the width of the pay shoot was reduced from 14 feet above it to 6 inches below it, and though the vein was stoped for another hundred feet down, the values were not good. It is estimated that 6,000 tons of ore were taken from this stope. A small pocket of ore was mined on level 6, 100 feet southeast of the vertical shaft.

A short distance northwest of the Hoosier is the Friday shaft, sunk 150 feet deep between the two veins mentioned above. From a lower shaft on the Friday, 200 feet deep, some ore is said to have been extracted along a dike.

HEAD OF SQUAW GULCH.

Squaw Gulch heads in an amphitheater surrounded by Raven, Bull, Ironclad, Globe, and Gold hills. There is here a large area of breccia which has thus far proved notably unproductive, though surrounded by mines of demonstrated value. No work is being done in this area at present, but the surface bears evidence of having been prospected pretty thoroughly.

The Humboldt, at the end of the southwestern spur from Ironclad Hill, found no ore of consequence in its 500-foot shaft. A little of the surface slide rock, however, was shipped. A vein containing much celestite is reported to course in a northeasterly direction from the Humboldt toward the Josie S. shaft, and to continue over to the Bull Hill side.

Some ore was taken from a shaft on the east end of the Colorado Boss claim on Gold Hill, across the gulch from the Humboldt, but the character of the vein could not be determined from examining the dump.

A dump on the Last Chance claim, just north of the Colorado Boss, shows fissures in oxidized breccia with drusy quartz. It is said that no ore was found.

The Jeff Davis mine, near Fairview, on the High Line, has several veins, the most important being a northwest-southeast vein dipping about 60° NE. The ore was oxidized. The production is said to have been between $10,000 and $15,000.

NORTH SLOPE OF IRONCLAD HILL.

Breccia occupies the upper part of the north slope of Ironclad Hill. The lower part shows schist and granite in two well-defined areas. Near the contact of schist and breccia are several small mines, which, however, have in the aggregate a fairly large production to their credit.

JERRY JOHNSON MINE.

The Jerry Johnson Mining Company owns the larger parts of the Jerry Johnson claims Nos. 1 and 2, as well as the Arapahoe and Little Pedro claims. The output to 1904 is about $125,000. The developments consist of the Jackson shaft, 450 feet deep; also two smaller shafts and about 1,000 feet of drifts and crosscuts. The elevation of the collar of the Jackson shaft is about 10,350 feet. The country rock is almost exclusively breccia, the workings approaching the schist contact in only one place.

The two principal veins are the Jerry Johnson, striking about N. 20° W. and dipping 45° WSW., and the W. P. H. vein, which first courses almost due north and then changes to north-northwest, with a dip of 50° W. Both veins are oxidized throughout and appear as narrow seams of clay or drusy quartz with silicification extending for several inches on each side of the vein. In some places there are a few more narrow parallel seams, making the width of the vein range up to 4 feet. The ore contains very little fluorite.

On the Jerry Johnson vein little of value was found from the surface down to the 300-foot level, but along this level ore occurred from the crosscut north for a distance of 80 feet. The ore extended only 40 or 50 feet above the level and was taken out about 1 foot wide. At the end of the drift a steep cross seam is faulted 2 feet by the vein, and a small bunch of ore occurred in the intersection. The same cross seam is faulted by the W. P. H. vein. No ore has been developed on the 350-foot level.

The W. P. H. vein lies 100 feet to the northeast of the Jerry Johnson vein. Developments on the 300-foot level have shown good values, the shoot extending for 100 feet, practically up to the ground of the W. P. H. mine. The central clay seam is rich and the rock is taken out 4 feet wide for the screenings. The ore reaches 40 or 50 feet above the level to a series of flat seams which are apt to cut out the values. In the southern part of the shoot, in what was known as Vogelman's ground, these flat seams, however, carried values themselves in the foot of the vein. At the 400-foot level good values occur at intervals, but it is believed that the principal shoot pitches north on the vein and has not yet been reached. This is just below the place where a rich pocket was found in 1904 in the W. P. H. mine.

W. P. H. MINE.

The property known as the W. P. H. mine, belonging to the Woods Investment Company, was in 1904 leased to Harrison & Sevier. The shaft is situated 300 feet

northeast of the Jackson shaft. Some ore was mined in 1903 from the so-called contact vein, but in the early part of 1904 a very rich shoot was found in the W. P. H. vein, from which during that year a total amount of $315,000 is reported to have been produced.

The shaft was 245 feet deep when visited, with about 200 feet of drifts on that level, corresponding to the 300-foot level in the Jerry Johnson. It is sunk in schist, and a short crosscut leads to the contact with the breccia, which dips 40° WSW. Some good ore is found on this important contact vein, which continues south-southeast to the Damon mine. Both free gold and tellurides occurred, the latter in places being contained in fresh schistose rock, in which they have evidently formed by replacement. Values are said to be cut off by a flat vein 12 feet below the level. The crosscut then continues west for 75 feet, and near the W. P. H. strikes a flat vein dipping 20° N., which contains no values, but faults the W. P. H. about 6 feet. The latter is twisted, but soon regains its old strike. Irregular values began near the flat vein, but gave out. Thirty feet south, on the W. P. H. vein, a small seam with free gold was noted in the hanging wall and immediately led into a rich pocket about 20 feet long, 8 feet thick, and extending for 18 feet along the dip of the vein above and below the level. It is believed to form part of a narrow shoot with northerly pitch. Above the level the values are probably cut off by a flat seam, as happened in the Jerry Johnson mine. Many tons of the ore from this pocket yielded at the rate of from $1,000 to $6,000 per ton.

The ore consists of massive and in places silicified breccia; it contains no fluorite and few large quartz seams. In the main it is oxidized, but tellurides are sometimes found, as well as a little galena and zinc blende, but no copper minerals. The tellurides in some instances occur directly in fragments of schist and granite and have then undoubtedly been formed by direct replacement. The rare minerals emmonsite and tellurite, the former a hydrated tellurite of iron, the latter tellurium dioxide, occurred in this rich mass. The ore is very poor in silver, even the richest parts rarely containing more than a few ounces to the ton.

DAMON MINE.

The Damon mine, which belongs to the Woods Investment Company, comprises claims situated a few hundred feet southeast of the Jerry Johnson mine. The total production is stated to be over $200,000. Lessees took out $145,000 between December, 1898, and May, 1901. The developments consist of the Jerry Johnson incline, the Damon incline, 270 feet deep, and the Damon vertical shaft, 500 feet deep. The latter is situated 150 feet northwest of the Damon incline. Drifts and crosscuts amount to 3,000 or 4,000 feet.

The principal country rock is a dense phonolitic breccia. The contact with the schist is frequently reached in the workings, but the latter do not extend into the schist.

There are two fairly persistent veins; one of them follows the breccia-schist contact, while the other lies parallel to this contact, from 10 to 25 feet to the west of it. Besides these two there are a large number of flat veins with dips of from 10° to 50° in various directions, and which really carried the larger part of the ore.

The contact vein is evidently the same which is exposed in the W. P. H. mine, 500 feet farther north, and at one point in the Jerry Johnson. It contains ore in places, but is not uniformly and persistently mineralized. The Damon vein has been traced more or less continuously for 400 feet, but is not always distinct. Both veins are really narrow sheeted zones, generally oxidized, and sometimes considerably shattered. The ores are chiefly contained in the narrow fissures and the oxidized tellurides are associated with a little quartz and fluorite.

The principal ore developments occurred on the upper three levels. Very little ore has been taken out from the two lower levels. The Damon incline is sunk 40 feet vertically in breccia; it then strikes the schist contact and follows its steep westerly dip for the remainder of the distance. The principal stopes on the contact vein begin near the point where the contact is reached and continue down below level 2; in places they are 20 feet wide. Another large stope has been mined on the same vein at the Jerry Johnson incline; it is 40 feet long and reaches 40 feet above and 10 feet below the level; the width is from 10 to 50 feet, the greatest width being attained just above level 2. The stopes on the Damon vein occur chiefly where the flat veins join it. One on level 1, at the junction with the principal flat vein, is 8 to 10 feet wide. The most important of these flat veins is that met just south of the incline on level 1, 60 feet below the collar of the vertical shaft. This flat starts at the Damon vein and dips 10° WSW. It has been stoped 6 feet high for over 100 feet westward, and the stopes extend north and south for about 200 feet. It contains one principal and several smaller oxidized seams in very hard breccia. It is said that the whole thickness of this vein was ore and some streaks 6 inches in width averaged 5 ounces per ton. Just south of the incline and a little below level 1 a vein is found which dips about 40° NNW. It is stoped 7 feet high, the stope trending northward for about 50 feet and making a considerable body where it joins the Damon vein. This stope extends down almost to level 2.

At the west side of the stope, on the contact vein near the Jerry Johnson incline, is the top of a raise which leads down into a stope on a vein dipping 45° NNW. This stope extends 30 to 40 feet below level 3. On level 3 a stope has also been opened on a flat vein some 50 feet west of the main shaft.

CHAPTER II.—MINES OF GOLD HILL.

GENERAL INTRODUCTION.

Gold Hill lies in the northwestern part of the productive area. Its northwestern slope (Pl. XXII, *A*), dotted with mines and with piles of waste rock and crowned by the conspicuous shaft house of the Anchoria-Leland mine, forms one of the most striking and characteristic views visible from the town of Cripple Creek. The hill is composed chiefly of the normal phonolitic breccia, bounded on the north and west by the schist and gneiss that underlie the town of Cripple Creek and on the southwest by the Cripple Creek granite. The breccia is cut by a mass of syenite at the southwest contact between the breccia and the granite, and by two masses of latite-phonolite, one near Anaconda and one in the upper part of Squaw Gulch, southeast of the summit of the hill.

The principal mines are on the western half of the hill. On the northwest are the Anchoria-Leland, Jefferson, Geneva, and Half Moon mines, all in breccia. On the west are the Moon-Anchor, Midget, Progress-Gold King, and Conundrum mines, partly in breccia and partly in gneiss. On the southwest are the Lexington, E. Porter Gold King, Mint, Pointer, Accident, and Red Spruce mines, partly in breccia and partly in granite and syenite, while on the south is the Anaconda mine in breccia and latite-phonolite.

Gold Hill is penetrated by a number of long adits. The most northerly is the Cripple Creek and Gold Hill tunnel, which is about five-eighths of a mile in length. It extends from the town of Cripple Creek in an east-southeast direction and at an elevation of about 9,500 feet to the Anchoria-Leland shaft. The Good Will tunnel, with its portal 32 feet lower and three-eighths of a mile south of the Cripple Creek and Gold Hill tunnel, has a general east-northeast course and also connects with the Anchoria-Leland shaft. The Ophelia tunnel, at an elevation of 9,268 feet, enters the west base of the hill about three-eighths of a mile southwest of the Good Will portal and extends with a nearly east course under the south slope of Gold Hill, past Anaconda. This tunnel was over 1¼ miles in length in 1903, and if carried to completion will tap the mines of Bull Hill over 1,000 feet below the surface. The Anaconda mine also has a long adit which extends for nearly a mile, in a direction slightly east of north, from the town of Anaconda under and past the summit of Gold Hill. The portal of this adit is at an elevation of nearly 9,500 feet, or about the same as the Cripple Creek and Gold Hill tunnel.

ANCHORIA-LELAND, JEFFERSON, GENEVA, AND HALF MOON MINES.

INTRODUCTION.

The Anchoria-Leland mine, situated on the northwest side of Gold Hill, is owned by the Anchoria-Leland Mining and Milling Company, of Denver, incorporated in 1892, with a capital of $600,000. The company owns the Anchor, Anchor No. 2, Midland, Lillian Leland, Chance, City View, and Cottontail claims,

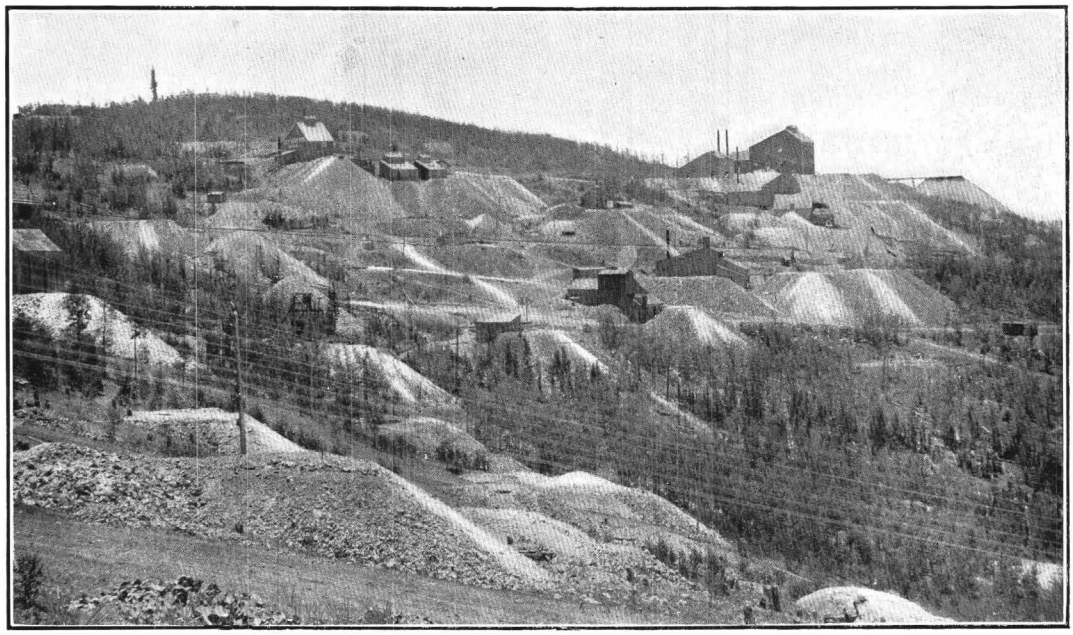
and also the Conundrum claim, which is elsewhere described. The mine has been worked principally by lessees and made its first shipment in 1895. It continued productive until the latter part of 1899; since then but little ore has been shipped. The Jefferson mine lies just north of the Anchoria-Leland, with workings confined to the Mattie L. claims. It is owned by the Jefferson Mining Company, of Denver, incorporated in 1892, with a capital of $1,100,000. The Geneva mine is northeast of the Jefferson and belongs to the Stratton estate, having been purchased in 1900, with the May Queen claim, for $300,000. Neither the Jefferson nor the Geneva mine is at present actively worked. The Half Moon mine is situated south of the Geneva and east of the Anchoria-Leland. It is owned by the Matoa Gold Mining Company, of Colorado Springs, incorporated in 1892, with a capital of $1,000,000. The company owns the Half Moon, Harlan H., and Gold Pass No. 1 claims, with other property in Arequa Gulch. Ore was discovered in the Half Moon in 1893 at a depth of 250 feet, and shipments were made at intervals for about five years.

PRODUCTION AND DIVIDENDS.

The Anchoria-Leland is credited with a gross production of over $1,000,000, and has paid $198,000 in dividends. The first dividend, $6,000, was declared in 1896 and the last, $18,000, in 1899. The gross production of the Jefferson is not accurately known, but is probably between $300,000 and $400,000. The Geneva shipped considerable ore in 1895, 1896, and 1897, but the gross production has not been ascertained. The Half Moon mine has produced between $600,000 and $700,000, chiefly through lessees. One dividend, $25,000, was declared in December, 1898.

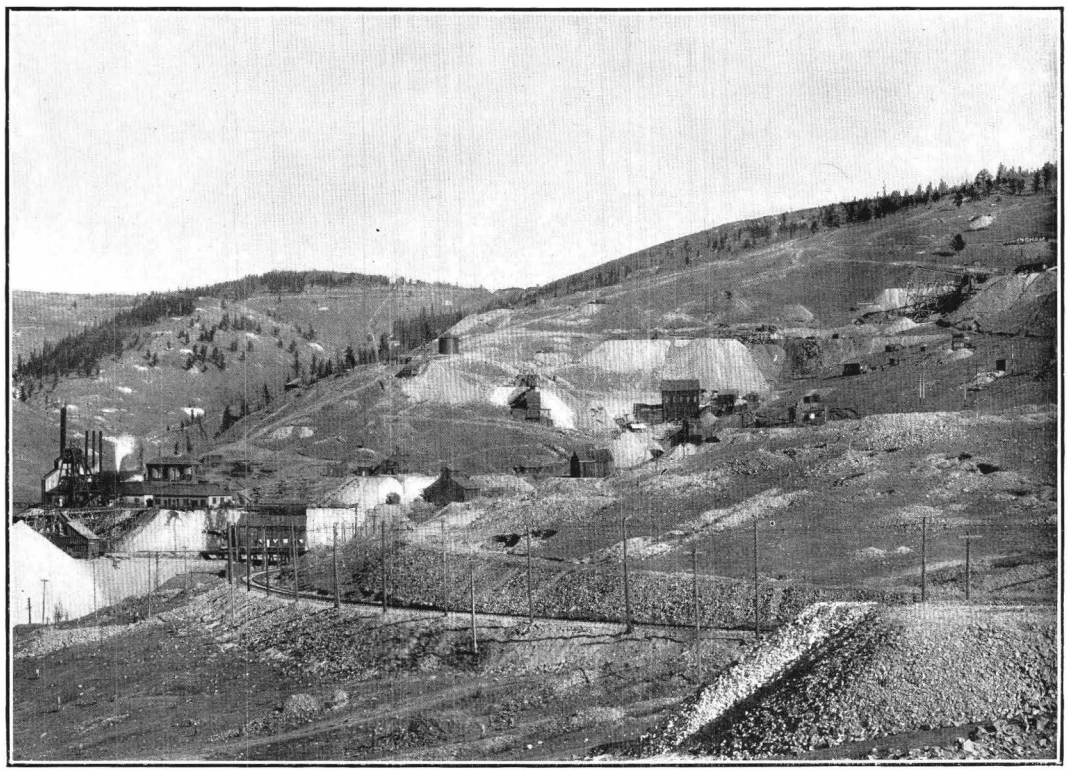
UNDERGROUND DEVELOPMENT.

The principal workings of this group of mines are on the Anchoria-Leland property. The Anchoria-Leland shaft is 1,100 feet deep, the collar being 10,139.46 feet above sea level. The first main level is 277 feet below the collar. Level 2 is 65 feet below level 1; level 4 is 153 feet below level 2; the Cripple Creek and Gold Hill tunnel is 270 feet below level 4; the Good Will tunnel, or level 6, is 32 feet lower; and level 8 is 142 feet below the Good Will tunnel. Levels 9, 10, and 11 follow at intervals of 96 feet. The levels of chief importance from their extent, productiveness, or geological interest are 1, 2, 4, and the two adit levels. The principal drifts are on the Chance lode and run nearly north-northeast and south and southwest. (See fig. 25.) The Jefferson and Geneva drifts are on the same line of fissuring. About 300 feet southeast of the Chance drifts is a series of drifts with nearly the same trend, on the Matoa and Potter lodes. Northwest of the Anchoria-Leland shaft there has been some irregular and disconnected drifting along the City View lode, which is associated with a basaltic dike. These drifts are mostly from 200 to 250 feet northwest of the Chance drifts and approximately parallel to the latter. There is a fourth series of drifts running north-northwest and south-southeast on the Mahoney lode. The Jefferson incline, 450 feet northeast of the Anchoria-Leland shaft, is about 650 feet deep and has eight short levels.



A. NORTH SLOPE OF GOLD HILL.

Anchoria-Leland mine on right; Half Moon mine on left.



B. WEST SLOPE OF RAVEN HILL.

Showing Doctor-Jackpot and Morning Glory group of mines.

The property is dotted with small shafts, most of which were sunk by lessees in the early period of the mine's history, when each lessee sunk a shaft on his particular section of a lode.

GEOLOGICAL FEATURES.

The general country rock of the Anchoria-Leland mine is the usual breccia of Gold Hill. This is cut by a few unimportant dikes of phonolite and by the City View basic dike. This dike is exposed in the Good Will and Cripple Creek and

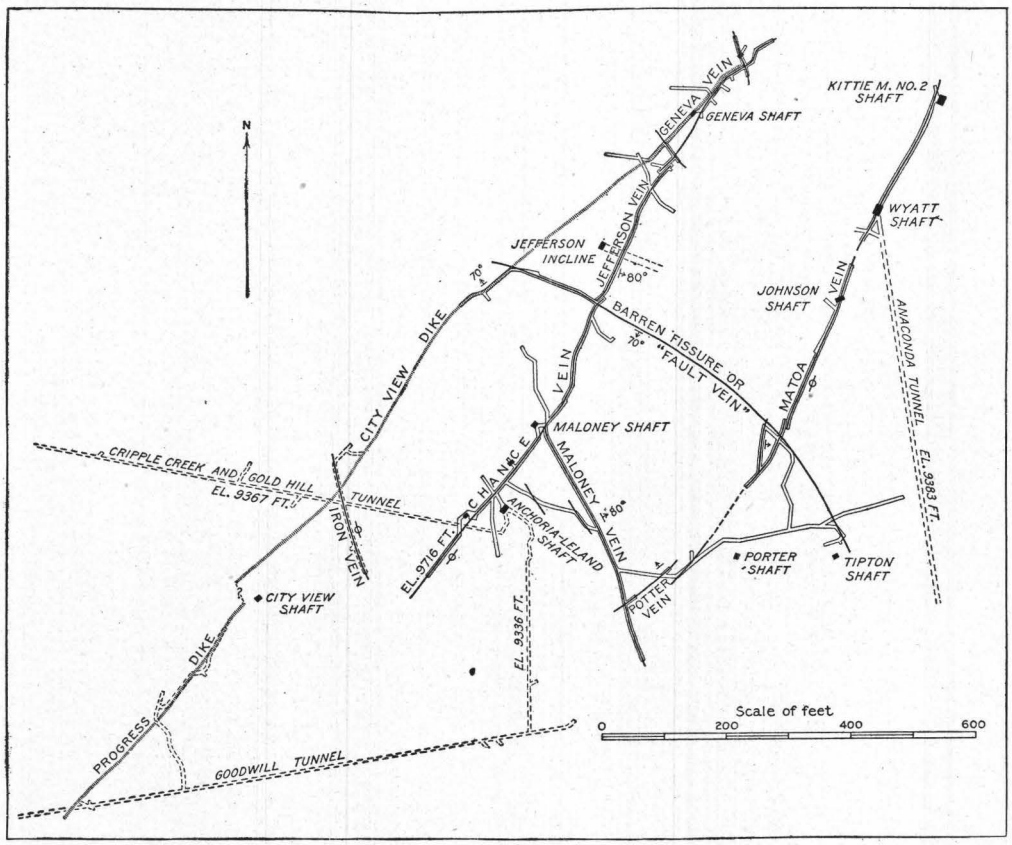


FIG. 25.—Plan of level 1 of Anchoria-Leland mine and of adjacent levels of the Jefferson, Geneva, and Half Moon mines, showing principal lodes.

Gold Hill tunnels, in the old Progress workings on the Gold King claim, in the City View workings, and on several of the main Anchoria-Leland levels. On the northeast it approaches the Chance lode and the two apparently come together near the Geneva shaft. The Geneva workings, however, were not visited. Like other basic dikes in the district, the City View dike frequently branches and pinches. In the Good Will tunnel at least four narrow "basalt" dikes are exposed in a zone about 300 feet wide. All may be branches of the City View dike. The dike is usually less than 2 feet in width.

LODE SYSTEMS.

The Chance lode passes close to the Anchoria-Leland shaft, with a general strike of N. 30° E. The lode is curved, however, the strike in different portions ranging from N. 15° E. to northeast. The dip also is variable, ranging from vertical southwest of the shaft to 80° in the Jefferson mine. The Chance lode has been explored for a length of over 1,200 feet. The Matoa lode is from 300 to 400 feet southeast of the Chance, and strikes N. 25° E. It is a complex and irregular lode of varying dip. In the Anchoria-Leland ground it meets the Potter lode, which strikes N. 55°–65° E. and dips north. In the region of intersection the two lodes lose their identity in a plexus of irregular fissures. The Matoa lode has been explored to a length of about 500 feet and the Potter lode for nearly 200 feet. About 200 feet northwest of the Chance lode is the City View lode, which in part coincides with the City View "basalt" dike and has a general northeast strike. The lode dips north, but exhibits considerable irregularity. The workings on the City View are unsystematic, disconnected, and in part inaccessible, so that it was impracticable to verify an impression gained at the time of visit, namely, that the name City View had been applied to different fissure zones in different parts of the workings. Between 300 and 400 feet northwest of the City View dike is the Wardel lode, which strikes N. 60° E. and dips about 85° NW. The Maloney lode intersects the Chance lode from 100 to 200 feet northeast of the Anchoria-Leland shaft. It strikes N. 30° W. and dips 80° NE. from the surface to level 3. Below level 3 it either changes its dip or is replaced by a rather indistinct sheeted zone with a northwesterly dip of 70°. The Maloney lode is not known northwest of the Chance lode. A long drift has been run in this direction on level 2, but the fissure followed contains no ore and dips southwest instead of northeast. The Maloney and Potter lodes cross without any appreciable faulting, the Maloney continuing through the Lexington mine into the E. Porter Gold King mine.

Some of the best-defined and most persistent fissures in these mines contain no ore. A good example of this is the so-called Fault vein, which has a curved but generally northwest strike and dips from 55° to 70° SW. This crosses the City View and Chance lodes near the Jefferson line and the Matoa lode near the Half Moon line, continuing south past the Tipton shaft. It slightly displaces the City View dike and possibly also the Chance and Matoa lodes. The displacement, however, probably nowhere exceeds 5 or 6 feet. The Fault vein is a sheeted zone, one or more of the fissures usually containing a few inches of soft decomposed or crushed breccia. This gouge material contains a little pyrite, but no ore.

Another barren fissure zone is the Iron vein. This strikes a little west of north and dips east. It is exposed on several levels northwest of the Anchoria-Leland shaft and crosses the City View lode without perceptible faulting.

The general relations of these fissures to one another are shown in fig. 25.

CHARACTER OF ORE.

All of the ore from these mines has come from the zone of complete or partial oxidation. No ore was visible at the time of visit. It appears to have consisted originally of calaverite, with quartz and fluorite, and to have been largely altered to free gold.

PAY SHOOTS AND LODE STRUCTURE.

All of the ore in the Anchoria-Leland mine except that in the City View dike occurred in typical narrow sheeted zones in breccia. The maximum width of the ore appears to have been about 5 feet. In places the sheeted structure is remarkably well developed, the rock having been fissured for a total width of a foot or more into thin plates a fraction of an inch in thickness. On each side such close sheeting passes through more widely spaced fissuring into the ordinary country rock. Such highly developed sheeting may be seen in the Chance and Wardel lodes on level 4, and less conspicuously in the Matoa lode. The fissures are often filled or partly filled with quartz or quartz and fluorite. In spite of the great regularity exhibited

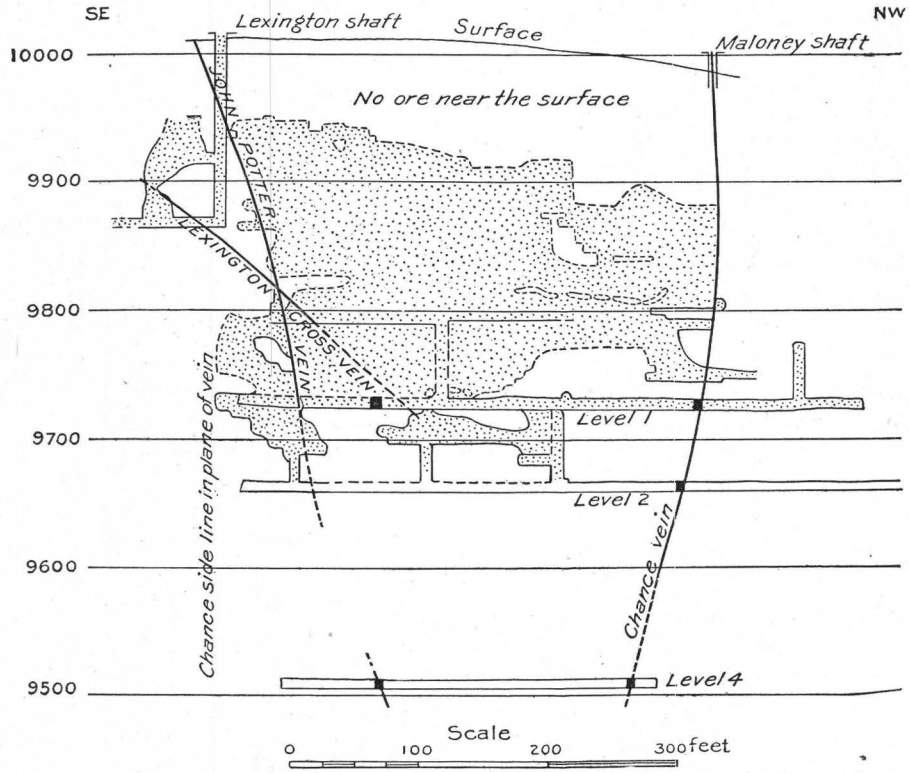


FIG. 26.—Longitudinal section of the Chance vein, Anchoria-Leland mine, showing vertical range of ore.

for short distances by these sheeted zones, they are not as a whole notably persistent. They sometimes dwindle to a single indistinct fissure or come to an end upon meeting another fissure zone of somewhat different strike and dip. This is well illustrated by that part of the Matoa lode within the Anchoria-Leland ground. The ore in this lode, as shown in the abandoned stopes, changed repeatedly from one set of fissures to another set of divergent dip or strike.

The most striking fact in connection with the Anchoria-Leland mine is the comparatively slight depth to which the ores extended. The Chance lode has, so far as known, no ore below level 2, and very little ore below level 1. Practically all the ore, in other words, was within 300 feet of the surface. Furthermore, the five or six

lessees' shafts on the Chance lode all passed through a barren zone, extending from 75 to 100 feet below the surface, before they reached the top of the ore (fig. 26). The Maloney lode exhibits a similar barren zone near the surface, and contains no

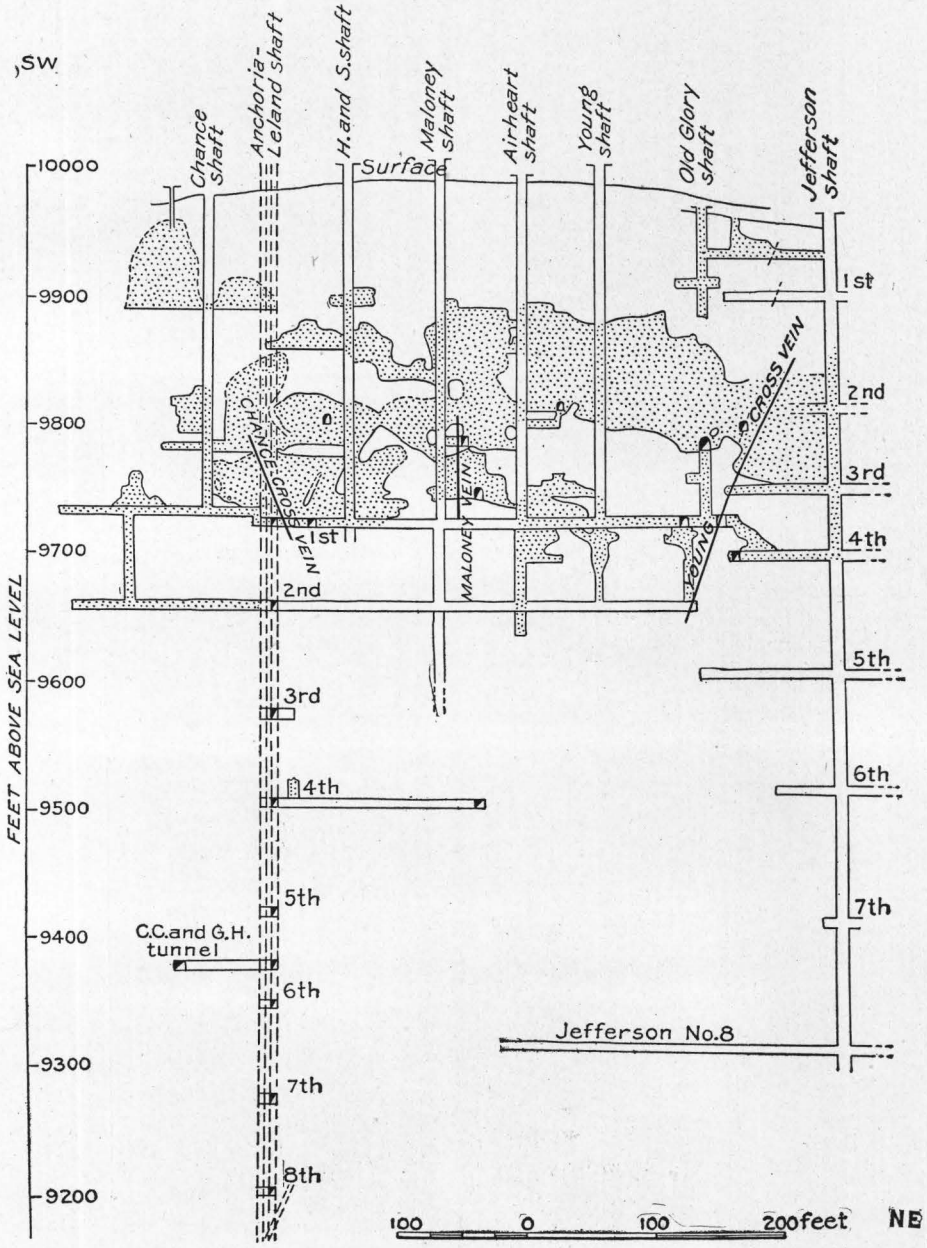


FIG. 27.—Longitudinal section of Maloney vein, Anchoria-Leland mine, showing vertical range of ore.

ore below level 2 in the Anchoria-Leland mine (fig. 27). In the Lexington mine, however, just south of the Anchoria-Leland, the ore is said to have extended to greater depth.

The pay shoot of the Chance lode extended from a point 100 feet southeast of the Anchoria-Leland shaft to a little beyond the Jefferson shaft—a length of about 600 feet. Details of the occurrence of the ore in the Geneva mine were not obtained, but it appears from the mine maps to have occurred near the intersection of the combined Chance lode and City View basalt dike with some cross fissures of north to northwest strikes.

In the Matoa lode the largest and most continuous ore body occurred in the Half Moon ground, northeast of the fault vein. Southwest of the fault vein the Matoa lode becomes a complex of intersecting fissures and the ore occurred in more or less isolated bunches.

In the Maloney lode the pay shoot extended from the Chance lode into the Lexington ground, pitching south at a low angle. Near the Chance lode the bottom of the Maloney ore was about 25 feet above level 1 of the Anchoria-Leland. Near the Lexington line, 300 feet farther south, the ore stopped about the same distance above level 2. The Lexington mine was not visited, but the main Maloney ore shoot apparently did not extend for more than 100 feet beyond the intersection with the Potter lode.

The City View lode is a sheeted zone in breccia which in some places follows the City View dike. It contained some ore near the surface, both in the breccia and in the dike. The Wardel lode also contained some small bodies of ore between the surface and level 4 of the Anchoria-Leland. It is a narrow sheeted zone in breccia. The rock is sometimes divided by this sheeting into very thin plates for a width of 5 or 6 inches, with more widely spaced fissures on each side. Locally the medial part of the lode may pass from thinly sheeted to brecciated material.

UNDERGROUND WATER.

The first water encountered in the Anchoria-Leland shaft was 653 feet below the collar, or 9,486 feet above sea. As the Moon-Anchor mine, however, had been pumping for some time ere the Anchoria-Leland reached water, the above level was probably below the natural water level. The maximum flow (550 gallons per minute) was reached 97 feet below the level of first water. The bottom of the shaft, 9,029 feet above sea, is now dry.

MOON-ANCHOR, MIDGET, AND CONUNDRUM MINES.

INTRODUCTION.

These three mines, while under separate ownership and management, are so closely connected as best to be described together. They are situated on the west slope of Gold Hill in the vicinity of the contact between the breccia and the gneiss. The Moon-Anchor mine is owned by the Moon-Anchor Consolidated Gold Mines (Limited), of London, capitalized at £2,000,000, and comprises the Little Anna Rooney, New Moon, and parts of the Anchor and Anchor No. 2 claims. The property was originally owned by the Moon-Anchor Gold Mining Company and was sold to the English corporation in 1899. Ore was first shipped from the Anchor claim in the latter part of 1895, and from the New Moon in 1896. In the latter year the two mines, hitherto worked by lessees, were combined as the Moon-Anchor, the new

company declaring its first dividend in the summer of 1897, and continuing to ship ore up to the transfer of the mine to its present owners.

The Midget mine, comprising the Protection, Maryland, Sunnyside, Midget, Cumberland, and parts of several other claims, lies southwest of the Moon-Anchor and is owned by the Midget Gold Mining and Milling Company, of Colorado Springs, capitalized at $1,000,000. The company also holds a lease on a part of the Bonanza King claim.

The Conundrum mine, owned by the Anchoria-Leland Mining and Milling Company, lies immediately northwest of the Moon-Anchor and Midget mines. Prior to 1900 a little prospecting only had been done on the Conundrum claim. During the last three years, however, it has been developed into a productive mine.

PRODUCTION.

Prior to its sale to the present owners the Moon-Anchor mine produced considerable good ore and paid dividends amounting to $261,000. Of late years it has not been so productive and has been worked chiefly by lessees.

The gross production of the Midget mine, as furnished by the company, is as follows:

Production of Midget mine, 1900–1904.

1900	$318,973.65
1901	121,710.01
1902	77,269.85
1903	143,989.84
1904	96,932.34
	758,875.69

The mine also produced a little ore in 1895, before the incorporation of the present company.

UNDERGROUND DEVELOPMENT.

The Moon-Anchor shaft was a little over 870 feet deep at the time of visit. Sinking had been begun by the company in December, 1903, the shaft at that time being about 835 feet deep. On January 9, 1904, water was encountered 870 feet below the collar, and work was stopped. This water, however, subsequently disappeared, and sinking was resumed near the end of the same month. The upper level, known as level 4, is 422 feet below the collar, which is 9,864.73 feet above sea level. Below this are levels 5, 6, 7, 8, and 9 at intervals of 104, 103, 65, 47, and 59 feet, respectively. The principal drifts run nearly northeast-southwest.

The Midget shaft, 550 feet southwest of the Moon-Anchor, has its collar 9,796.2 feet above sea level, and at the time of visit was about 800 feet deep. There are ten main levels. Level 5 is about 300 feet below the collar. Below 5 the levels are at approximately 100-foot intervals, except levels 9 and 10, which are 60 feet apart. The main drifts in the Midget fall into three classes—a series of drifts running in general north-northeast and south-southwest on the Midget lode, a series running east-northeast and west-northwest on the Bonanza King lode, and a series of nearly north-south drifts on the Conundrum lode. These drifts in general converge in the vicinity of the gneiss and breccia contact southwest of the Midget shaft.

The Conundrum mine is worked through an adit, at the end of which is an underground station and an inclined winze on the lode. Hoisting is done by electric power. Although the top of the station, excavated in gneiss, is only about 50 feet below the surface of the hill, no timbering is necessary and the station is practically dry. The adit enters Gold Hill 450 feet west of the Midget shaft and about 130 feet below the collar of the latter and runs for 300 feet N. 20° E. until it reaches the lode. The winze goes down on the dip of the lode, about 70° E., to a vertical depth of 620 feet

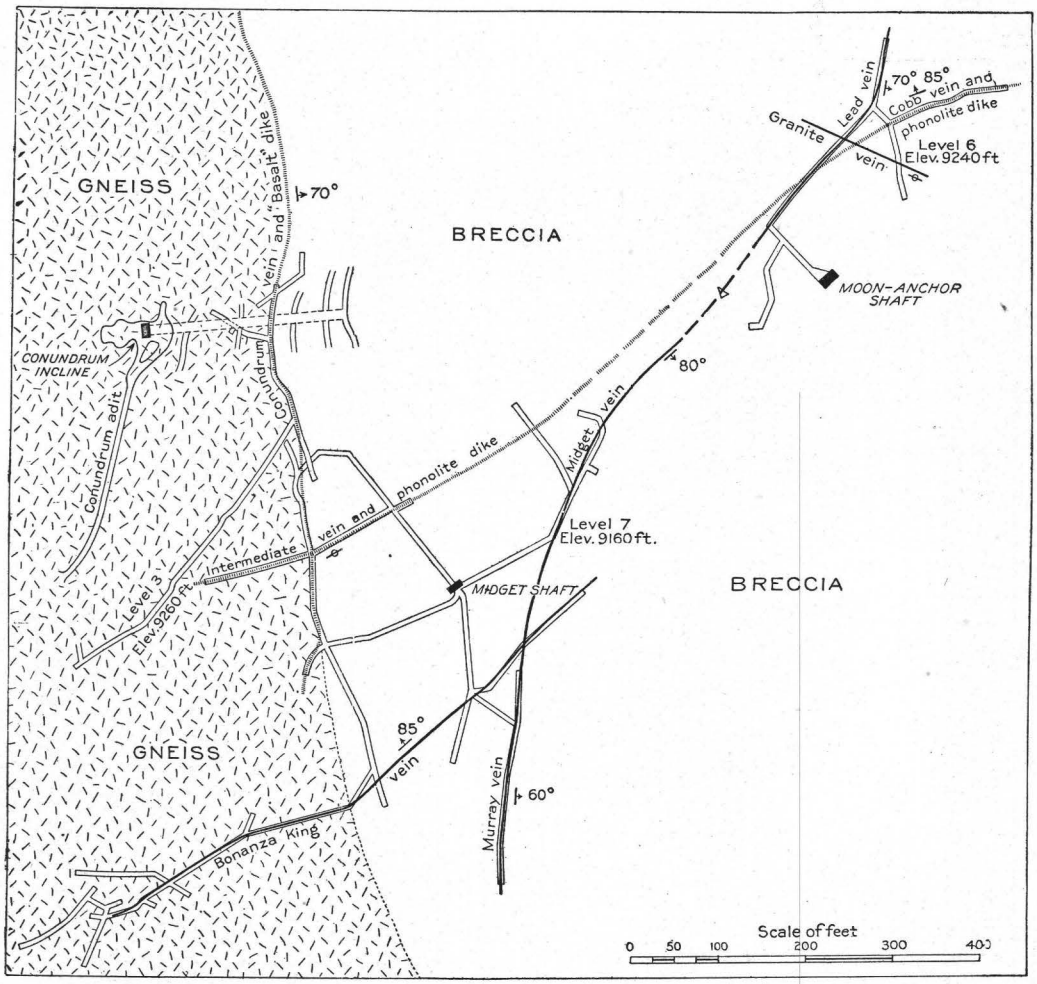


FIG. 28.—Geological plan of portion of level 3 of the Conundrum, level 7 of the Midget, and level 6 of the Moon-Anchor mine, showing relations of principal lodes.

below the adit. There are six main levels, the successive vertical intervals from the adit down being 110, 155, 135, 60, 95, and 65 feet. The workings of the Conundrum are simple and consist chiefly of drifts along the nearly north-south lode. There is, however, an important stope in the northern part of the mine on a zone of cross-fissuring.

A general understanding of the relation of the workings of these three mines may be had from figs. 28 and 29.

GEOLOGICAL FEATURES.

The Moon-Anchor workings are entirely within the breccia, the Midget workings are partly in breccia and partly in the fine-grained gray gneiss of this vicinity, and the Conundrum workings, which for the most part follow the Conundrum basic dike, are chiefly in gneiss.

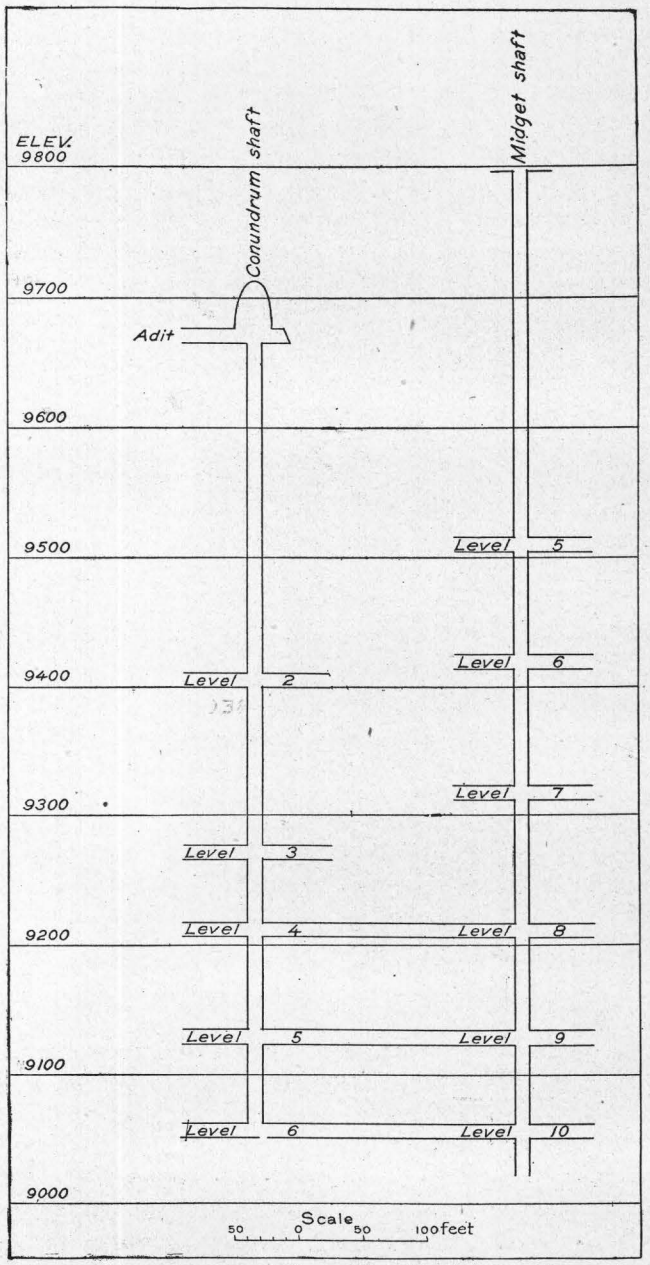


FIG. 29.—Diagram showing relative position of levels in Conundrum and Midget mines.

The contact between the gneiss and breccia is irregular, is often very poorly defined, and has not been exposed in a sufficient number of places to fully establish its form and character. Near the Conundrum incline the contact at the surface practically coincides with the Conundrum dike. It dips, however, at a somewhat lower angle to the east than does the dike, and on the lower levels of the Conundrum mine lies within the little-explored hanging wall of the lode. Thus on level 8 of the Midget, northeast of the shaft, the contact is about 35 feet east of the Conundrum dike. On level 9 the Midget shaft is in gneiss, showing the contact to be here at least 90 feet east of the dike, and indicating a decided local flattening of the dip. North of the Conundrum incline the breccia seems to overlie the gneiss in such a manner as to indicate an unusually low inclination of the contact. This is shown by a northeast crosscut from level 6, which extends to a point 1,050 feet northeast of the portal of the Conundrum adit or 400 feet north-northwest of the Moon-Anchor shaft. This crosscut is all in gneiss, although a vertical line through its face would emerge at the surface in the breccia fully 700 feet from the nearest exposure of gneiss.

(See Pl. II, in pocket.) The southeasterly dip of the contact, near the bend in the latter between the Conundrum and Abe Lincoln mines, is thus probably rather under 40°. In both the Midget and Conundrum mines the gneiss, sometimes for a hundred feet or more from the volcanic breccia, is shattered to fragments, which often average only 2 or 3 inches in diameter. This shattering is very noticeable along both sides of the Conundrum lode, and it is usually impossible to determine closely where the shattered gneiss ends and the volcanic breccia begins. The fragments of gneiss are partly separated by interstices as if the finer material had been in part removed. The fragments are in some cases only slightly coherent; in others they are coated and cemented by crystalline envelopes of purple fluorite. The shattering evidently antedated the intrusion of the basaltic dike, as the latter is not brecciated.

The breccia in the Midget and Moon-Anchor mines is more varied in texture and composition than is common in so small an area. It usually contains abundant fragments of phonolite, schist, granite, and gneiss held together in a matrix containing many minute particles of pink feldspar, evidently derived from the granite and gneiss of the vicinity. This variety of the breccia may be well seen in the dump of the Ben Hur shaft, south of the Midget. Another variety occurs along the general line of the Midget lode, particularly between level 6 and the surface, where it may be seen in various pits between the Moon-Anchor and Midget shafts. This is a fine-grained altered tuff, which underground somewhat resembles decomposed basalt, and is characterized by a reddish or purplish tint. The clastic structure of this material is sometimes plain, sometimes obscure, and in the latter case the rock is often called basalt by the miners.

The breccia in the Midget and Moon-Anchor mines has undergone local shattering similar to that already described in the gneiss near the Conundrum lode. In the Midget this shattered rock occurs in the vicinity of the shaft on levels 7 and 8, passing into brecciated gneiss on levels 9 and 10. The rock is a loosely coherent, porous mass of angular fragments, showing considerable pyritic mineralization. No ore occurs in this material, and lodes as they enter it from the solid breccia are lost. Similar shattered breccia occurs on levels 7, 8, and 9 of the Moon-Anchor mine just northwest of the shaft, the material looking as if it had been passed through a rock crusher and dumped into an old stope. The fragments are in part loose, in part cemented at points of contact by pyrite and quartz. This material passes peripherally into breccia traversed by countless fractures belonging to sheeted zones running in various directions through the rock. This fissured rock in turn passes gradually into breccia showing only the usual amount of jointing.

Both gneiss and breccia are cut by several irregular dikes of phonolite, which are also locally shattered, though usually less so than the breccia. These dikes are often indistinct and difficult to trace in the breccia, particularly in the shattered portions.

The Conundrum basalt dike strikes on the whole a little west of north and dips about 70° E. It is rather curved and irregular and ranges in width from a fraction of an inch up to 3 feet. It is usually mineralized, constituting ore, or is soft and decomposed.

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LODE SYSTEMS.

The Conundrum lode is coincident with the Conundrum "basalt" dike and has a general strike of N. 5° W., with an easterly dip of 70°. The Bonanza King is a strong, regular lode which lies south of the Midget shaft and strikes N. 60° E. It dips steeply to the northwest. The Midget lode, near the Midget shaft, strikes N. 23° E. As the Moon-Anchor mine is approached, however, the lode curves eastward, and near the compromise line between the two properties strikes N. 50° E. South of the shaft the Midget lode curves gently southward and crosses the Bonanza King lode with a nearly north-south strike. That part of the lode south of the Bonanza King is known as the Murray lode. The Midget lode dips southeasterly, the angle ranging from 60° south of the Bonanza King to nearly 80° near the Moon-Anchor ground. The Midget and Bonanza King lodes cross without any apparent faulting or any indication of difference in age. The Conundrum lode usually becomes irregular and rather indistinct as it approaches the Bonanza King lode. The two apparently cross without noticeable faulting, but the Conundrum lode has proved of very little economic importance near the Bonanza King. About 100 feet northwest of the Midget shaft is a lode known as the Intermediate vein, which accompanies a phonolite dike. This strikes in general N. 60° E., it and the Midget lode coming together near the Moon-Anchor ground. What becomes of the Midget lode in the Moon-Anchor mine is not clear. The principal lode of that mine, the Cobb vein, is associated with a phonolite dike and is apparently a direct continuation of the Intermediate lode of the Midget mine. The Intermediate or Cobb lode dips steeply northwest. The Cobb lode in the Moon-Anchor is accompanied by a number of other fissures in the breccia, which show a general tendency to diverge to the northeast. It is crossed at an acute angle by the Lead vein, which, so far as known, has not been recognized in the Midget workings, though it may be the Midget vein. The general strike of the Lead vein is N. 30° E., and the dip about 70° SE. The intersection of these lodes is well shown on levels 7 and 8 of the Moon-Anchor mine. The Lead vein, as it comes into the Cobb from the south, turns and follows the latter for 75 to 100 feet and then resumes its former course and continues into the hanging wall of the Cobb lode. The phonolite dike, which elsewhere invariably accompanies the Cobb, is absent where the two lodes coincide, being apparently faulted by the Lead fissure.

The so-called Granite vein in the Moon-Anchor mine strikes nearly northwest and southeast. It is a nearly vertical, narrow zone in the breccia characterized by unusual abundance of granitic fragments. It was apparently a fissure in at least partly consolidated breccia, which became filled largely with granitic detritus. This filling has been mineralized with pyrite, and most of the granitic fragments are altered to spongy aggregates of secondary feldspar.

CHARACTER OF ORE.

Not much ore could be seen in the Moon-Anchor mine at the time of visit. It appears to have been of the usual type—calaverite and fluorite in narrow fissures in breccia and phonolite—and was partly or wholly oxidized above level 6. Some of the best ore is said to have occurred in the phonolite dike of the Cobb lode.

In the Midget mine the ore in the Midget lode nearly all occurs above level 6 and is all partly oxidized. Calaverite, free gold, and fluorite are said to be characteristic constituents. As seen just above level 6, this ore consists of breccia containing small disseminated crystals of pyrite and traversed by minute irregular veinlets of fluorite. Some of the veinlets are oxidized and show a little rusty gold. No calaverite was seen, but it is said to be sometimes visible. The ore of that part of the Bonanza King lode which is in breccia is similar to the ore of the Midget lode. In the gneiss, however, the ore is distinguished from the country rock by the presence of tiny veinlets of pyrite. These veinlets sometimes contain a little quartz, feldspar, and fluorite, but so far as observed no visible calaverite. That calaverite or sylvanite is really present with the pyrite in the little veinlets is clearly shown, however, by the action of oxidation, which within 30 or 40 feet of the surface has changed the telluride to visible specks of dull native gold, while the pyrite is unaltered.

The ore of the Conundrum lode consists of mineralized "basalt." The rock is traversed by numerous narrow fissures, sometimes reticulating, but usually showing general parallelism with the dike walls. These little fissures are filled or partly filled, sometimes with purple fluorite, sometimes with quartz, and sometimes with both minerals together, giving the rock a banded appearance. These gangue minerals are not always confined to the fissures, but sometimes permeate the altered basalt between the distinct fractures.

As seen under the microscope, the "basalt" between the veinlets is thickly sprinkled with minute pyritohedral crystals of pyrite and with granules of secondary quartz. These lie in an exceedingly fine-grained and obscurely crystalline aggregate of uncertain composition. It appears to be partly quartz, partly feldspar, and partly some isotropic material, but the texture of the material is too fine for the microscopical determination of its constituents. It reveals no trace of the original igneous texture of the rock.

The gold occurs as calaverite associated with the quartz and fluorite and with pyrite. The ore, however, is often oxidized even below level 9 of the Midget or level 5 of the Conundrum, and the calaverite changed to native gold. Little specks of galena and sphalerite are common in the Conundrum dike, usually accompanying the gold ore. These minerals appear to have been deposited at least in part by replacement of the basalt and sometimes form bunches or lenses several feet long and 5 or 6 inches in thickness. This galena and sphalerite ore frequently contains 2 or 3 ounces of gold and about the same quantity of silver per ton. Galena and sphalerite are not confined to the Conundrum lode, but occur also in the Midget mine in the Bonanza King lode as lenticular masses a foot or so in thickness, replacing fissured gneiss. On level 8 this galena and sphalerite are associated with the usual calaverite gold ore and barely pays to mine. In the Moon-Anchor mine galena, sphalerite, and pyrite, associated with quartz, fluorite, and rhodochrosite, constitute the Lead vein, in breccia.

The ore in gneiss in the northern part of level 6 of the Conundrum consists of calaverite, often beautifully crystallized, occurring in the vugs of quartz-fluorite veinlets.

PAY SHOOTS AND LODE STRUCTURE.

The Cobb, the principal lode in the Moon-Anchor mine, is a zone of fissuring along a phonolite dike, the latter being usually less than 2 feet wide. On level 4 of the Moon-Anchor, which is about 35 feet above level 6 of the Midget, the Cobb lode has been stoped for about 200 feet, these stopes being continuous with those on the Midget lode. The Midget and Cobb ore bodies are thus in reality parts of a single pay shoot, although, as already pointed out, the Cobb phonolite dike, accompanied by some fissuring and mineralization, is probably what is known as the Intermediate vein in the Midget mine. (See fig. 28, p. 299.) The Midget-Cobb pay shoot pitches northeast at an angle of about 45°. At a depth of about 400 feet it crosses the provisional or "compromise" line from the Midget into the Moon-Anchor ground and at the same time changes from the Midget fissure zone with southeasterly dip to the Cobb fissure zone with northwesterly dip. Just what takes place at the point of change is difficult to determine in the present state of the workings. It is certain that a number of other fissures, including the Lead vein, converge toward the debatable ground where the Midget, Cobb, and International lodes come together. On the lower levels of the Moon-Anchor the Cobb pay shoot is shorter and is usually confined to the intersection of the Lead and Cobb lodes. The ore in such case occurs in the sheeted breccia on one or both sides of the sphalerite and galena streak of the Lead vein. The latter, so far as known, contains no workable ore. The only ore thus far stoped from the Intermediate lode in the Midget mine occurs just above level 6, northwest of the shaft. In the Murray lode, which is the continuation of the Midget lode south of the Bonanza King lode, some small pay shoots have been worked just above level 6 of the Midget.

In the Bonanza King lode the ore occurs in two rather irregular pay shoots, one mainly in the breccia and one mainly in the gneiss. The ore in the breccia lies chiefly to the east of the Midget or Murray lode and has been stoped from the surface to level 6. Its maximum length is about 350 feet, but it includes some portions of the lode too low in grade to work and might be considered as made up of two or more separate pay shoots.

The western pay shoot, in gneiss, is more compact and irregular. It has been stoped from a point above level 5 to level 7, and ore is known also on level 8. This pay shoot pitches about 60° SW. and attains its greatest length, 250 feet, near level 6. The gneiss along the course of the lode is traversed by numerous small irregular fissures which contain the ore. The stopes are occasionally 15 or 20 feet wide. In the western part of the workings, near the Protection and Mariposa shafts, the Bonanza King lode is crossed by some small fissures striking north-northeast. The gneiss in the vicinity of these interstices is traversed by numerous small irregular fractures containing pyrite and calaverite, with quartz and fluorite. This ore is being stoped between the Midget level 5 and the surface. It forms irregular bodies at the intersections of the more prominent fissures and is partly oxidized.

The main pay shoot of the Conundrum lode lies partly in the Midget mine and partly in the Conundrum. The pay shoot begins near level 1 of the Conundrum

and becomes longer on successively lower levels, reaching a maximum length of about 600 feet on level 9 of the Midget and level 5 of the Conundrum. Below this only a few isolated bodies of pay ore have as yet been found. The pitch of the southern edge of the ore body is practically 90° and of the northern edge about 45° to the north.

The ore of the Conundrum lode is confined to the "basalt" dike, which is usually from 18 inches to 3 feet in width. The dike is traversed by numerous little fissures, usually parallel to the walls, but sometimes of irregular trends. These range in width from an eighth of an inch to those visible only with a strong lens or microscope. The calaverite occurs chiefly in the quartz and fluorite veinlets filling these fissures, but probably to some extent throughout the mass of the rock, which is altered to a gray porous material containing pyrite in minute crystals implanted on the walls of the little cavities and disseminated through the rock.

In the northern part of the Conundrum mine, in the Mary Ann claim, is an important pay shoot in gneiss which has been stoped from level 6 nearly to level 5, and has been explored by a winze below level 6. The ore occurs in a zone of east-west fissuring, just east of the basalt dike. On an intermediate level, 50 feet above level 6, this pay shoot was about 70 feet in length and on level 6 about 25 feet in length. On both these levels the ore was found to be limited on the west by the basalt dike and on the east by a phonolite dike striking northeast and dipping northwest about 75°. Below level 6 the ore, as followed in the winze, is said to go through the phonolite dike and continue into the gneiss on its under side. Although the ore body has a general east-west trend it is not a distinct lode, but consists of a number of small intersecting fissures of various dips and strikes and has no definite walls. The ore occurs in the fissures as calaverite in a quartz and fluorite gangue. It is unoxidized.

UNDERGROUND WATER.

The Moon-Anchor shaft, the first of the three to reach any considerable depth, originally encountered water, in April, 1899, 376 feet below the collar, or 9,489 feet above sea level. The flow was about 400 gallons per minute. The maximum flow, however, 1,100 gallons per minute, was found near level 6, or 9,241 feet above sea level. This water slowly receded and in January, 1903, the sump, 9,030 feet above sea level, was dry. Early in 1904 water was again encountered 870 feet below the collar of the shaft, or 8,994.7 feet above sea level, but this soon disappeared, allowing sinking to be resumed without pumping. The water record of the Midget shaft presents no additional features of interest, and the Conundrum, keeping above the water level, has always been dry.

E. PORTER GOLD KING MINE.

The E. Porter Gold King mine is situated a few hundred feet south of the summit of Gold Hill. Its production is estimated at $50,000. The underground development consists of a shaft about 500 feet deep and four levels representing 1,500 feet of drifting. An incline called the Jaycox shaft extends from the surface to level 1. The entire workings are in breccia. A "basalt" dike with a practically north-south course is shown by surface pits and is cut on level 4.

Several veins have been opened in the mine. The principal one has a south-southeast course and an easterly dip of 75° to 80°. It outcrops west of the main shaft and is followed by the Jaycox shaft. This vein has been stoped for 120 feet, from the surface down to level 2, and has been stoped also in the Lexington mine. A vein with similar strike, but nearly vertical, runs through the main shaft. It has been stoped a little about 50 feet north of the shaft. A north-south vein recently opened on the 150-foot level just east of the shaft is furnishing ore. A vein with a north-northeast direction has been cut just north of the shaft on level 2, and has furnished some ore.

MINT, POINTER, ACCIDENT, AND RED SPRUCE MINES.

INTRODUCTION.

The Mint, Pointer, Accident, and Red Spruce mines are situated on the southwest spur of Gold Hill, near the "Low Line" track. They have been intermittently worked, chiefly by lessees, and the greater part of the ore has come from the Pointer mine, which began shipping in 1896 and is still producing. The Accident shipped a little ore in 1897 and again in 1902, but was idle at the time of visit, as was the Red Spruce. The Mint shipped ore in 1901, and was being operated by lessees early in 1904. All are small mines.

UNDERGROUND DEVELOPMENT.

The Pointer shaft is 530 feet deep, with seven levels. The Mint shaft, 600 feet northeast of the Pointer, is about 750 feet deep and has four levels—levels 3 and 4 of the Mint being continuous with levels 5 and 7 of the Pointer respectively. The Accident shaft is about 330 feet northwest of the Pointer shaft,the two being connected by level 5 of the Pointer. The Red Spruce shaft is close to the Accident. Neither of these shafts were entered and no maps of their underground workings were seen. The principal drifts in the Pointer and Mint mines run approximately northeast-southwest.

GEOLOGICAL FEATURES.

The geological relations are somewhat obscure, owing to poor surface exposures and limited underground development. The Mint shaft is in breccia, just north of the main contact. The Pointer shaft is in a mass of syenite, which is described on page 85. This syenite is exposed also in the Ophelia tunnel, south of the Pointer shaft, where it exhibits porphyritic facies near the contact with the breccia and is apparently irregularly intruded into the latter. The breccia near the syenite is altered to a hard, ringing rock which contains disseminated pyrite and in which the original clastic structure is partly obliterated. The relation of the syenite to the older granite of the vicinity is nowhere clearly shown. The syenite, however, is presumably intrusive into the granite. The syenite and breccia are cut by some irregular dikes of phonolite and "basalt." The contact between the syenite and breccia is very irregular, and on the lower levels the

intrusive rock extends much farther northeast than it does on the surface. It is the prevailing rock in the crosscuts which extend from the Mint shaft under the abandoned Keystone shaft, which is 150 feet east of the Mint.

LODE SYSTEMS.

The principal lode is the Pointer, which strikes N. 33° E. and dips 80° NW. The Pointer and Mint shafts are approximately on the line of the lode. In the Pointer workings the lode is very close to the contact between the syenite and breccia. It is in syenite down to level 7, and that level practically marks the contact. About halfway between the Pointer and Mint shafts the lode passes through a phonolite dike. Northeast of the dike the Pointer lode is in breccia, and is less distinct than in the Pointer mine. There are at least two other northeast-southwest lodes in these workings. One of these is the New vein, which has been exploited in some short drifts northwest of the Mint shaft; the other is the Keystone lode, southeast of the Mint shaft. Neither of these has been continuously followed for over 200 feet on any level. They have generally northwesterly dips, but are branching and rather irregular fissure zones, apparently of no great persistency. The New vein is in breccia and the Keystone vein, as seen in levels accessible from the Mint shaft, is in syenite. The latter lode probably passes into breccia, however, near the surface.

CHARACTER OF ORE.

No ore was to be seen in the Mint mine at the time of visit. The ore of the Pointer lode contains a gold-silver telluride, probably sylvanite, in a quartz and fluorite gangue. Certain portions of the lode contain galena, sphalerite, and tetrahedrite, often associated with rhodochrosite. The quartz, fluorite, and sylvanite appear to have been deposited, as a rule, after the formation of the other vein minerals named. The ore containing tetrahedrite and galena is usually rich in silver, which appears to occur chiefly in the tetrahedrite. Some of this ore is reported to contain over 500 ounces of silver per ton, and Stevens[a] records a statement of the superintendent of the Accident mine, to the effect that about 1,000 pounds of gray copper ore from that mine contained 2,500 ounces of silver and 25 ounces of gold. The ore being shipped by lessees from the Pointer mine at the time of visit was running about $53 per ton, with silver and gold present in about equal proportion by weight.

PAY SHOOTS AND LODE STRUCTURE.

The productive portion of the Pointer lode is a narrow sheeted zone in syenite, with a pay streak rarely exceeding 5 inches in width. The main pay shoot extends from a point a few feet above level 4 of the Pointer mine, or about 300 feet below the surface, to an unknown distance below level 7. Its maximum length of 400 feet is attained on level 5. On level 7 the shoot is a little over 100 feet in length, and it is doubtful whether it continues far below the level. On the northeast the ore ends at the phonolite dike, the lode being of no value in the dike or in the

[a] Basaltic zones as guides to ore deposits in the Cripple Creek district, Colorado: Trans. Am. Inst. Min. Eng., vol. 33, 1903, p. 698.

breccia beyond. There is usually one main fissure in the sheeted zone, and to this the ore is practically confined. It is in places as much as 5 inches in width. Some portions have a very open, vuggy structure, the calaverite or sylvanite occurring in the quartz and fluorite lining the vugs. Other portions are more solidly filled and contain abundant galena and tetrahedrite. Where rhodochrosite forms the principal filling of the fissure the ore is of little value.

Some small shoots of ore have been stoped from the New and Keystone lodes in the Mint mine, and a very little ore has been found in the Pointer lode northeast of the phonolite dike.

UNDERGROUND WATER.

These mines are at present dry, and appear never to have been seriously hampered by water. Information on this point, however, is not available.

ANACONDA MINE.

INTRODUCTION.

The Anaconda mine is situated in the town of Anaconda, with workings extending northward through Gold Hill. The property comprises about 20 claims, covering 150 acres. It was originally owned by the Anaconda Mining and Milling Company, which was afterwards reorganized as the Anaconda Gold Mining Company, capitalized at $5,000,000. In 1900, on a failure of the stockholders to respond to assessment, the company was reorganized as the Anaconda Mining Company, with a capital stock of $2,000,000.

The mine was one of the first producers in the district, and from 1892 to 1897 was actively worked and produced large quantities of ore, mainly from the open cut on Gold Hill and from stopes near the surface. In 1892 this mine was the largest shipper in the district and had a stamp mill of 15 tons daily capacity. For the past few years the property has been worked by lessees.

PRODUCTION.

The Anaconda mine has produced ore to the gross value of about $1,500,000, over $1,000,000 of this having been mined prior to the year 1900. None of the companies ever paid a dividend.

UNDERGROUND DEVELOPMENT.

The mine is at present worked through an adit (fig. 30) having its portal at Anaconda and connecting with very extensive drifts and crosscuts under Gold Hill. The adit level extends northward about 4,200 feet to the north end of the Kittie M. claim and connects with the workings of the Half Moon and Kittie M. shafts on the north side of Gold Hill. Branches of the same level extend eastward to the Colorado Boss ground of the Cripple Creek Consolidated Mining Company. The old workings from which came the ore shipped from 1892 to 1897 are all above this adit and for the most part not accessible. Below the adit level, or level 4, are six other levels. Of these, only level 10, 400 feet below the adit, is extensive. These lower levels are reached by a winze 1,150 feet from the adit portal.

GEOLOGICAL FEATURES.

The prevailing country rock of the Anaconda mine is breccia of the usual type found on Gold Hill. Within this breccia are some irregular bodies of latite-phonolite and a few dikes of phonolite and "basalt." In the northern part of the adit level is exposed the same mass of schist that outcrops as an isolated area in the breccia at Fairview, on the northeast side of Gold Hill. The general distribution of the various rocks, so far as it has been ascertained, is shown in fig. 30, a plan of the adit level. The latite-phonolite is probably intrusive into the breccia, but, as is so frequently the case in this district, the contacts are too indistinct to furnish decisive evidence on this point. A small phonolite dike sometimes accompanies the Anaconda lode, but is not a constant feature. There are two important basic intrusions in the mine. One of these is exposed at three points on the adit level in the vicinity of the Excelsior shaft (fig. 30). It is apparently a rolling, irregular sill with a general dip of about 20°. Near the Excelsior lode the dip is easterly, but farther south, where the "basalt" is cut by the Anaconda lode, the dip is southerly. The same sill is cut on level 8, 200 feet below the adit. It seems to be generally parallel with the Howard "basalt" sill, but to lie from 200 to 300 feet vertically below the latter. If so, it may be cut in the Mary McKinney mine when level 6 is extended north. The other basic intrusion is a north-south dike in breccia, in the Colorado Boss ground. There is also a small basic dike in the breccia north of the syenite-porphyry mass, but it has been exposed for only a short distance.

LODE SYSTEMS.

The principal lodes exposed in the Anaconda mine are the Anaconda, Virginia M. or Lincoln, Howard Flat, Work, Excelsior, Colorado Boss, and Kittie M. or Matoa. They are all shown in fig. 30.

The Anaconda lode strikes from north to N. 5° E. and dips 70° E. On the south, although the lode shows a tendency to split up into a number of irregular fissures, the general zone of fissuring probably continues into the Mary McKinney as the No. 2 lode. Toward the north the Anaconda on the adit level retains its regular course until it meets the Excelsior lode (fig. 30). The Anaconda is commonly supposed to turn at this junction and run northeast, following in part the contact between the latite-phonolite and the breccia. Whether it does so or whether the northeast lode is a different fissure zone could not be satisfactorily determined, owing to the number of subordinate fissures at the junction of the Anaconda and Excelsior lodes. No north-south lode corresponding to the Anaconda is known, however, north of the Excelsior lode. In the northern part of level 10, which could not be visited on account of impure air, the Anaconda lode apparently curves to the east before it reaches the Excelsior lode.

The Excelsior lode for about 450 feet east from the Anaconda lode strikes N. 80° E. It then turns about 20° to the south and soon becomes indistinct. West of the Anaconda lode the Excelsior is practically unknown. It dips about 60° N. The Excelsior and Anaconda lodes pass at their junction into a plexus of fissures within which it is impossible to determine the exact relation of one lode to the other.

The Colorado Boss lode, worked by lessees through the Anaconda adit, is a

mineralized north-south "basalt" dike dipping about 80° E., and usually less than a foot wide. The general country rock is breccia.

Probably the most important lode now worked in the Anaconda is the Virginia M. or Lincoln, which strikes N. 65° E. This lode is cut in the adit about 500 feet

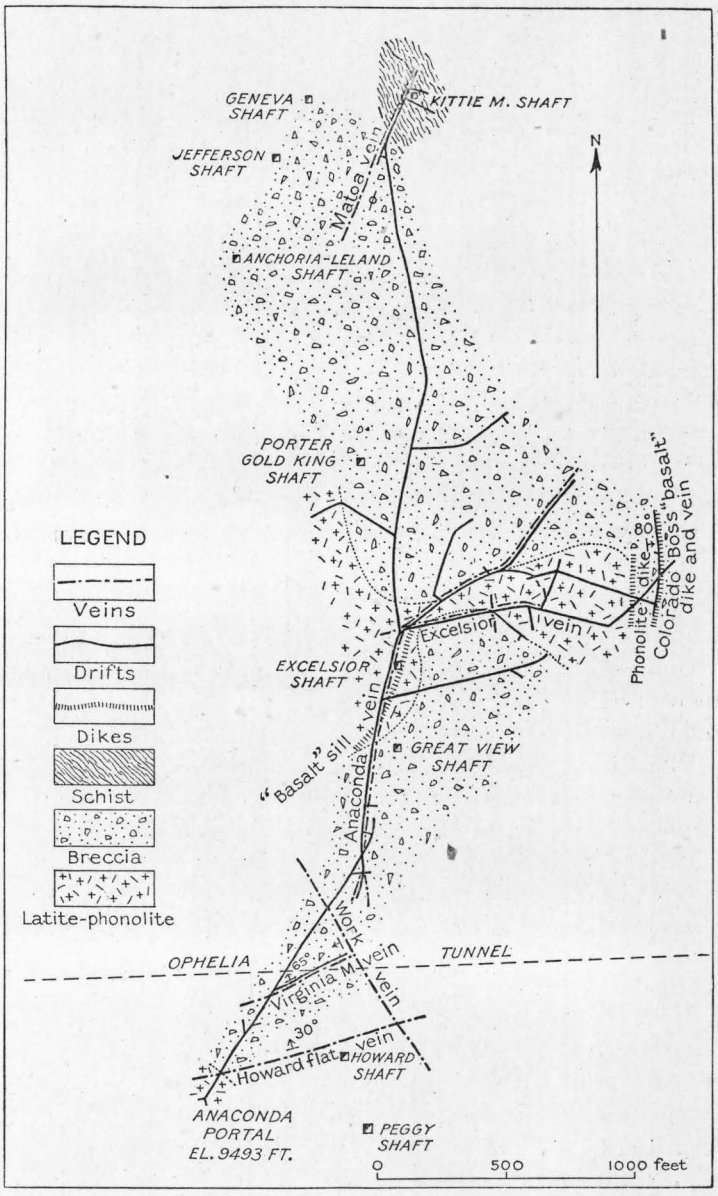


FIG. 30.—Plan of adit level, Anaconda mine, showing approximate distribution of rocks and position of principal lodes.

from the portal and has been explored northwestward to the line of the Anaconda lode. It has also been exploited in the old Virginia M. workings, just north of the Anaconda adit. East of the latter lode the Virginia M. is unknown, and it has not

yet been certainly identified on the levels below the adit. The Virginia M. should intersect the Anaconda lode near the northwest corner of the Mary McKinney ground, but the present developments in this vicinity fail to show the exact relation of the two lodes.

The Black or Work lode is cut in the adit about 800 feet from the portal and has been drifted on for over 700 feet on level 10. It strikes N. 30° W. and dips steeply southwest.

Between the junction of the Anaconda and Excelsior lodes and the Kittie M. lode the adit level passes for nearly 2,000 feet through breccia showing no lodes of any importance. The Kittie M. or Matoa lode strikes about N. 23° E., and on the whole is vertical. Near the surface and in the Half Moon and Anchoria-Leland mines the Matoa lode is in breccia. On the adit level of the Anaconda, however, it is chiefly in schist and is less distinct than in the breccia.

CHARACTER OF ORE.

The ore taken from the Anaconda and Excelsior lodes from 1892 to 1897 was all partly oxidized, containing free gold and some calaverite or sylvanite. Some of it is said to have carried 16 ounces of gold per ton, in carload lots. None of this ore could be seen in 1904. The ore of the Virginia M. lode is also partly oxidized and similar in general character to that from the Anaconda lode. A little tetrahedrite, said to contain considerable gold and silver, occurs in a small fissure with quartz and kaolin in the breccia north of the Excelsior lode on th adit level. The same level near the Half Moon shaft cuts through a vein containing galena, sphalerite, and pyrite. These occurrences, however, have not proved of economic importance, the valuable mineral of the ore of the Anaconda mine being essentially a telluride of gold, or free gold derived from the telluride by oxidation of the tellurium.

PAY SHOOTS AND LODE STRUCTURE.

The Anaconda lode is a typical sheeted zone, for the most part in breccia, but cutting also through latite-phonolite. Where comparatively unoxidized, as on level 10, the fissures of the lode are filled with small vuggy veinlets of fluorite, carrying as a rule little or no ore. The lode has no well-defined walls and the width of the sheeting varies greatly. As stope maps are not available and the old levels are abandoned, the Anaconda pay shoot can not be described in detail. It extended from the surface to within 100 to 200 feet of the adit level and probably had a maximum stope length of 700 to 800 feet. The ore appears to have occurred wholly within the zones of complete and partial oxidation.

An isolated body of ore was stoped from the southern part of the Anaconda lode on the adit level and is said to have yielded $78,000. The ore, however, was a mere bunch and came to an end 10 feet below the level. Another little body of ore was taken from a short branch or spur from the Anaconda lode on level 10, and yielded $11,000. These occurrences show that while the original Anaconda pay shoot has a definite lower limit above the adit level, yet a certain amount of good ore may occur as bunches in the lode at any depth within the range of the present workings.

The Excelsior lode in its typical portions is also a sheeted zone in breccia and has been stoped above the adit level. The northernmost fissure of the zone is regular and persistent, so that the lode has a fairly definite hanging wall. On the adit level some isolated bodies of ore have been stoped from the Excelsior at points where it is intersected by one or more subordinate north-south fissures.

The pay shoot worked in the Virginia M. lies just west of the line of the Anaconda lode, apparently at the point where the Virginia M. is intersected by the Work lode. The Virginia M. here consists of two narrow sheeted zones a few feet apart, in both of which small pay shoots occur. The one now being exploited is in the southern branch. The ore body is about 80 feet in length and pitches west. The width of the pay shoot is only 6 inches, but the ore is of high grade. It contains fluorite and calaverite, the latter partly oxidized to free gold.

The Kittie M. or Matoa lode as seen on the adit level is a zone of crushed and altered rock from 1 to 2 feet wide. In places it contains considerable kaolin, but elsewhere is a porous and somewhat limonitic mass. Some good ore was stoped above from the portion of the lode in breccia, near the schist. There is no ore, however, on the adit level.

The Howard flat vein contains no ore in the Anaconda ground, though it was very productive in the Mary McKinney. It is a regular sheeted zone in breccia. For about a foot in width the breccia is divided into thin sheets separated by vuggy veinlets of fluorite and quartz. Above and below this thinly sheeted portion the fissures are separated by larger and larger intervals until the vein is no longer to be differentiated from the country rock. From the adit level of the Anaconda it is possible to crawl into the old stopes near the first level of the Burke and Fry or Howard shaft. Here it can be seen that the ore body in the flat vein, in places over 6 feet in thickness, occurred where the latter is intersected by nearly vertical fissures. The ore occurred in the angle between the Anaconda or No. 2 lode and the No. 4 cross lode of the Mary McKinney mine (fig. 32, p. 323), and the approximately vertical fissures are probably connected with these lodes.

The Work lode has the same general character in the Anaconda as in the Mary McKinney mine. The sheeting, as seen on level 10, is very regular and closely spaced. Abundant fluorite is characteristic of this lode, but it contains no ore except near the point where it intersects the No. 2 lode of the Mary McKinney.

On the adit level, near the point toward which the Anaconda, Work, and Virginia M. lodes converge, the breccia is traversed by a great number of fissures of various strikes and dips. Individually these fissures are of no importance, though many of them contain a little calaverite. Where two or more of them intersect, however, there is usually a small body of telluride ore. Several such pockets or bunches have been discovered and are profitably exploited by lessees.

UNDERGROUND WATER.

All of the Anaconda workings are above the present level of underground water, as shown in the Mary McKinney mine, and are dry except for a little water coming down through the old stopes.

GAS.

The mine as a whole is well ventilated and objectionable gases have little opportunity to accumulate. The northern part of level 10 could not be entered at the time of visit, on account of impure air, but this drift has only one connection with the surface and the air is nearly stagnant. There is apparently no conspicuous influx of gas from the rock into the mine at any point.

CALEDONIA MINE.

The Caledonia is situated about a quarter of a mile northeast of Mound, on a low southwest spur from Gold Hill. It has been developed by three shafts and some irregular drifts and crosscuts. The lode strikes about N. 30° E., and has been explored for a length of about 500 feet and a depth of 250 feet. The general country rock is granite, which is cut by an irregular dike of phonolite, shown on the geological map (Pl. II, in pocket). This phonolite turns as it is followed down, until at a depth of 150 feet it becomes a nearly horizontal sill extending to the east of the workings. The lode is a well-defined sheeted zone, dipping 75° or 80° SE. It cuts through the phonolite without perceptibly faulting it. The ore occurred in rather irregular bunches in the phonolite or in the granite immediately above or below the phonolite. The maximum length of the pay shoot was about 300 feet and practically no ore has been found at a greater depth than 100 feet. The ore is said to have been all more or less oxidized. The gross output of the mine has been about $140,000, most of which was produced in 1894 and 1895.

CARDINAL SHAFT.

The Cardinal shaft is situated on the point of a ridge a few hundred feet south of the Caledonia. The production is said to be at most 1,000 tons of ore containing about $20 per ton. The incline shaft descended at an angle of 70° to a depth of 265 feet and two levels are turned. The vein is in granite, but crosses a narrow phonolite dike 100 feet north of the shaft. The direction of the vein is northerly, the dip 70° E. A well-defined hanging wall is strongly marked by horizontal striations. The vein is about 1 foot wide and consists of crushed granite. A streak of galena was found on the hanging wall near the bottom of the shaft, also some calaverite. Ore has been stoped 3 feet wide for about 75 feet north of the shaft on level 1, but the shoot was not found on level 2. Some good ore was lately encountered in the bottom of the shaft.

CHAPTER III.—MINES OF RAVEN AND GUYOT HILLS.

GENERAL INTRODUCTION.

Raven Hill lies in the southwest part of the central volcanic area. At its west base is the town of Anaconda and on its lower south slope the town of Elkton. On the southwest Guyot Hill forms a prominent spur, while on the northeast a gently sloping saddle joins Raven Hill with the higher Bull Hill.

The prevailing rock of Raven Hill is phonolitic breccia, cut by numerous dikes of phonolite and "basalt." This breccia is bounded on the west by Cripple Creek granite and on the south by Pikes Peak granite.

The mines of Raven Hill, which are numerous and important, are mostly on the western and southern slopes. Between Anaconda and the summit of the hill is a group comprising the Morning Glory, Doctor-Jackpot, Ingham, Mattie D., and Elizabeth Cooper mines (Pl. XXII, *B*, p. 292). Immediately west of this group is the Mary McKinney mine, with workings extending under Anaconda into Gold Hill. South of the Mary McKinney, on the north slope of Guyot Hill, are the Aileen and Katinka mines. On the south slope of Raven Hill are the Gregory, Tomado, Elkton, and Thompson mines, all owned by the Elkton company. On the southeastern slope is the Moose mine, and on the summit are the Joe Dandy and Ida May mines.

DOCTOR-JACKPOT AND MORNING GLORY MINES.

INTRODUCTION.

The Doctor-Jackpot and Morning Glory group includes a number of mines which were formerly worked under individual ownership, but which are now controlled by three companies. The Doctor-Jackpot Company owns the Ingham, Mattie D., Jack G., Doctor, Elizabeth Cooper, Jackpot, and other claims, which were consolidated November 30, 1901. The Work Mining and Milling Company owns the Morning Glory, Morning Glory No. 2, Morning Glory No. 4, Ida B., and Little Clara claims. The present Morning Glory Gold Mining Company, with a capital of $1,250,000, was organized in 1902 as a successor to the Morning Glory Mining and Leasing Company. The new company owns the Aileen, P. C. W., Little Grant, and Lantishie claims and has long-term leases on the Morning Glory, Morning Glory No. 2, Ida B., two-thirds of the Morning Glory No. 4, and the Rose Maud claims. Most of the work on the Work Mining and Milling Company's property for the past few years has been done by the Morning Glory Company, largely through the Morning Glory shaft, which was sunk under an agreement for the joint operation of the various claims. With the exception of the Aileen, the group thus constitutes practically a single mine, of which the total output is probably about $4,500,000. Most of this has come from the Doctor and Jackpot claims.

The Morning Glory, Doctor, Ingham, and Mattie D. mines began to ship ore in 1893, and the Elizabeth Cooper and Jack G. in 1895. In August, 1895, rich ore was found in the Doctor, and during the month of September, 1896, this mine was reported as shipping 600 tons of 10-ounce ore. In 1898 the Jackpot began to ship, and in the following year paid dividends amounting to $150,000. In 1900 the Doctor and Jackpot companies became involved in a legal contest for possession of the great ore shoot, which was settled by the consolidation, as previously stated, of the two companies in November, 1901. The Doctor-Jackpot mine continued to ship ore during 1902, but the company was much hampered in its operations by water. In 1903 the main pay shoot had been nearly worked out down to the water level and the company suspended operations. The mine is at present operated by lessees.

UNDERGROUND DEVELOPMENT.

The workings of this group of mines are extensive, the numerous drifts and crosscuts penetrating a large portion of the western half of Raven Hill. The area exploited has a length from west to east of about 2,800 feet, and from north to south of about 1,800 feet. The principal access to the workings at present is the vertical Morning Glory shaft, near the "Low Line" station of the same name. This shaft is a little over 700 feet in depth and has three levels situated 100, 550, and 700 feet below the collar. Of these the 550-foot level is most extensive and is shown in fig. 31. The mouth of the Doctor inclined shaft is 950 feet east of the Morning Glory shaft and about 200 feet higher up the slope of Raven Hill. It follows the northwest dip of the Doctor-Jackpot lode down to a point about 40 feet above the 700-foot level of the Morning Glory shaft. The Doctor levels are about 50 feet apart vertically, the 700-foot Morning Glory level corresponding to level 17 of the Doctor, and the 550-foot Morning Glory level to level 14 of the Doctor. The general angle or dip of the incline is 55°. The Doctor shaft house was destroyed by fire a year or two ago, and the incline is no longer used. None of the levels above 10 were accessible at the time of visit. On the Jackpot claim are two shafts, one vertical and one inclined. The vertical shaft, 300 feet southeast of the Morning Glory shaft, connects with the 550-foot Morning Glory level and is still in use. A small shaft on the Elizabeth Cooper claim is also in use by lessees. Scattered over the property are a number of other shafts, such as the Ingham and Chief, on the Ingham lode, which are no longer in use. There are also two adits, formerly of more importance than now. These are the Doctor tunnel, with its portal near the collar of the Doctor incline; the Orehouse tunnel, which is level 1 of the Doctor shaft, and the Mattie D. tunnel, about 500 feet east-southeast of the Doctor incline. The Mattie D. tunnel follows the Mattie D. lode, which has been worked also through an inclined winze to a depth of nearly 300 feet below the adit level.

The Anaconda-Raven tunnel passes through the property and connects with the Doctor shaft at level 5. About 700 feet northeast of the Raven is the Standard tunnel (not the Standard drainage tunnel), which connects with the Doctor shaft at level 4.

The principal drifts of the Doctor-Jackpot and Morning Glory mines follow the northeast-southwest Doctor-Jackpot lode, the longest single drift being that

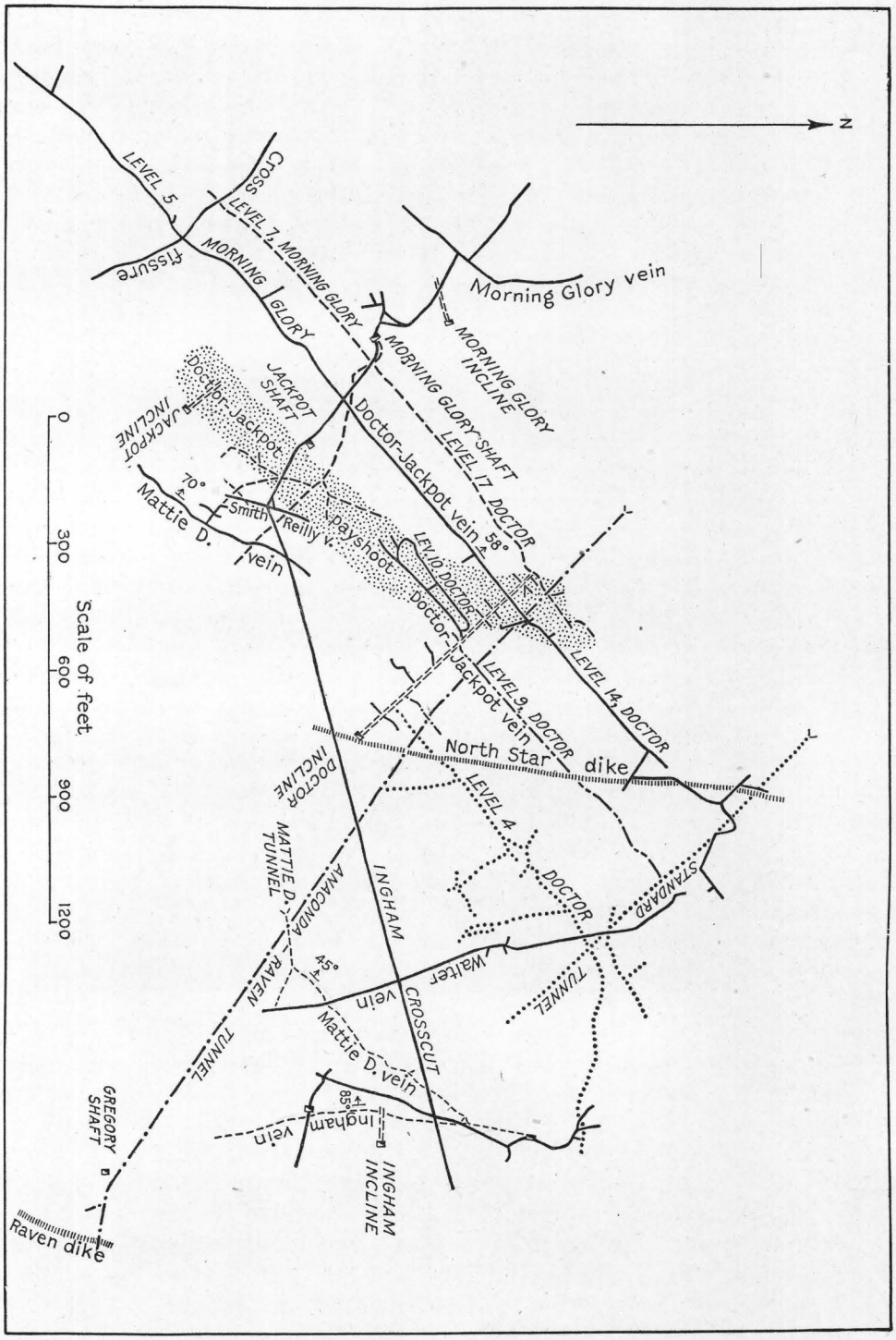


FIG. 31.—Plan of parts of underground working at Doctor-Jackpot and Morning Glory mines, showing principal lodes and dikes and approximate outline of the Doctor-Jackpot pay shoot.

on the 550-foot Morning Glory level, shown in fig. 31 (p. 316), which explores the lode for a distance of 2,900 feet. Northwest of these drifts are comparatively short drifts on the nearly north-south Morning Glory lode and on an intersecting fissure zone of the same general trend as the Doctor-Jackpot lode. East of the Morning Glory shaft are numerous nearly north-south drifts on the Smith-Reilly or Elizabeth Cooper, North Star, Walter, and Ingham lodes, and some northeast-southwest drifts on the Mattie D. lode. The general plan of these drifts as seen on a single level is well shown in fig. 31. The principal crosscut of this group of workings is the Ingham, on the 550-foot Morning Glory level, which extends from the Morning Glory shaft to the eastern edge of the property.

GEOLOGICAL FEATURES.

The general country rock is breccia, of the type prevalent in Raven Hill, and is all indurated or otherwise altered. It contains abundant fragments of phonolite and in places consists chiefly of this rock, fragments of other rocks being locally subordinate. No granite fragments were seen. Some of the breccia is much shattered, as may be well seen at the south end of the Walter drift, on the 550-foot Morning Glory level. The rock is here an incoherent, porous mass of angular fragments which are usually less than 6 inches in diameter. The loose fragments are not original breccia fragments, but are the result of local shattering of breccia previously solidified into a firm rock. The breccia is cut by numerous irregular dikes and sills of phonolite which appear to have no significant relations to the ore. Several small basic dikes, mostly with north-south trend, are encountered in the Doctor-Jackpot workings. The only one of these of any economic interest is the North Star dike, which has produced some ore in the North Star workings, just north of the Doctor-Jackpot line. This dike is well exposed in the Anaconda-Raven and Standard tunnels. Its general course is N. 10° E., and it is practically vertical. It is usually 2 to 3 feet wide, but like other basic dikes in the district, occasionally pinches out and reappears a few feet to one side of the line previously followed. The rock of this dike is generally soft and decomposed.

A feature in these mines of much interest is the presence of small quantities of bituminous coal in the breccia in the form of irregular bunches and veinlets. It occurs at several points on the 550-foot Morning Glory level, particularly in the Ingham crosscut near the Smith-Reilly lode. It is found also in the Doctor-Jackpot lode near level 15 of the Doctor, just northeast of the Doctor shaft. It here forms a narrow seam, 3 or 4 inches in width, filling one of the fissures of the Doctor-Jackpot lode and closely associated with the ore.

LODE SYSTEMS.

The lodes exploited in the Morning Glory and Doctor-Jackpot workings fall into two general classes. The first of these is a system of fissures striking nearly northeast and dipping to the northwest at angles of approximately 50°. Belonging to this class is a lode northwest of the Morning Glory shaft whose name was not learned, but which may be called the Galeta lode, from the Galeta inclined shaft sunk upon it; the Doctor-Jackpot lode; and the Mattie D. lode. The lodes of the

second class range in strike from north to N. 10° E. and are represented by the Smith-Reilly, North Star, and Ingham lodes. The North Star lode is about vertical, the Ingham dips very steeply west, while the Smith-Reilly has a westerly dip of about 70°. The so-called Walter lode, followed on the 550-foot level (fig. 31, p. 316), has a general strike of N. 15° W., and so does not belong strictly with either of the two main sets of lodes. Another lode, exploited on the 550-foot level about 100 feet east of the Smith-Reilly and called the Mattie D. lode (though its identity with the Mattie D. as known higher up the hill is not established), strikes N. 30° E., so that it is intermediate in strike between the lodes of the two general classes. Like nearly all the other lodes in this part of Raven Hill, it dips northwest, the angle being about 70°. The Mattie D. lode, as seen in the Mattie D. tunnel and incline, has an average northwest dip of about 45°, though in some places the dip is only 20°. It intersects the Ingham lode, neither lode being displaced or showing any distinct difference in age. The relative positions of the various lodes are shown in fig. 31 (p. 316).

The relation of the Doctor and Jackpot veins has been much discussed and constituted an important question in the litigation that led to the consolidation of the two mines. They are supposed by some to be merely parts of the same zone of fissuring. Others maintain that the Jackpot vein has a slightly different strike from the Doctor vein and is more nearly vertical. Those who hold the latter view believe that the Doctor and Jackpot veins intersect at a small angle and that the Doctor vein carries ore only at this and other intersections. At the time of visit the mine workings were not in a condition to allow a satisfactory decision to be reached on this mooted point, and as the observed relations are most readily accounted for on the supposition that the so-called Doctor and Jackpot veins are really part of one persistent zone of fissuring, this zone will be referred to in this report as the Doctor-Jackpot lode.

CHARACTER OF ORE.

It is not possible in the present condition of the workings to give a detailed account of the ore of these mines. The large and rich shoots of the Doctor-Jackpot lode have been worked out, and accurate information concerning the character of ore that occurred in the abandoned stopes is difficult to obtain. In the lower levels, below the zone of oxidation, two fairly distinct types of ore are found in the Doctor-Jackpot lode. One of these shows the usual association of calaverite or sylvanite with quartz, fluorite, and often a little dolomite, in the veinlets of the sheeted zone. Some of the crystals of calaverite project into small vugs, but in many cases are inclosed in a compact aggregate of quartz and purple fluorite. This ore is by some considered characteristic of the Doctor lode. The other type is characterized by the presence of tetrahedrite, associated with pyrite, quartz, and dolomite, but with little or no fluorite and, so far as observed in the few specimens obtainable, no visible tellurides. Some of the specimens of this ore show a definite mineralogical sequence. Pyrite and tetrahedrite crystalized first on the walls of the fissures, accompanied by a mineral, probably celestite, crystallizing in rather slender prisms of rhombic cross section. Deposition of quartz, with sometimes a little fluorite, followed, and during this deposition the prismatic mineral was altered to hollow siliceous pseudomorphs. The alteration seems to have consisted in a partial

external silicification of the unknown mineral, with subsequent solution and removal of the unsilicified core. Finally pyrite was deposited in small sharp crystals upon the surfaces of the quartz crystals. Other specimens show that the fissure walls were in part coated with crystals of dolomite upon which are implanted tetrahedral crystals of tetrahedrite associated with a little pyrite. This second type of ore is by some considered characteristic of the Jackpot lode.

Some of the tetrahedrite ore being stoped by lessees on level 15, near the Doctor shaft, contained from 6 to 27 ounces of silver per ton, while some ore previously extracted was said to contain up to 200 ounces of silver and 20 ounces of gold. At this point in the mine a seam of coal (see also p. 31) lies along the foot wall of the tetrahedrite ore and is stoped with the latter. The coal is reported to have given an assay value of $40 per ton in gold, but it is doubtful whether the sample was taken with sufficient care to avoid including some of the adjacent ore.

The ore now mined by lessees from the Smith-Reilly lode and associated fissures is of the usual type—calaverite associated chiefly with quartz and fluorite in narrow cracks in the breccia.

PAY SHOOTS AND LODE STRUCTURE.

The Doctor-Jackpot lode is a remarkably well-defined and regular zone of parallel fissuring. It has been followed on the 550-foot Morning Glory level for 2,900 feet, and is without doubt one of the most distinct and persistent sheeted zones in the district. In its typical development, as seen on the 700-foot level northeast of the Morning Glory shaft, the lode consists of two regular and well-defined parallel fissures from 3 to 6 feet apart. These fissures, particularly the foot-wall fissure, exhibit more evidence of movement of the walls than do most of the Cripple Creek lodes, and some slickensided surfaces were observed, but not such as to indicate any great displacement. Between the two main fissures the breccia is usually sheeted, or divided into thin slabs of an average thickness of 2 or 3 inches by minor parallel fissures, and close examination often reveals less conspicuous cracks dividing these slabs into still thinner plates. The fissures of this sheeted zone are not all filled with the same material. Some are occupied by veinlets composed chiefly of a fine-grained purple aggregate of quartz and fluorite, locally inclosing calaverite. Others contain dolomite and quartz with tetrahedrite and a little fluorite, and still others are filled with rather crumbling aggregates of pyrite. In some cases the veinlet forms a fairly solid filling, but in others it is more or less open and vuggy. The lode varies from point to point in width and in the number and disposition of its constituent fissures. In some places there is little more than a single well-defined fissure. In others the fissures diverge so as to inclose horses of country rock as much as 30 feet in width. Such a horse appears in the northeastern part of the 700-foot level, where the stronger hanging-wall zone is sometimes called the Doctor lode, while the foot-wall zone is called the Jackpot lode, and contains tetrahedrite. Somewhere below the 550-foot Morning Glory or Doctor level 14 these two zones of fissuring appear to join and form a single well-defined lode. Near the Doctor level 10, however, in the vicinity of the Doctor shaft, the lode again shows two sheeted zones separated by a horse of breccia with a maximum width of about

30 feet. The main stopes, coming from below, follow the northwest or hanging-wall branch of the lode, though the foot-wall branch has been stoped to some extent just above level 10. At both ends of level 10 the two fissure zones approach each other, but the level has not been carried far enough to determine whether they actually join on the lines of strike. Owing to the bulkheading of the Doctor shaft near its mouth, the levels above 10 and below 1 were filled with gas at the time of visit, and no further observations could be made on the relations of the supposed Doctor and Jackpot lodes.

The pay shoots of the Doctor-Jackpot lode occupy but a small part of the whole length of the lode. The ore forms at least two distinct shoots, one coming to the surface near the Doctor shaft and one near the Jackpot shaft. They may be conveniently distinguished as the Doctor and Jackpot pay shoots. The Doctor pay shoot lies for the most part east of the North Star basaltic dike and has been worked chiefly from the Doctor and Orehouse tunnels, and probably from the now inaccessible northeast drifts on the Doctor levels 2 and 4. Some of the ore was seen at the northeast edge of the old stope, about 50 feet below the Orehouse tunnel, where lessees were working at the time of visit. This ore is partly oxidized, showing calaverite and free gold, but no tetrahedrite. The best of it, a narrow oxidized seam along the hanging wall, was said to carry about 3 ounces of gold per ton. The depth to which this pay shoot extended could not be ascertained at the time of visit, but it apparently ended well above the Anaconda-Raven tunnel, or Doctor level 10. Below it the Doctor shaft went through a nearly barren part of the lode until it reached the Jackpot shoot, near level 12. The Jackpot pay shoot has an unusually low northeast pitch, probably considerably less than 30°, which carries its upper limit from the surface near the Jackpot shaft to level 12 at the Doctor shaft. The maximum length of this pay shoot on any one level was from 400 to 500 feet, and on the Doctor level 15 it was stoped for 225 feet in length. It has been stoped practically from the surface to the 700-foot Morning Glory level, though there are comparatively barren portions just above the latter level and near the Doctor levels 10 and 14. Exploitation below the 700-foot level has hitherto been impracticable on account of water. The width of the ore in the Jackpot shoot below the Doctor level 10 varies from 5 to 10 feet, being widest where small cross fissures intersect the main lode. This is the principal pay shoot of the property and the question of its ownership was the subject of the legal contest which in 1901 resulted in the consolidation of the Doctor and Jackpot mines.

No work has been done for some time on the Morning Glory lode and very little could be seen in these old workings at the time of visit. Penrose[a] describes the lode as a well-developed sheeted zone cutting breccia and phonolite, the ore containing gold telluride and free gold associated with quartz and fluorite. He refers to the presence of several northeast-southwest fissures which we now know to be generally parallel with the Doctor-Jackpot lode.

The Ingham lode is an irregular zone of fissuring in phonolitic breccia. The principal pay shoot in this lode occurred between the Ingham and Gregory shafts, and is said to have attained its greatest width, 20 feet, in the vicinity of a small

[a] Mining geology of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 188-189.

basalt dike crossed by the lode. This dike, however, could not be found at the time of visit, nor was any of the ore visible. The latter is reported to have been partly oxidized, containing free gold and tellurides, and to have been worth $35 to $40 per ton. No ore has been found on the Ingham lode on the 550-foot Morning Glory level, and the lode below this is unexplored.

The Mattie D. lode is structurally very similar to the Doctor-Jackpot, with an even and well-defined hanging wall. Along this hanging wall is usually a few inches of brecciated rock indicating some tangential displacement of the walls, although the lode does not perceptibly fault the Ingham lode. There are, as a rule, two or three other fissures parallel with the hanging-wall fissure, the average width of the lode being about 3 feet. Several small pay shoots have been stoped on the Mattie D. lode, but no large body of ore.

The Walter vein, as known in the Doctor-Jackpot mine, has been explored chiefly on the 550-foot Morning Glory level, with negative results. It is a rather obscure fissure zone cutting the breccia and several phonolitic intrusions.

The ore in the North Star lode occurred in the altered basalt of the North Star dike within 300 feet of the surface and was worked chiefly through the old North Star shaft, now abandoned. Its occurrence was described by Penrose.[a]

Considerable ore has been stoped between the surface and the 550-foot Morning Glory level from short pay shoots in the Smith-Reilly lode and in some small associated cross fissures. This ore is partly oxidized, carrying free gold and tellurides. So far as known these pay shoots do not extend to the 700-foot level.

UNDERGROUND WATER.

The first water reported in these mines was at a depth of about 600 feet below the collar of the Morning Glory shaft, or 9,121 feet above sea level, and was encountered in 1900. As the Standard tunnel, with its face 9,056 feet above sea level, had at this time passed its maximum discharge and as the deeper Mary McKinney mine had been actively pumping, the water in the Morning Glory shaft evidently stood considerably below its natural local level. The maximum flow was reached at the 700-foot level (9,021 feet above sea level) in 1901, when the pumps raised 1,890 gallons per minute. In the summer of 1902 steady pumping had lowered the water level 100 feet and pumping, being no longer necessary to keep open the 700-foot level, was discontinued. Since then the water has very slowly receded in the sump, the rate, according to Mr. V. G. Hills, being 0.03 foot per day. In July, 1903, the water in the sump was 2 feet below the 700-foot level.

MARY McKINNEY MINE.

INTRODUCTION.

The Mary McKinney mine is situated on the south side of Squaw Gulch, opposite the town of Anaconda. Adjacent mines are the Anaconda and Peggy on the north, the Morning Glory and Doctor-Jackpot on the east, and the Katinka and Aileen on the south. The property comprises the Mary McKinney, Mary McKinney

[a] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 188.

No. 2, Republic, Mayflower, Le Clair, and Thurlow claims, and covers about 34 acres. It is owned by the Mary McKinney Company, of Colorado Springs, incorporated in 1892, and capitalized at $1,000,000. Up to the beginning of 1889 the mine was worked by lessees, the first shipment of ore being in 1893. Early in 1899 the company began operations on its own account, and erected the present shaft house. The first dividend was declared in October of the same year.

The mine has produced a large amount of ore and has undoubtedly been profitable to the company. Statistics of production, however, are not obtainable.

UNDERGROUND DEVELOPMENT.

The main shaft, 609 feet deep, is on the Republic claim, about 1,000 feet from the south end of the property. There are four other smaller shafts, of which the only one now in use is the Burke and Fry shaft, in the northern part of the mine, operated by lessees.

There are five main levels, which at the shaft are approximately 135, 210, 280, 380, and 485 feet below the surface. These extend through the Republic and Mary McKinney claims in a general north-northeast direction, practically from one end of the property to the other. In the southern part of the mine the drifts are of simple linear plan, following the Mary McKinney and Le Clair lodes, which intersect at a small angle. In the northern part of the mine, however, the workings, as may be seen from fig. 32, are more complex, owing to the less regular character of the fissuring and to the existence of a number of so-called "flat veins," some of which are shown in fig. 33. The Ophelia tunnel passes through the northern end of the mine, 15 or 20 feet above level 4.

GEOLOGICAL FEATURES.

The workings of the Mary McKinney mine are mainly in breccia and phonolite. Although on the surface the granite-breccia contact is less than 400 feet west of the shaft, it was seen at only one point in the mine, in a west crosscut on level 4, south of the shaft. It is here fairly distinct and seems to be about vertical. It is probably cut also in an old unused adit connecting with level 1.

The main country rock of the mine from the south end to a point about 1,200 feet north of the shaft is phonolite, varying in texture from the greenish aphanitic variety, common in the dikes and smaller intrusive masses of the district, to trachytic facies showing phenocrysts of feldspar and pyroxene. The form of this phonolitic mass can not be even approximately determined from existing workings. It does not appear to reach the surface, though it is the principal rock of all the levels from 1 down. The crosscut into the granite on level 4 shows breccia between the phonolite and the granite, but the contact between the phonolite and breccia is very obscure. In the northern part of the mine the contact is comparatively sharp and regular. It strikes nearly east and west and dips 85° S. On level 4 it has the appearance of an intrusive contact, but on level 3 this relation, if, as seems probable, it is the true one, is obscured by the abundance of phonolite fragments in the adjacent breccia.

One of the most interesting geological features in the northern part of the mine is a sill, or recumbent dike, of trachydolerite, locally known as the Howard

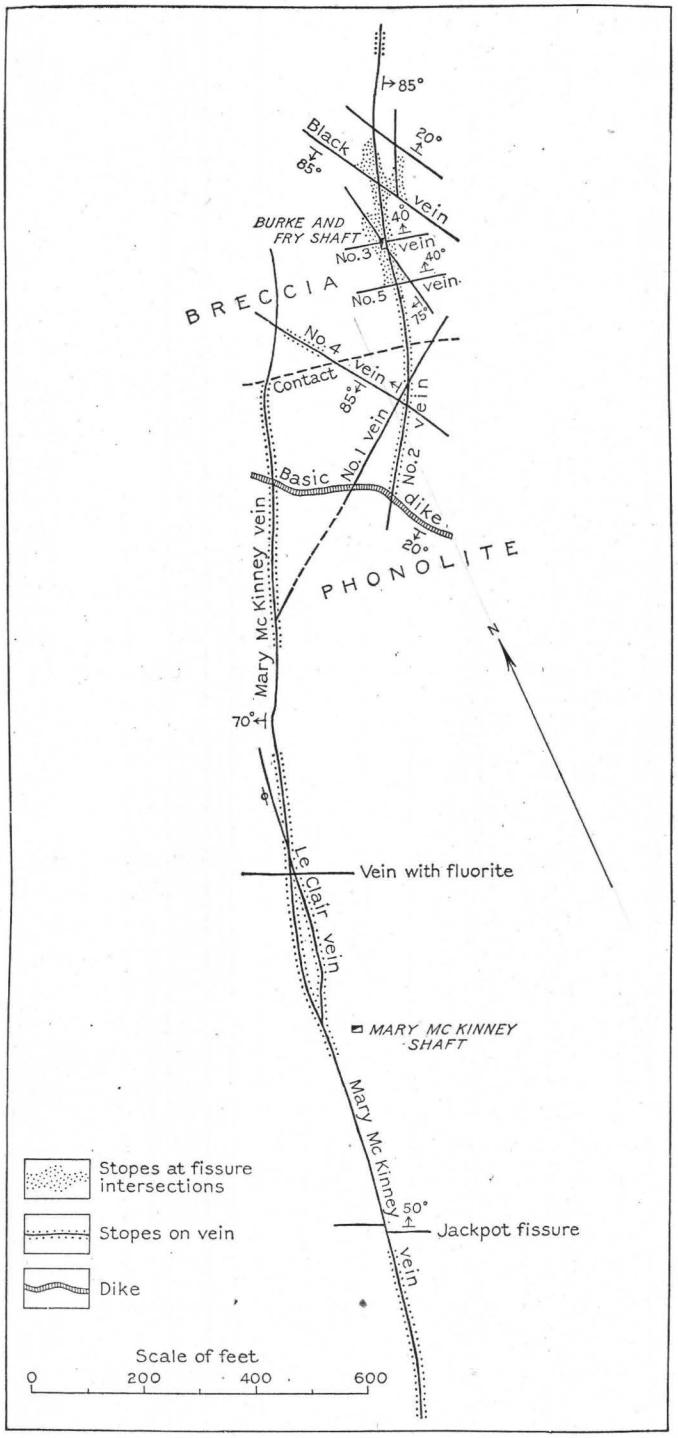


FIG. 32.—Plan of the veins of the Mary McKinney mine, level 4.

dike, or Mary McKinney "flat vein." This strikes approximately northwest and southeast, and dips southwest at an average angle of 20°, which is about the same as the slope of Gold Hill. It is cut in the Burke and Fry shaft 400 feet below the surface. On level 3 it appears about 50 feet north of this shaft, in the breccia. It is here about 4 feet in thickness and has a higher dip than usual. Toward the north it passes about 75 feet above the Ophelia tunnel at the point where the latter cuts what is known as the No. 2 vein of the Mary McKinney mine. The basic sill exposed in the Ophelia tunnel about 3,900 feet from the portal is probably the same as that known in the Mary McKinney mine. The more conspicuous sill exposed from 4,600 feet to 4,800 feet in from the portal is apparently a second and lower sheet of "basalt" which seems not to have been encountered as yet in the Mary McKinney workings. On level 4 of the Mary McKinney the Howard sill occurs about 200 feet south of the Burke and Fry shaft and is here in phonolite. It is about 3 feet thick on this level. On level 5 the trachydolerite is cut about 425 feet south of the Burke and Fry shaft, and has been followed for over 300 feet in a curved drift. Here also it is in phonolite. A general idea of the geological relations in the Mary McKinney mine may be had from fig. 32 (p. 323), which is a map of level 4.

LODE SYSTEMS.

The horizontal relations of the principal lodes are shown in fig. 32. On all the levels the Mary McKinney lode maintains its usual regularity from near the south end of the property to within about 200 feet from the contact between the phonolite and breccia, in the northern part of the mine. South of the shaft the lode strikes N. 9° E. North of the shaft, however, it curves gently eastward until it strikes N. 25° E. The dip is westerly and ranges from 65° to 75°.

The Le Clair is a vertical lode, striking N. 6° E., and intersecting the Mary McKinney lode at an acute angle. On level 2 the crossing of the two lodes is well shown and is about 200 feet south of the shaft. Neither lode appears to displace the other at the crossing, nor is there any indication of one lode being older than the other. On level 3 the intersection occurs about 100 feet south of the shaft. On level 4 the lodes cross about 275 feet north of the shaft, but continue close together and apparently coalesce near the shaft. At 175 feet south of the shaft a fissure zone turns off to the south and has been followed for over 100 feet in a drift. This is probably the Le Clair. If so, the two lodes practically coincide on this level for a distance of over 400 feet. On level 5 the Mary McKinney and Le Clair lodes join 375 feet north of the shaft, run together for about 100 feet, and then gradually diverge. They appear to meet again near the shaft. South of the shaft on this level the Le Clair is unknown. It has been explored for a total length of about 1,000 feet. At several points the Mary McKinney lode is crossed at acute angles by other fissures similar to the Le Clair, but of less persistency and carrying much smaller values.

In the southern part of the mine these two lodes are the only ones of economic importance. In the northern part, however, the fissuring, as already stated, becomes more complex, as may be seen from fig. 32 (p. 323). As the Mary McKinney lode is followed north it shows a tendency to split up near the contact between

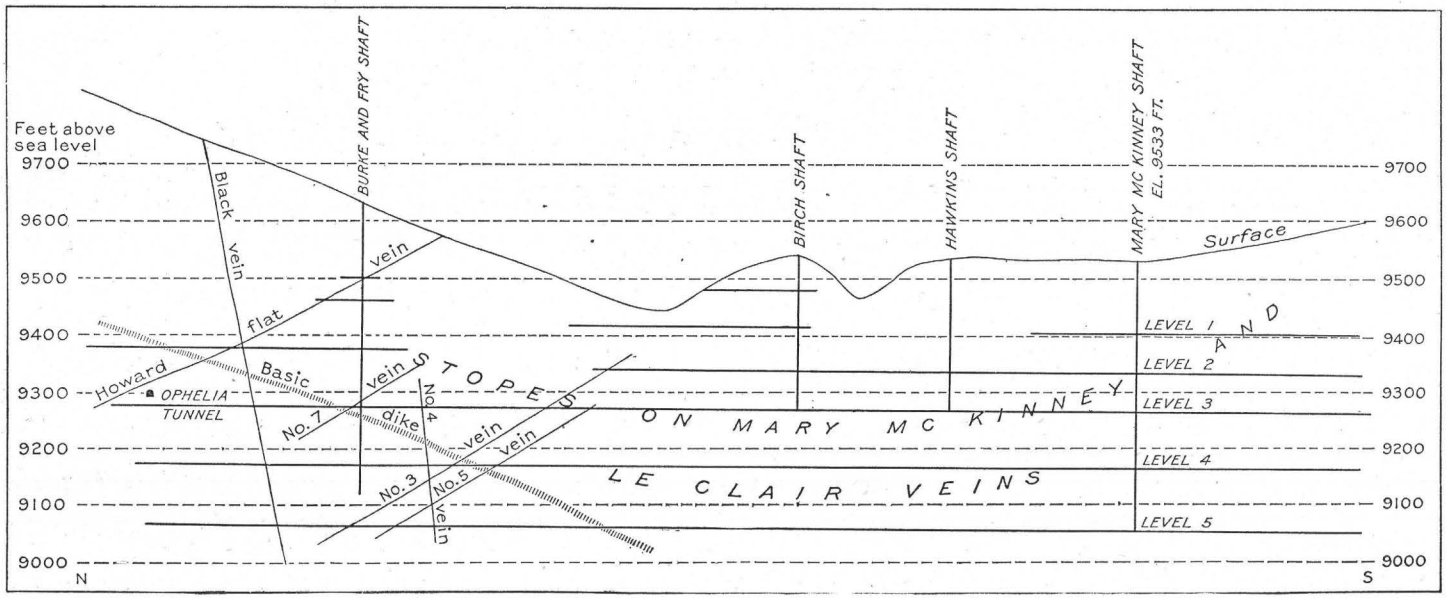


FIG. 33.—Generalized longitudinal section of the Mary McKinney mine, showing relation of flat veins and Howard basic dike.

the phonolite and breccia and to turn northeasterly. Beyond this turn it becomes increasingly difficult to follow. As the Mary McKinney lode loses in distinctness another lode, lying east of it, becomes prominent. This is the No. 2 vein, striking generally N. 20° E. Unlike the Mary McKinney, it dips easterly, the angle ranging from 80° to 85°. The lode continues northward under the Howard flat into the Anaconda mine, and is there known as the Anaconda vein. The farthest point south to which the No. 2 vein has been followed is on level 5, about 500 feet south of the Burke and Fry shaft. In a general way its importance diminishes as the Mary McKinney lode west of it becomes more regular and distinct.

Linking the No. 2 lode with the Mary McKinney lode is the No. 1 vein. This is a rather irregular and somewhat indistinct fissure zone striking northeast and dipping northwest at varying angles. It is not known to extend west of the Mary McKinney lode, though it apparently crosses the No. 2 lode.

In addition to the lodes of meridional to northeasterly trend, the mine contains a number of cross lodes. One of these, south of the shaft (fig. 32, p. 323), is known as the Jackpot vein though not the same as the productive lode of the Doctor-Jackpot mine. This strikes about N. 80° W. and dips north at an angle of about 50°. It is faulted by the Mary McKinney lode. The throw can scarcely exceed 10 or 15 feet and the displacement corresponds to a reversed fault. About 100 feet and 250 feet north of the main shaft the Mary McKinney and Le Clair lodes are crossed by two approximately vertical cross veins, striking N. 60° W. No displacement of any of the lodes can be discovered at the crossings. One of the most important cross veins in the mine is known as the No. 4 vein, and crosses the Mary McKinney No. 1 and No. 2 veins in the vicinity of the contact between the phonolite and the breccia. This lode strikes N. 31° W. and dips 85° SW. No perceptible faulting occurs at its intersections with the other lodes. About 300 feet northeast of the No. 4 lode is the parallel Black or Work vein, a persistent sheeted zone which is known also in the Anaconda mine and in the Ophelia tunnel.

The northern part of the Mary McKinney mine contains a number of so-called "flat veins" with generally northerly dips of less than 45°. One of the most interesting of these is the Howard flat vein. Were it exposed at the surface this lode should outcrop about 150 feet south of the Burke and Fry shaft. It is cut in this shaft 150 feet below the surface and dips about 30° N. It lies above the present accessible workings of the Mary McKinney mine, but can be well seen in the Anaconda and Ophelia workings. Two hundred feet vertically below the Howard flat vein is the generally parallel No. 7 flat vein, which is well exposed on level 3, just north of the Burke and Fry shaft. About 200 feet below the No. 7 flat is the No. 3 flat vein, and about 40 feet below the latter is the No. 5 flat vein. Between the named members of this system of generally parallel flat veins dipping north at angles from 20° to 40° are a number of other fissures which have not been recognized as distinct lodes. The breccia in the northern part of the mine is thus characterized by well-marked parallel sheeting, the planes of this sheeting having a general northerly dip of about 30°. As a rule the nearly vertical fissure zones intersect this sheeting and the Howard basalt dike without appreciable faulting. In one case only was faulting observed. This was on level 3, where a small, unimportant vertical fissure faults the No. 7 flat vein with a throw of 4 or 5 inches.

PAY SHOOTS AND LODE STRUCTURE.

The principal pay shoot is in the Mary McKinney lode, a regular sheeted zone in phonolite. This shoot has been stoped from the surface to level 5 and for a length of nearly 2,000 feet. Although portions of the lode have proved to be of too low grade for stoping, yet the sheeted zone constitutes an essentially continuous ore body from a point 700 or 800 feet south of the shaft north to the contact of the phonolite. In other words, where the fissuring is regular and distinct it usually carries ore. Some bodies of ore occur in the Mary McKinney sheeted zone in the breccia, but these can hardly be considered as belonging to the main pay shoot. The lode on the whole is rather narrow, stopes over 5 feet in width being apparently exceptional. At the time of visit, however, the Mary McKinney lode had been nearly worked out down to level 5 and there were few opportunities of studying the occurrence of the ore. There is usually a main fissure up to 4 or 5 inches in width, carrying quartz and dark, compact fluorite and showing vuggy cavities in its medial plane. Where such vugs occur, and particularly where roscoelite is associated with fluorite, the ore is usually good and crystals of calaverite may be seen in the vugs and embedded in the quartz and fluorite. This relation, however, does not hold everywhere, for certain vuggy portions of the lode, containing much roscoelite, are too poor to pay. Associated with the main fissures are others of less persistency. Some of these are parallel with the main fissure, while others are of irregular character. These subsidiary fissures usually contain quartz and fluorite and some of them carry calaverite and tetrahedrite. According to Superintendent Buckles there is a definite relation between the tenor of the ore and the character of the jointing on the hanging-wall side of the lode. Where the joints dip generally east or into the lode the ore is good. Where they dip west or away from the lode the ore is poor.

The Le Clair lode is similar to the Mary McKinney in structure and mineralogical character, but the pay shoot is much shorter. It nowhere extends for more than 500 feet from the intersection with the Mary McKinney lode, and as a rule ends within a much shorter distance.

The northern part of the mine contains a number of short pay shoots, some in the nearly vertical lodes, some in the flat veins, and some at points of intersection of two or more zones of fissuring.

The No. 2 lode is a sheeted zone of the usual type, in which the ore occurs rather erratically to a maximum width of about 12 feet. At the north end of level 4 the fissures of the sheeted zone are abundant and narrow, the calaverite occurring in them and in the more irregular joints of the breccia, associated with thin films of fluorite much as in the Captain stopes of the Portland mine. Short pay shoots occur also in the No. 1 lode and in the No. 4 cross lode. These are mineralized sheeted zones of the usual type, the ore consisting of calaverite in the narrow fissures cutting either breccia or phonolite. The No. 1 lode is not a regular sheeted zone, but is composed of a number of such zones of slight individual persistency which intersect at small angles. It thus shows frequent variation in strike and dip and the ore occurs in isolated bunches. Some of the flat veins, particularly the No. 3, have proved individually productive. The No. 3 flat vein

where stoped between levels 3 and 5 consists of a sharply distinct veinlet of fluorite, quartz, and calaverite rarely more than an inch in width. This is usually associated with a little parallel sheeting of the breccia, but the value of the ore lies almost wholly in the small veinlet, which in spite of its diminutive size is rich enough to stope. The calaverite occurs chiefly along the sides of the veinlet and and in the medial quartzose vugs.

The main interest in the northern part of the mine centers in the occurrence of ore bodies at various intersections of lodes with each other and of lodes with the Howard dike. Such a body occurs just above level 4, where a triangular portion of the "basalt" bounded on the northwest by the Mary McKinney lode, on the northeast by the No. 4 cross lode, and on the south by the contact plane between the breccia and phonolite carried enough calaverite in the innumerable minute fissures or joints of the rock to constitute an important pay shoot. A similar though less extensive mineralization of the dike occurs between levels 3 and 5 along the intersection with the No. 2 lode.

Another important pay shoot occurs at the Burke and Fry shaft on level 5, along the line of the No. 2 lode. This body of ore is about 250 feet in length and has a maximum width of about 40 feet. The ore does not extend more than 15 or 20 feet above the level, but how far it goes below is not yet known. The ore body occurs where a number of fissures, including the No. 2, Work, No. 6, No. 3, and No. 5 flat veins intersect. In the vicinity of this intersection the breccia is elaborately fissured. In addition to the named sheeted zones, there is also a pronounced local sheeting with a dip of about 35° S., a system of fissures generally parallel with the No. 2 lode, and much irregular jointing. The ore occurs not only in the intersecting lodes, but in practically all of the immediately adjacent fissures, forming a body of irregular shape with no definite boundary separating it from the breccia country rock. The value lies in the fissures, in the form of calaverite associated with thin films of quartz and fluorite.

The Work lode is of no economic importance in the Mary McKinney mine except at the intersection with the No. 2 lode. It is, however, a strong, prominent vein, locally showing over a foot of fluorite and quartz between well-defined walls. This vein is usually accompanied by parallel sheeting of the breccia. In some portions the filling is chiefly dark, compact fluorite, whence the name Black vein. Elsewhere the filling is chiefly quartz with abundant open vugs. This quartz is clear and vitreous, resembling that described in the Howard flat vein, in the Ophelia tunnel, and Anaconda mine. The Jackpot lode is also a well-defined sheeted zone, but contains only small bunches of ore at the intersection with the Mary McKinney lode.

CHARACTER OF ORE.

The principal gold-bearing mineral of the Mary McKinney mine is calaverite, which occurs associated with quartz, fluorite, dolomite, roscoelite, tetrahedrite, and pyrite. So far as observed the calaverite is found only in the fissures, never within the unfissured country rock. Pyrite, on the contrary, is widely disseminated through the country rock. In the breccia of the northern part of the mine some of the calaverite occurs with mere drusy films of quartz or fluorite in extremely

narrow cracks or joints, the ore thus resembling that found in the Captain stopes in the Portland mine. The ore occuring in "basalt" is apparently of similar character, although very little of this ore was visible at the time of visit.

Usually, however, the calaverite occurs in distinct veinlets of quartz and fluorite ranging in width from a fraction of an inch up to about 6 inches. The quartz and fluorite often show comb or vug structure, but sometimes form a solid, compact vein. The best example of such compact vein matter is furnished by the Work vein, much of which consists of a dark-purple fine-grained aggregate of quartz, fluorite, and a carbonate—probably dolomite. This material, however, is rarely sufficiently auriferous to be ore. Although the calaverite occasionally projects into the vugs, it is more commonly entirely inclosed in the gangue minerals. An earthy green mineral, determined by Doctor Hillebrand to be a vanadiferous silicate, probably roscoelite, is abundant in portions of the Mary McKinney vein and usually, though not always, indicates good ore. It occurs particularly near the walls of the veinlets and as an alteration product of small fragments of country rock inclosed in the quartz and fluorite.

Tetrahedrite occurs in massive form in the Mary McKinney vein a few feet below level 5. It is found in close association with calaverite in little stringers of quartz and fluorite in phonolite. Some of the stringers contain a little dolomite, and hollow siliceous pseudomorphs after celestite occur in occasional small vugs. There can be no question that in this case calaverite, tetrahedrite, quartz, and fluorite all crystallized contemporaneously.

There is very little oxidation in the Mary McKinney mine below a depth of 200 feet and no oxidized ore is now being produced.

UNDERGROUND WATER.

Water was originally encountered in the Mary McKinney at an elevation of 9,498 feet above sea, or at a depth of only 35 feet below the collar of the shaft. In 1899, owing to the lowering of the water by pumping and by the Ophelia and Standard tunnels, the level stood at 9,241 feet above sea, or 292 feet below the collar of the shaft. About this time level 5 was opened, but owing to the excessive water was soon afterwards temporarily abandoned. It was not recovered until April, 1901, when the Elkton is reported to have been pumping 1,200 gallons per minute in order to regain its level 8. The water continued to fall and in January, 1903, stood at 9,023 feet above sea, or about 10 feet below level 5, and was going down at the rate of 0.03 foot per day.[a]

Upon the opening of the El Paso drainage tunnel on September 6, 1903, the water began to fall more rapidly, the record being as follows:

Recession of water in Mary McKinney mine after opening of El Paso drainage tunnel.

	Inches.
First week	29.00
Second week	17.00
Third week	10.00
Fourth week	8.00
Fifth week	7.25

[a] Hills, V. G., Ninth Ann. Rept. Portland Gold Mining Company, 1903, p. 91.

When the mine was visited on January 12, 1904, the water was about 35 feet above level 6, or about 8,988 feet above sea. On April 17 the water was 31 feet lower and its recession was being hastened by pumping 360 gallons a minute.

PEGGY MINE.

The Peggy is of interest as being one of the most recently developed mines in the district, work having begun early in 1903 on the Sunset, a small fractional claim surrounded by the properties of the Mary McKinney, Work, Rose Maud, and Cripple Creek Consolidated mining companies. While really in Gold Hill, the mine is so closely related to the Mary McKinney mine as to be best described in this place. The shaft, situated in the town of Anaconda, is about 361 feet deep, with two small levels, one 300 feet and the other 361 feet below the collar. The workings are all in breccia. The shaft was sunk in the expectation of finding ore at the intersection of a nearly north-south fissure with the Howard dike or sill. At a depth of 300 feet, however, a flat vein was encountered, striking about N. 70° E. and dipping 45° N. This can scarcely be the Howard flat vein, but may possibly be what is known as the No. 3 flat vein in the Mary McKinney mine. The Peggy vein consists of a little veinlet of fluorite, usually only an inch or two wide, accompanied by minor parallel fissures. The ore occurs as calaverite or sylvanite, chiefly in the fluorite of the main veinlet, but also to some extent in the accompanying fractures. The best ore is said to occur near the intersection of the Peggy vein with the nearly north-south fissure passing through the shaft. The ore is said to carry from 4 to 10 ounces of gold per ton. Stoping had barely begun at the time of visit, and the present level 2 had not been opened. Lessees working through the Peggy shaft have opened a good body of ore on the south end of the Colorado Boss No. 3 claim, just north of the Peggy ground. This ore occurs as calaverite in a number of small irregular fissures of various dips, but striking generally N. 25° E. These fissures are in the hanging wall of the flat Peggy vein, which becomes very indistinct in their vicinity.

KATINKA MINE.

The Katinka Gold Mining Company, capitalized at $1,250,000, owns the Katinka, August Flower, Chicken Hawk, and Hobo claims on Guyot Hill, immediately south of the Mary McKinney mine. The mine is operated by lessees. The underground workings comprise a crooked incline about 600 feet in depth, with seven short and unsystematic levels. There is also a vertical shaft, which, however, is not connected with most of the levels and is not used.

The Katinka lode is a somewhat irregular southerly continuation of the Mary McKinney lode. The country rock is chiefly breccia, which lies between the intrusive phonolite mass of the Mary McKinney mine and the granite of the southwest side of Guyot Hill. The breccia contains many granitic fragments and is cut by several phonolite dikes. The only important ore body of the Katinka occurs near the Mary McKinney line from 400 to 500 feet below the surface. It is the south end of an ore shoot stoped in the Mary McKinney mine above level 3. The production of the Katinka mine is not known, but can not have been large.

ELKTON MINE.

INTRODUCTION.

The Elkton property is owned by the Elkton Consolidated Mining and Milling Company, of Colorado Springs, capitalized at $3,000,000. When visited by Penrose in 1894 it was a small mine, 200 feet in depth, with workings confined to the Elkton and Kentucky Bill claims. In 1898 the company bought the Appie Ellen mine and in 1899 the Thompson. In 1900 the Raven mine, one of the first locations in the district, and the Tornado mine were consolidated with the Elkton. The Gregory mine was subsequently acquired and the Elkton property now stretches northward from the village of Elkton, between Arequa and Eclipse gulches, past the summit of Raven Hill. In this irregular north-south strip, over 4,000 feet in length, are embraced the Thompson, Raven, Walter, Snide, Katherine, Gregory, Princess E., and a number of other claims. The main shaft, situated in Elkton, is well equipped with a steel gallows frame, first-motion flat-rope hoist, and 40-drill compressor. While the Thompson, Tornado, and Gregory are really separate mines, they are so closely connected with the Elkton proper that, in this report, all may be conveniently included under the name Elkton mine.

PRODUCTION AND DIVIDENDS.

The production and dividends of the Elkton mine, so far as they are obtainable, are given in the following table. The figures, however, do not include the output of the Raven and Gregory mines prior to their consolidation with the Elkton. No separate account was kept by the company of the small amount of silver in the ore.

Production and dividends of the Elkton mine.

Year.	Gross value.	Gold.	Dividends.	Year.	Gross value.	Gold.	Dividends.
		Ounces.				*Ounces.*	
1893	$18,759.76	937.98	.....	1899	$617,308.29	30,865.41	$63,750.00
1894	113,602.50	5,680.12	$41,546.57	1900	1,029,260.59	51,463.02	258,758.00
1895	79,019.65	4,850.98	.....	1901	1,044,017.88	52,200.89	325,000.00
1896	463,732.02	23,186.60	100,000.00	1902	493,248.28	24,662.41	100,000.00
1897	555,164.78	27,758.23	270,000.00	1903	533,409.14	26,670.45	.....
1898	552,982.15	27,649.10	220,000.00				

UNDERGROUND DEVELOPMENT.

There are four important shafts on the Elkton property, three of which, the Thompson, Elkton, and Tornado, lie on a nearly due north-south line, while the Gregory lies a little east of that line. (See Pl. III, in pocket.) The principal drifts run north and south, following the Walter lode, but there are also important north-northwest drifts on the Raven lode and some very irregular workings in granite near the Thompson shaft. (See fig. 34.)

The main Elkton shaft is 800 feet deep and connects with eight levels about 100 feet apart (fig. 35). The Thompson shaft, 700 feet south of the Elkton, connects with Elkton levels 4 and 5, the latter being the bottom of the shaft. The Tornado

shaft, 1,300 feet north of the Elkton and 390 feet higher, is about 875 feet deep, the ninth or bottom level being the Elkton level 5. The Gregory shaft, 850 feet north-northeast of the Tornado and 163 feet higher, is 680 feet in depth, its bottom level being the Anaconda-Raven tunnel. This tunnel runs from Anaconda under Raven Hill, in a direction S. 57.5° E. to the Gregory shaft. It then continues eastward until it cuts the Raven dike, about 200 feet from the Gregory shaft, and follows this dike for about 900 feet to the south-southwest, connecting near the Tornado shaft with the main Elkton and Tornado workings.

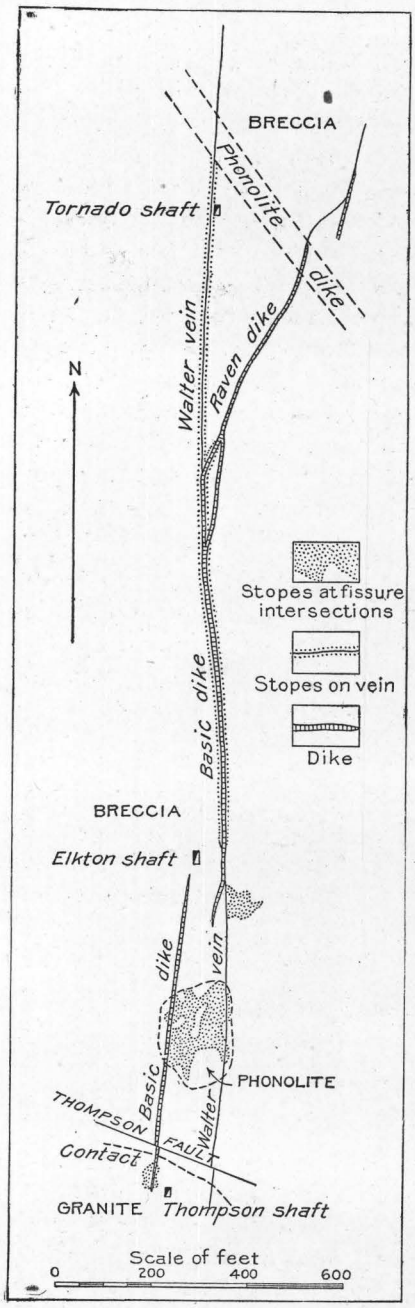
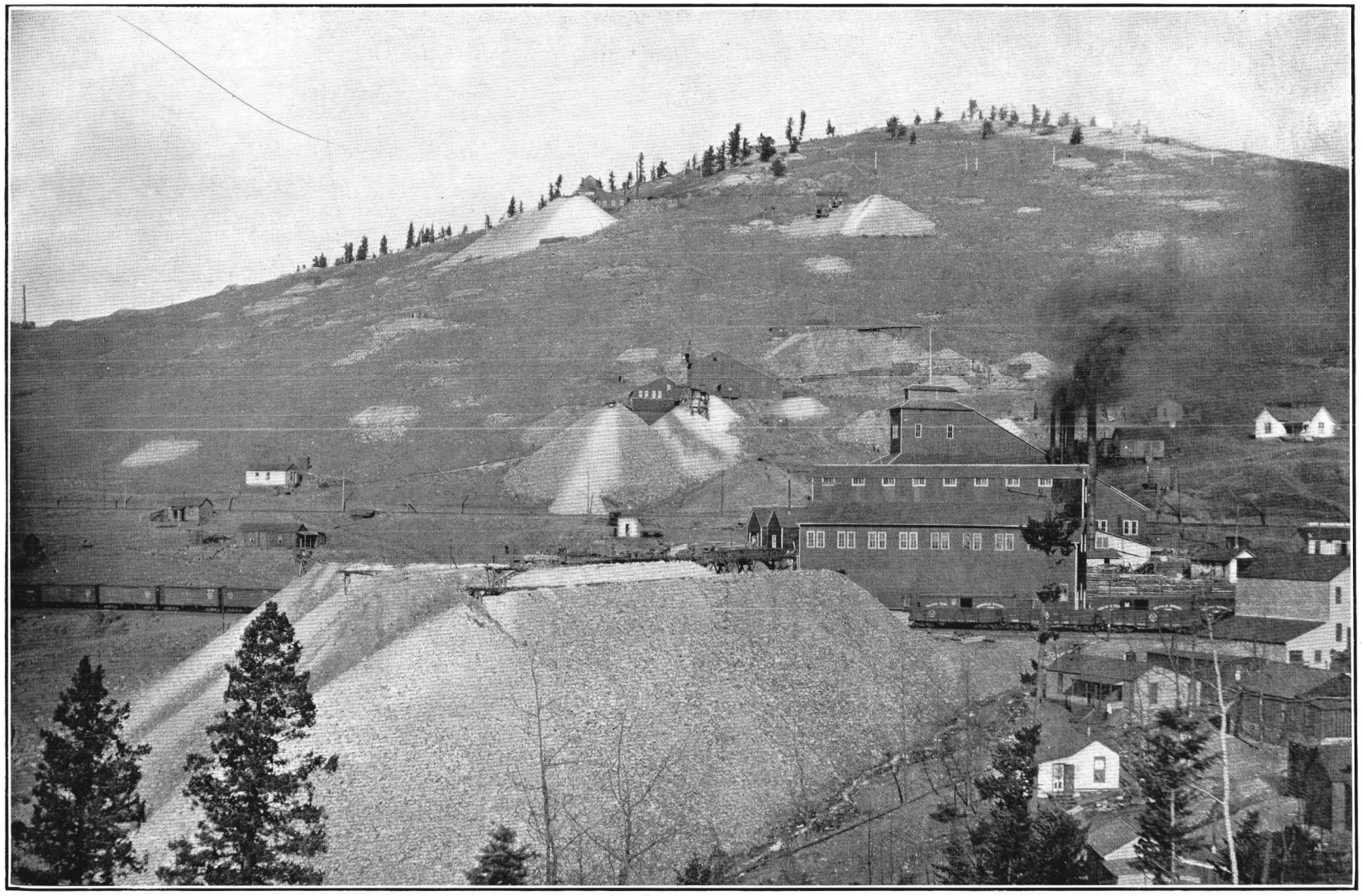


FIG. 34.—Plan showing principal dikes and fissures on level 7 of the Elkton mine.

LODE SYSTEMS.

The principal lode in the Elkton property is the remarkably regular Walter vein, one of the straightest and most persistent zones of fissuring in the district (fig. 34). Its general strike is N. 1° E. Near the Elkton shaft the Walter lode dips east at angles ranging from a minimum of 75° between levels 4 and 5 to a practically vertical attitude between levels 7 and 8. The average dip is about 84°. The dip gradually steepens northward until at a point about 600 feet north of the Elkton shaft the lode is vertical and continues so to the Tornado shaft. North of the Tornado shaft and south of the Elkton shaft the Walter lode becomes less regular and is followed with increasing difficulty. On the south a series of fissures, ranging in strike from north to northeast, which are probably collectively representative of the Walter lode, continue into the granite and have influenced the deposition of the Thompson ore. On the north the Walter lode finally loses its identity in the ordinary minor fissuring of the country rock.

Another important lode is the Raven, striking N. 20° E. and following the Raven basalt dike. The Raven lode and dike join the Walter lode between the Elkton and Thompson shafts, the dike being generally coincident with the Walter fissure zone south of the junction. On the whole the Raven dike is about vertical, but it is irregular, and, like most dikes of its kind in the district, often pinches and is replaced by another dike a few feet to one side. It is a narrow



ELKTON MINE AND SOUTH SLOPE OF RAVEN HILL.

Main Elkton shaft in foreground; Tornado shaft on sky line.

zone of dikes rather than a single continuous dike. The junction of the dike with the Walter lode occurs at distances varying from 350 to 850 feet north of the Elkton shaft. In general the junction is farther north on the lower than on the upper levels. The general relation of the Walter and Raven lodes may be seen in fig. 34.

South of the Elkton shaft the Walter lode and the accompanying Raven or Elkton dike become irregular and are less readily followed. The narrow fissure zone known to the north as the Walter vein here widens to a zone of intersecting and individually nonpersistent fissures at least 150 feet in width, as may be well seen on level 7 (fig. 34). Attempts have been made to identify one or more of these fissures with the Walter vein, but with little success. It seems more reason-

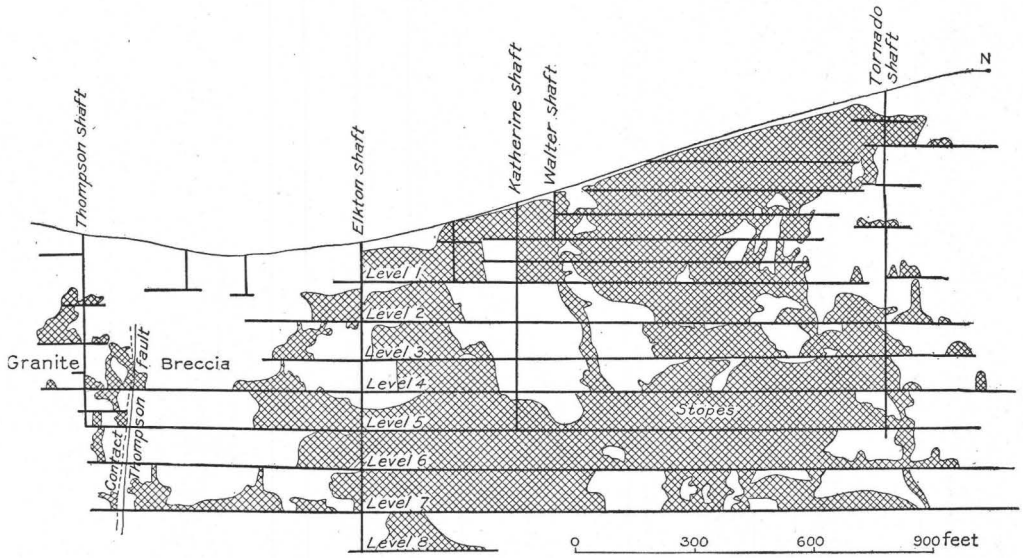


FIG. 35.—Generalized longitudinal section of the Elkton mine.

able to conclude that, owing to certain geological relations presently to be described, the same forces which farther north produced the well-defined and regular Walter sheeted zone here produced a much wider zone of less regular fissuring, no single fissure of which can be selected as being alone the equivalent of the Walter lode.

A third interesting fissure is the so-called Dead vein, an unproductive fault lying just north of the Thompson shaft. The Dead vein, or Thompson fault, as it may more appropriately be called, strikes N. 72° W. and dips 83° S. On level 4 it passes about 100 feet north-northeast of the Thompson shaft, and has been followed for 80 feet in a drift. It is well exposed also on levels 5, 6, and 7 and shown to be a regular and persistent fault which is later than the Walter lode, slightly offsetting the basalt dike and the north-south fissure zone on all levels. It will be further described in the following section:

GEOLOGICAL FEATURES.

The prevailing country rock of the Elkton mine is breccia of the same general character as that exposed over the western half of Raven Hill. The Thompson shaft, however, and the workings immediately adjacent to it are in granite of the

coarsely porphyritic Pikes Peak type, such as forms Squaw Mountain. North of the Thompson the granite-breccia contact runs nearly east-west, while east of the shaft it runs nearly north-south. The Thompson shaft is thus situated within a local granite promontory which juts northeastward into the breccia. The contact is very irregular in detail, but it is clear from its position on successive levels that the promontory in general steeply overhangs the breccia. The granite, as a rule, shows considerable shattering near the contact, which, however, is usually fairly sharp. Fragments of granite are also abundant in the breccia, in many places for distances of more than 300 feet from the contact.

The Thompson fault, already referred to, is chiefly in the breccia, though nowhere, so far as the present workings show, very far from the granite, except where the latter turns southward, east of the Thompson shaft. It is in some places a simple fissure containing a foot or more of soft slickensided gouge, in others two or more narrower parallel fissures filled with similar material. The Thompson fault slightly offsets the basalt dike and the north-south fissures of the Walter zone. The net displacement is probably not over 100 feet, though no actual measurement of the movement could be made with the exposures available at the time of visit. The throw is apparently normal. At a few points, as on level 4, the Thompson fault locally marks the contact between the granite and the breccia. The fault is merely a more conspicuous example of such local faulting near the contact as was noted in the Portland mine (p. 435), the fault fissures approaching much more nearly to a plane surface than does the adjacent granite-breccia contact.

The breccia occasionally exhibits a banded structure similar to that observed in the Portland mine. Such structure may be seen on level 7, about 450 feet north of the Elkton shaft. The banding is here about vertical and is produced by very distinct and sharp alternations in the relative coarseness of the breccia particles. Similar lamination of the breccia occurs on level 6, about 200 feet south of the shaft, the structure in this case dipping north at an angle of 40°. As in the Portland, this banding seems to be a local feature and passes by indefinite gradations into the ordinary breccia.

Among the recognizable fragments composing the breccia, phonolite undoubtedly predominates, both in the Elkton mine and in the Anaconda-Raven tunnel, which furnishes a section through Raven Hill. Fragments up to 6 inches in diameter are common, while much larger masses are occasionally found. The alteration of the breccia near the ore bodies consists chiefly of the metasomatic development of valencianite, quartz, fluorite, and a little sericite, pyrite in sharp minute pyritohedrons, and apatite in small greenish-white prisms. Carbonates, particularly dolomite, which are common in the altered breccia of other mines, are not abundant in the Elkton, and in many places seem to be entirely absent.

The volcanic breccia of the Elkton workings is cut by several irregular intrusive masses of phonolite. One of these is the dike of "purplish phonolite" which was noted by Cross[a] in the upper Raven tunnel and which is exposed on the surface passing just above the mouth of the tunnel and the Tornado shaft. The same

[a] Geology and mining industries of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey pt. 2, 1895, p. 89.

dike is seen in the Anaconda-Raven tunnel, just east of the Tornado shaft. It is here at least 100 feet in width. It is probably cut also in the north end of the Elkton level 5, north of the Tornado shaft, but this point could not be reached from the Elkton shaft at the time of visit. On level 7 this dike is probably cut in the main Walter drift north of the Tornado shaft and in the Raven drift, but as no particular search for it was made at these points at the time of visit, it was not noted. A west crosscut, however, 150 feet north of the Tornado shaft, enters a mass of phonolite about 100 feet west of the main drift, which is probably this same dike. It will be noted that this dike practically marks the northern limit of the Walter pay shoot. As the Walter lode enters the dike from the south the fissures become more regular and contain no ore.

A smaller dike of phonolite with a general northwesterly strike is cut by the Walter lode about halfway between the Elkton and Tornado shafts, and consequently near the point where the Walter lode and Raven dike diverge. This dike was observed on levels 5 and 6 and seems to dip to the northeast.

Another important body of phonolite is exposed on level 7, about halfway between the Elkton and Thompson shafts. The exact outlines of this body can not be determined from existing workings, but it apparently has the general form of a small sill or laccolith about 200 feet in average diameter and probably not more than 20 to 30 feet in thickness. This mass is considerably fissured and shattered, and its contact with the inclosing breccia is seldom well defined. Between this body of phonolite and the Elkton shaft occur a number of small masses of phonolite, but it could not be determined whether they represent somewhat shattered intrusions or are merely isolated fragments in the breccia. A number of phonolite dikes are cut in the Anaconda-Raven tunnel in its course through Raven Hill. They are of the usual type, and no special study was made of them.

Granite, breccia, and phonolite are all cut by the Raven or Elkton basic dike, which ranges from a fraction of an inch up to 6 feet in width. The average width is probably about 3 feet. The Raven dike is exposed at a number of points near the surface of Raven Hill, in the upper and lower Raven tunnels, in the Anaconda-Raven tunnel, and in the main Elkton workings. One of the most interesting features of the dike is its sharp change in course from S. 20° W. to south, where it joins the Walter lode. The dike is irregular at the turn, splitting and inclosing horses of breccia. Another notable characteristic is the manner in which the dike, after being followed for perhaps several hundred feet, gradually becomes narrower and finally disappears, though one or more fissures usually continue on beyond the point of disappearance of the basalt. Crosscuts into the walls at the point of disappearance usually result in the recovery of the dike, or, rather, of another dike belonging to the Raven dike zone. This behavior is well shown in the Anaconda-Raven tunnel, particularly where the dike, as it is followed southward, cuts the Tornado phonolite dike. After penetrating the phonolite for a few feet the dike pinches out. About 40 feet to the west another dike is cut, which also pinches out in the phonolite about 100 feet south of the point where the first dike disappeared. About 30 feet west of this dike is a third, which continues southward as the main Raven dike. A similar behavior may be noted on level 7 of the Elkton, between the Elkton and Thompson shafts. The Raven dike, at a point about 75 feet south

of the Elkton shaft, turns rather sharply to the south-southwest and soon pinches out. Fifty feet farther west another basalt dike is cut, which continues southward through the western edge of the phonolite laccolith and into the granite near the Thompson shaft. Many other examples might be cited illustrative of this tendency of the Raven-Elkton dike, but it is a feature so characteristic of the basaltic dikes of the district as to render unnecessary detailed reference to each case.

Although portions of the dike are hard and fairly fresh, it is usually rather soft and decomposed and breaks up upon exposure to the air. As a rule it is traversed by numerous fine cracks, generally parallel with the plane of the dike and particularly abundant near the walls. As in the Portland, some of these cracks are filled with veinlets of calcite. In general, however, this platy structure of the dike is much less conspicuous than the sheeting of the adjacent breccia. It has less the appearance of sheeting produced by external stresses than of originally incipient cracks due to the cooling of the basaltic magma and rendered visible by later alteration. This contrast, as well as the way in which the Raven dike turns and follows the Walter sheeting zone, strongly suggests that the main sheeting of the breccia, granite, and phonolite occurred before the intrusion of the basalt, though, as will presently be shown, the mineralization is certainly mainly post-basaltic. This was clearly the conclusion reached by Penrose,[a] who writes:

> In fact the dike seems to have been originally intruded into a much-fissured zone and to have come up along slightly different lines even in local areas. In several places, also, it forks and follows two diverging fissures, though one branch usually comes quickly to an end. The zone of fissuring occupied by the dike and that occupied by the [Raven] vein represent different lines of fracture and cross each other at low angles; but both fissures were formed before the intrusion of the dike, as is shown by the fact that at the crossing of the fissures near the Raven shaft the dike throws out a fork for a few feet from the main dike along the vein fissure, thus clearly proving its later age.

The so-called Catherine dike, noted by Penrose[b] on level 1 of the Elkton and supposed by him to be older than the Raven dike, could not be found on the levels now accessible and was probably merely a local offshoot from the Raven dike along the sheeted zone of the Walter lode.

FORM AND STRUCTURE OF THE ORE BODIES.

The important Elkton ore bodies fall into three general classes—first, distinct lodes, following either the "basalt" dike or well-defined sheeted zones; second, irregular bodies in granite largely due to metasomatic replacement; and, third, the peculiar "flat" ore bodies on level 7 between the Elkton and Thompson shafts.

The main Walter pay shoot has a maximum length of about 1,700 feet and with the exception of a few low-grade portions has been stoped continuously from the Elkton to the Tornado shaft and from level 7 to the surface. North of the Tornado shaft relatively little ore has been found, the north end of the main Walter pay shoot practically coinciding with the southwest contact of the Tornado phonolite dike. From the collar of the Elkton shaft the southern limit of the Walter ore body pitches south to a point on level 4 about 350 feet south of the shaft. It thence pitches north until, on level 7, the south end of the Walter pay shoot proper is again at the Elkton shaft. There are, however, below level 6 isolated pay shoots

[a] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 181-182.

[b] Op. cit., p. 185.

between the Elkton and Thompson shafts on various members of the broad fissure zone, which here seems to represent the Walter lode.

The best ore of the Walter lode occurs along the portion of the fissure zone that is accompanied by the Raven dike. North of the point where the dike, turning off to the northeast, is known as the Raven vein the Walter pay shoot usually contains ore of somewhat lower grade than between this branching point and the Elkton shaft. The richest of the Walter stopes thus far worked are said to have been between levels 5 and 6. The width of the stopes ranges from 3 to 15 feet, the widest stope seen on the Walter lode being on level 5, where the lode crosses the small phonolite dike about halfway between the Elkton and Tornado shafts. Where the dike is present the ore usually occurs in the small parallel fissures in the basalt, which are practically abundant near the walls. It is not restricted to these, however, some of the small irregular fissures in the middle portion of the dike being sufficiently mineralized to allow of the whole of the dike being stoped as ore. The portions of the dike containing ore are usually abundantly impregnated with small crystals of pyrite, this pyritic mineralization being so characteristic that it is used as an indication of good ore. In many instances, however, the calaverite or sylvanite occur with quartz, fluorite, and dolomite in minute veinlets in the basalt, the rock between the veinlets exhibiting very little pyritic mineralization. One of this character was seen in a stope above level 6, near the point where the basalt and the Walter lode separate. The ore is not always confined to the basalt, but sometimes extends for 6 or 7 feet into the breccia on either side, as was seen in a stope between levels 7 and 8, south of the Elkton shaft. Here the breccia on the east side of the dike shows abundant fine pyrite disseminated through it. It has been locally shattered, the interstices between the fragments now constituting little vuggy cavities lined with small crystals of adularia, quartz, fluorite, pyrite, and probably sylvanite or calaverite, though the tellurides are not as a rule distinctly visible. There are no definite walls to this ore. It passes gradually into the country breccia. On level 7, 350 feet south of the Elkton shaft, the east wall of the basalt dike, here a part of the phonolite laccolith already described, is also locally brecciated and mineralized with pyrite. In this case, however, the pyrite is accompanied by visible crystals of sylvanite in the drusy cavities of the rock.

North of the junction with the basalt dike the Walter lode is a sheeted zone in breccia. The average stoping width is about 4 feet, though the zone of distinct sheeting is in many places only about a foot wide. The ore, however, is not confined to the regular fissures of the nearly vertical sheeted zone, but extends for varying distances into the less regular fractures of the breccia on each side. In other words, the lode has no walls. The unoxidized ore occurs exclusively in the small vuggy veinlets in and near the sheeted zone as crystals of calaverite or sylvanite associated with quartz, fluorite, and in some cases calcite or dolomite. More or less pyrite always accompanies tne tellurides.

Bodies of ore were formerly stoped in the Raven tunnels along the "basalt" dike, but nothing could be seen of these ore bodies in 1903, and the Raven dike has not proved productive in the Elkton workings proper, except where it coin-

cides with the Walter lode. According to Penrose[a] the Raven vein is a sheeted zone which crosses the dike at a very small angle. The ore is described as occurring in the sheeted zone and also in the dike where the two coincide.

The granitic ore of the Thompson mine occurs in very irregular masses, generally similar to those described in the Ajax and Portland mines. These ore bodies are related to fissures and occur mainly on the east side of the basic dike, particularly where two or more fissures intersect (fig. 36). The dike is small and irregular in the Thompson ground and is not uniformly present, being at some points represented by a mere crack in the granite. The main fissures run approximately north and south, and probably correspond to the sheeted zone known farther north as the Walter lode. There are also a number of fissures on the east side of the basalt dike, which strike about N. 35° W., and a few fissures of northeasterly strike. The ore is not confined, as in the breccia, to the actual fissures, but extends out very irregularly into the granite, which is locally altered to a porous mass, containing much secondary feldspar and quartz, together with fluorite and pyrite. This metasomatically altered porous granite constitutes the ore, which probably owes its value to the occurrence of minute crystals of sylvanite or calaverite in the small drusy cavities with which the rock is honeycombed. The tellurides, however, are rarely visible.

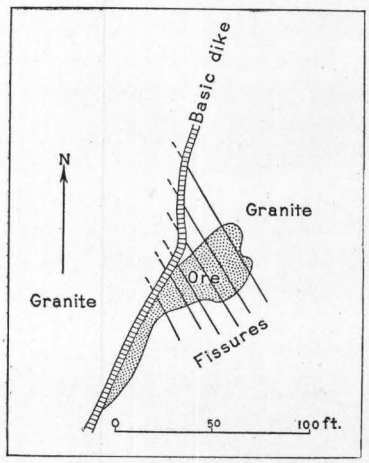


FIG. 36.—Plan of ore body in granite, Elkton mine, level 4, showing relation of ore to dike and fissures.

Between the Elkton and Thompson shafts, on level 7, are two so-called flat ore bodies of somewhat unusual type. The larger of these, which is almost midway between the two shafts, while irregular in detail, is of generally oval plan and corresponds very nearly to the plan of the small phonolite laccolith in which the ore occurs. Near its western edge this phonolite is cut by the Elkton (Raven) basic dike. Near its eastern edge it is cut by a zone of fissuring commonly supposed to be the Walter lode. The ore occurs chiefly between these two north-south lines, which are about 120 feet apart. As the north-south fissures, which collectively represent the narrower sheeted zone of the Walter lode as known farther north, enter the northern edge of the phonolite mass they become very irregular, split up, and in part pass into nearly horizontal fissures. One set of such nearly horizontal fissures lying a few feet above level 7 constitutes a fairly definite sheeted zone within the phonolite, and is called the "flat vein." The bulk of the ore occurs along this nearly horizontal sheeted zone, but is very irregular in thickness and frequently extends for varying distances above or below it along nearly vertical fissures. The ore in the "flat vein" proper, however, apparently averages about 6 feet in thickness and is of relatively low grade. The most interesting peculiarity of this ore body is the fact that the ore is practically confined to the much-fissured mass of phonolite, nowhere extending for more than a few feet into the surrounding breccia except along the Elkton dike to the south and along the main eastern

[a] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 181-183.

sheeted zone to the north. The ore minerals (probably sylvanite and calaverite, though these are not usually visible) occur in minute veinlets and in little vugs, containing quartz, fluorite, roscoelite, and pyrite, at the intersections of minute irregular fractures in the phonolite, which is itself impregnated with pyrite.

The second "flat" ore body lies about 100 feet southeast of the Elkton shaft and is smaller than the one just described, extending eastward from the Walter lode for a distance of about 50 feet. It is a local expansion of the ore from the main lode along a set of probably not very persistent fissures which dip into the latter from the east at a low angle. The ore was associated with large open cavities lined with crystals of fluorite and quartz and containing loose masses of phonolite and breccia coated and in places partly cemented together by the same minerals. When first opened these cavities were found to be full of water, which is said to have flowed out in such volume as to flood the level in about an hour. It is not clear whether there was originally a small intrusive mass of phonolite at this point, but a portion of the country rock is certainly breccia. There appears to have been considerable local shattering, with probably a removal of some of the finer shattered material in solution by the abundant water which deposited the quartz and fluorite in the cavities so formed. As all of the ore had been removed at the time of visit, the details of its occurrence could not be studied.

CHARACTER OF ORE.

The ores of the Elkton mine occur in granite, monchiquite ("basalt"), breccia, and phonolite, and consequently exhibit considerable variety. The granitic ore is of the same general character as that described in the Ajax and Portland mines, but exhibits, if anything, more intense alteration. Much of this ore is exceedingly porous, even the original microcline phenocrysts being reduced to spongy skeletons. A part of the rock has certainly been removed in solution, while the remainder has in some places entirely recrystallized as a carious aggregate of adularia, quartz, fluorite, pyrite, and some calaverite, though the last is rarely visible.

Under the microscope it is seen that the clear secondary feldspar is in many cases optically continuous with residual kernels of the older turbid microcline. Fluorite occurs partly in solid aggregates, but very largely as minute crystals disseminated through the partly sericitized microcline. Pyrite in aggregates or in small octahedral crystals occurs abundantly in both the original and secondary feldspars, showing a noticeable tendency in the older feldspar to develop in the vicinity of microscopic fissures. The exceedingly irregular pores or vugs of this ore are lined sometimes with quartz, sometimes with adularia, sometimes with fluorite, but more commonly with all three minerals, together with pyrite. Some of the pyrite as seen under the microscope is intimately associated with small quantities of an obscure opaque material, gray in incident light, which is probably molybdenite.

Fluorite varies greatly in abundance in different parts of the ore bodies and is in some places absent. The average tenor of the granitic ore is about an ounce in gold to the ton.

The ore in "basalt" presents at least two aspects. In the northern part of the mine the mineralized "basalt" is a compact gray rock, containing abundant microscopic crystals of pyrite thickly disseminated through it. The gold occurs in the form of calaverite in little veinlets of quartz which are usually a fraction of an inch in width and occur most abundantly near the walls of the dike. Some of these veinlets contain druses of fluorite, dolomite, and celestite, as well as quartz. In the southern part of the mine the altered "basalt" is light gray and has a porous texture, and the crystals of pyrite are larger. The rock contains numerous little cavities of dissolution lined with adularia and pyrite. The gold probably occurs with the pyrite as calaverite, but this mineral is rarely visible.

Under the microscope this porous gray ore is seen to be an aggregate of adularia, sericite, apatite, and pyrite, with probably some calaverite. The sericite occurs in exceedingly minute form and its identification is not entirely satisfactory. The apatite, which is remarkably abundant, is in slender greenish-white prisms distinct in habit and appearance from the stout prisms of smoky apatite that occur in the latite-phonolite. The pyrite is chiefly in small pyritohedrons, which are sometimes clustered into aggregates.

The ore found in the volcanic breccia also exhibits two varieties similar to those shown by the basaltic ore. In the northern part of the mine, in the Walter vein, the ore occurs as calaverite in the usual little quartz-fluorite veinlets of a sheeted zone in pyritized breccia. The calaverite is usually most abundant in the open vuggy portions of the veinlets and often associated with little hollow quartz pseudomorphs after celestite. In the southern part of the mine most of the ore in the breccia is found near the basalt dike. Much of this ore has an open cavernous structure, apparently due to the removal by solution of some of the finer interstitial material of the breccia. The remaining fragments are coated and cemented together by drusy incrustations of quartz and pyrite, with locally a little fluorite. Associated with these minerals, sometimes in crystals of visible size, occur calaverite, sylvanite, and molybdenite. The breccia fragments themselves are more or less porous and contain irregular cavities of dissolution lined with quartz, pyrite, tellurides, and molybdenite. They also contain disseminated pyrite. In some places in the southern part of the mine, particularly in the first "flat stope" south of the shaft on level 7, fluorite is very abundant not only incrusting the fragments of the breccia, but often cementing it into a solid mass. Some of the fragments of breccia inclosed in the granular fluorite are rounded and embayed and appear to have been partially replaced by the fluorite. It is probable, however, that their angles received a preliminary rounding by solution before the deposition of the flourspar. The microscope shows that between the fluorite and the phonolite fragments of the breccia there is usually an intervening zone of quartz and adularia. These two minerals have formed by metasomatic replacement of the breccia.

Another variety of breccia ore occurring in the same flat stope consists of a dark-gray spongy mass, looking much like a frothy slag, which fills the interstices between masses of shattered breccia. The microscope shows that this porous crystalline material consists chiefly of adularia, pyrite, and an obscure opaque mineral, bluish gray in incident light, which is intimately associated with the

pyrite and is probably molybdenite. Within the thicker portions of some of the irregular septa of the sponge-like mass of residual particles of phonolitic breccia not transformed to adularia. Probably some calaverite or sylvanite is present, but it is not microscopically distinguishable from the pyrite. Quartz seems to be entirely absent, except in the form of little hollow pseudomorphs after celestite in some of the open pores of vugs. This material is a local metasomatic alteration of the breccia along zones of fissuring and shattering, the spongy mass passing gradually into breccia in which fragments of phonolite are still recognizable.

The occurrence of phonolite ore is best illustrated in the flat stopes on level 7. This ore is a light-gray rock abundantly speckled with minute crystals of pyrite and flecked with purple fluorite. It is characterized by a rather porous texture, due mainly to the existence of small very irregular spaces of dissolution. The origin of these cavities is not always clear. In many instances, however, they are enlargements of minute fissures and particularly of several fissures at points of intersection. In other cases they are probably due to the removal of amphibole or pyroxene phenocrysts and the subsequent irregular enlargement of the cavity. Occasionally these spaces are entirely filled with fluorite. More often, however, they are only partly filled with projecting crystals of fluorite, quartz, pyrite, and probably calaverite, though the last-named mineral can scarcely ever be distinguished by the eye from the bright crystals of pyrite abundant in these little vugs.

Under the microscope, although small crystals of pyrite are abundantly disseminated through the rock, and though the original pyroxene or amphibole phenocrysts have been replaced by fluorite and pyrite, the feldspathic portion of the phonolite shows remarkably little alteration.

Very little oxidized ore is now seen in the Elkton mine. In the Thompson workings the granitic ore is more or less oxidized to a depth of about 300 feet. No particular difference in value has been noticed between the oxidized and unoxidized ore. Generally throughout the mine there is very little oxidation below the 300-foot level.

UNDERGROUND WATER.

The occurrence and behavior of the underground water of the Elkton mine have been fully described in the section devoted to the underground water of the district. (See p. 242.) It has been one of the wet mines and the history of its water is closely connected with that of the Standard and El Paso tunnels.

MOOSE MINE.

INTRODUCTION.

The Moose mine is situated on the southeast slope of Raven Hill, about half a mile northeast of Elkton. The mine is owned by the Moose Gold Mining Company, incorporated in 1893, with a capital of $1,200,000. The company owns the Moose claim and leases portions of adjoining claims, including the Bertha B. and Kentucky Belle. The Trilby mine, also owned by this company, is elsewhere described.

The Moose was one of the first mines in the district to become productive, and up to the end of 1896 made steady shipments of rich ore, the average value for considerable periods being nearly $140 per ton. In 1897, however, the ore shoot,

which did not extend for more than 400 feet below the surface, was exhausted and the mine was closed. It was subsequently reopened and in spite of serious difficulties due to water and copious flow of gas into the workings, exploration was continued with great persistency in an endeavor to find deeper ore bodies. Early in 1904, however, the search was abandoned and the mine is now idle.

PRODUCTION.

The Moose mine has produced about 5,100 tons of ore of a gross value of $525,000, or an average value of nearly $103 per ton. The dividends paid by the company amount to about $144,000.

UNDERGROUND DEVELOPMENT.

The Moose shaft, a steep incline with collar 10,117.96 feet above sea level, is 1,050 feet deep. It connects with 15 levels at various distances apart. The main drifts run nearly north and south and explore the Moose basalt dike for a maximum distance of about 2,000 feet. Level 6, 350 feet below the collar of the shaft, extends farthest south, being prolonged to the surface as an adit, of which the portal is 1,200 feet south of the Moose shaft. Level 15 (fig. 37) has the greatest northward extension, having been driven beneath the old workings of the Bertha B. mine. The country rock on each side of the dike has been explored by crosscutting and diamond drilling. There are two winzes below level 15, one of 60 feet about 450 feet north of the shaft and one of 20 feet in the Bertha B. ground.

GEOLOGICAL FEATURES.

The general country rock of the Moose mine is breccia of the usual Raven Hill type. This is cut by a dike of phonolite of general north-south trend and by the Moose "basalt" dike. The latter exhibits the usual tendency of these dikes to branch or to pinch out and reappear a few feet away in one wall or the other of the particular branch first followed out. The general strike of the basic dike is 10° 15° west of north, so that it crosses the phonolite dike. The actual crossing could not be seen, but the "basalt" is undoubtedly later in age than the phonolite. The general relation of the two dikes, as well as the frequent compound character of the basaltic dike, is shown in fig. 37, which is a geological plan of level 15. The phonolite dike is usually 10 or 12 feet wide, and is fairly regular and persistent. It is in some places aphanitic, in others porphyritic in texture, the latter being particularly the case in the southern part of level 6. The dike is practically vertical. The "basalt" dike is usually from 2 to 3 feet in width. Near the shaft it dips steeply to the east, but on the whole is nearly vertical. The most interesting feature of the breccia is the pronounced local fissuring and shattering that it has undergone, particularly on the lower levels north of the shaft. This is well shown on level 15, where, from a point 128 feet north of the shaft, the breccia for a distance of 650 feet north is a porous mass of partially coherent angular fragments, resembling the material described in the Conundrum, Moon-Anchor, and Midget mines. This shattering is said to extend for about 400 feet above level 15, but the levels in which it is exposed were so filled with gas at the time of visit as to be inaccessible. On level 13 this

shattered rock was described by Superintendent Bush as passing into breccia showing very conspicuous sheeting parallel with the walls of the basalt dike. Some of the fissures of this sheeted zone were so open as to admit a man's arm. A little sylvanite or calaverite was found on the faces of these slabs, associated with fluorite. The breccia was clearly indurated, shattered, and to some extent recemented before the intrusion of the "basalt," which shows only the usual platy parting or sheeting parallel with its walls. The eruptive contact of the "basalt" is well shown in winzes below level 15, and in one or two cases the interstices between the fragments of shattered breccia were observed near the dike to be filled with basaltic glass or pitchstone. Throughout the mine the rocks exhibit a dominant north-south vertical sheeting.

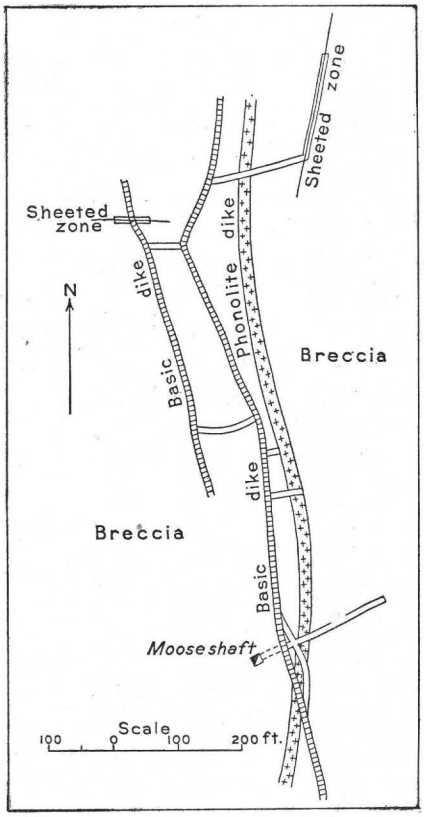


FIG. 37.—Plan of level 15 of the Moose mine, showing relation of phonolite and basic dikes.

LODE SYSTEMS.

The only lode of importance in the Moose mine is the basic dike, already described. In the northern part of level 15 a sheeted zone in breccia, striking about N. 20° E., has been followed toward the Kentucky Belle mine, but no ore has been found.

CHARACTER OF ORE.

The ore which made the Moose one of the best-known mines in the early history of the district occurred above level 6 and within 300 feet of the surface (fig. 38). It was for the most part oxidized, consisting of dull gold in minute irregular fractures in the basic dike. Calaverite was occasionally found, and was evidently the form in which the gold was deposited prior to oxidation. Specimens of this ore preserved in the office of the mine show more or less greenish emmonsite (?) and earthy tellurite associated with the gold. According to Mr. Philip Argall, some of the Moose ore contained as much as 25 ounces of silver per ton, the average being about 1 ounce of silver to 2 ounces of gold. It is not known in what form this metal occurred, but it was probably in tetrahedrite. The deeper levels of the mine have shown occasionally a little calaverite associated with fluorite in fissures in the basalt dike and in the neighboring breccia. In the winzes below level 15 little veinlets of tetrahedrite, galena, and sphalerite, associated with quartz, fluorite, and dolomite or calcite, were noted at the time of visit. These little veinlets occur in the "basalt" or at the contact between the "basalt" and the breccia, and are usually less than a quarter of an inch in width, the ore minerals occurring in their medial portions. Some of the cavities and small fissures in the shattered breccia near the dike are lined with a drusy aggregate of quartz, fluorite, dolomite, pyrite, and

molybdenite. Sylvanite or calaverite occurs sporadically in the dike to the bottom of the mine.

PAY SHOOTS AND LODE STRUCTURE.

The ore of the Moose mine all occurred in the basalt dike, principally in two pay shoots separated by about 100 feet of barren ground. One of these pay shoots was at the shaft, the other south of it. The northern body extended from the surface nearly to level 6, or to a depth of about 300 feet. It attained its maximum length of 160 feet on level 5. The southern pay shoot extended from level 2 to level 5, having a vertical range of about 175 feet. Its greatest length, 200 feet, was attained between levels 3 and 4 (fig. 38). There was also a small pay shoot north of the

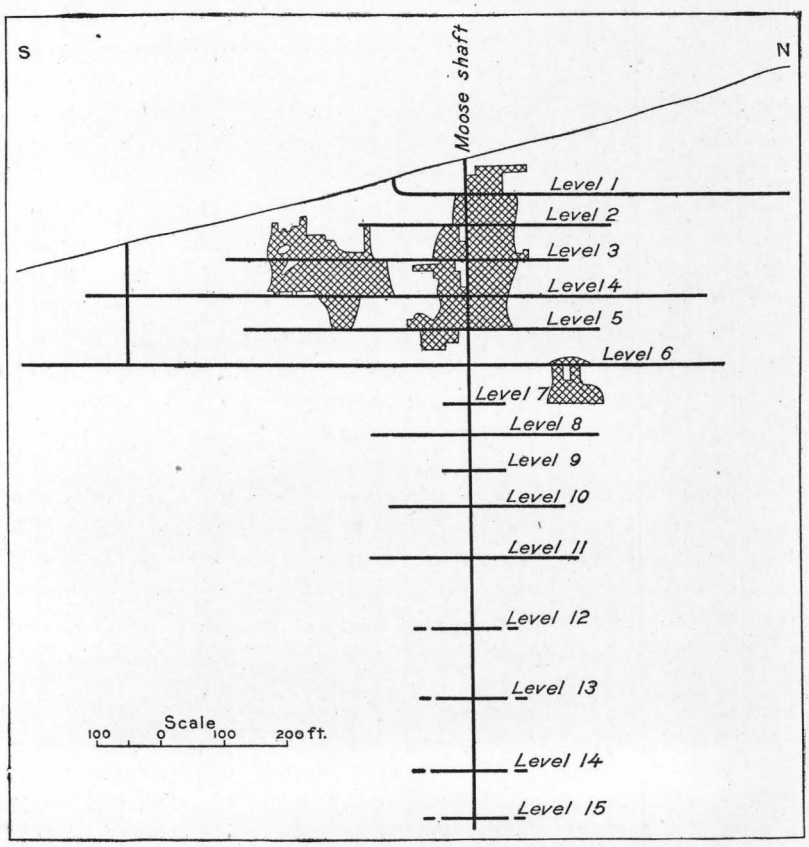


FIG. 38.—Longitudinal section of the Moose mine.

shaft, between levels 6 and 7. Below level 7, which is 380 feet below the collar of the shaft, no body of workable ore has been found. The old stopes are abandoned and not safely accessible, so that it is not practicable to study the occurrence of the ore. Specimens show, however, that much of it occurred in minute, very irregular fissures in the basalt. The latter was altered in the vicinity of the ore to a light-gray, aphanitic, almost jaspery mass, probably through the introduction of silica. So far as known, the localization of the ore in pay shoots was not determined by cross fissures.

UNDERGROUND WATER.

Early in 1896 water was encountered at a depth of about 650 feet, or 9,467 feet above sea. The water, however, has been drained away by the drainage tunnels and by deep mines at lower altitude, so that the Moose is now dry.

GAS.

A heavy gas is exceedingly troublesome in the Moose mine. Its behavior is described on page 260.

JOE DANDY MINE.

This privately owned mine is situated near the summit of Raven Hill, at an elevation of about 10,400 feet. The developments comprise two shafts, each with five levels and about 270 feet apart. The southern or main shaft is 580 feet deep, and the elevation of the collar is 10,370 feet. Drifts and crosscuts aggregate about 5,000 feet in length. The production is not known, but must have been fairly large. The mine was closed in 1903 and 1904.

A north-south phonolite dike about 12 feet wide runs just east of the shaft house, cutting through the volcanic breccia which forms the country rock. The ore occurs chiefly in this dike, which is sheeted and contains disseminated pyrite; tellurides occur in the fractures. The dike dips steeply to the east.

Level 1, which is 180 feet deep, shows a fissure zone which lies 80 feet west of the dike in breccia. This zone has been extensively stoped. Large irregular bodies of ore have also been stoped in the fissured breccia between this zone and the phonolite dike. The ore occurred in seams with fluorite in this mineralized rock.

These two veins—that is, the mineralized phonolite dike and the western fissure zone in breccia—come together about 140 feet below the first level, the western vein having the flatter dip to the east. They are also said to converge in strike so as to join near the road north of the Joe Dandy shaft. On the whole, the stoped areas form a shoot continuous at least to the 480-foot level, dipping about 70° S. on the plane of the vein and having a maximum horizontal length of 200 feet.

NEW HAVEN MINE.

Just east of the Joe Dandy mine on Raven Hill is the Eclipse No. 1 claim, which is owned by the New Haven Gold Mining Company. The production up to January 1, 1900, is given as $4,000, but a considerable amount of ore has been taken out since that time. The workings consist of an old incline shaft 135 feet deep and a vertical shaft 300 feet deep, 150 feet south-southwest of the incline. From these shafts about 1,500 feet of drifting and crosscutting has been done.

The workings are entirely in dense breccia, usually but little oxidized. A phonolite dike 50 feet west of the vertical shaft corresponds in position to the Joe Dandy dike. It appears to be faulted by a fissure striking N. 55° E. and dipping 50° NW. The direction and amount of displacement are not shown. This fissure is one of a system of parallel fissures or joints. Another system runs N. 10° E. and dips about 75° E. These two sets of fractures are well defined along a

zone 20 to 30 feet wide, 20 to 25 feet high, and about 200 feet long, parallel to the north-south fissure system. The vertical shaft is near the eastern side of this zone. Within this area the rock is cut into a series of more or less regular blocks, but at the margins of the zone the fissures become narrower and less distinct till at last they can not be traced at all. Neither system appears to fault the other. The levels from the vertical shaft below the first or 130-foot are not extensive nor important.

The workings from the incline shaft expose three definite groups of fissures corresponding to those which strike N. 55° E. and dip 50° NW. Each group consists of a series of approximately parallel fractures at small but varying distances apart, forming a vein from a few inches to 2 or 3 feet in width. The incline shaft is sunk on one of these. A second one occurs about 20 feet southeast of the shaft on level 1. It is about 12 feet from the other vein on level 2, showing that the two approach with depth, and on the third or bottom level the two are probably united to form one, for the second is not seen. The third vein is shown only on level 3, where it is 70 feet southeast of the vein on which the incline is sunk. It is drifted onto the southwest and connects by a 20-foot winze with the first or 130-foot level of the vertical shaft.

The vein on which the incline shaft is sunk carries no ore. The vein just to the southeast of it, however, is stoped from the surface down to the first or 38-foot level, 3 to 4 feet wide and 60 feet long. Although the vein is oxidized at the surface, tellurides soon appear with increasing depth, and from level 1 down oxidation is very slight. The values occur in the narrow seams which collectively make up the vein. The fissuring and consequent distribution of the values in this vein were sufficient to permit shipping of all the materials broken from the vein.

The shoot narrows in going down, the stope being 20 feet wide just below level 1 and 10 feet at the second or 72-foot level, below which the values were too low to make mining profitable. There is no indication of the presence of cross seams in this ore shoot.

On level 3 of the incline the third vein, 70 feet southeast of the shaft vein, carries an ore body which has been stoped 4 to 6 feet wide and 15 to 30 feet long 25 feet above and 35 feet below the level. The ore is similar to that in the vein above. No cross seams of importance were observed.

Level 1 of the vertical shaft explores the area affected by the two series of fissures already described. Here ore was encountered. It consisted mainly of tellurides contained in the main fissures and the many parallel small seams. The rock itself carried very little gold, and hence only the screenings were shipped, giving returns of 3 to 5 ounces. When one series of fissures got beyond the influence of the other system, the values suddenly decreased and soon gave out altogether. The shaft is about in the center of a stope which is 60 feet long, 10 feet wide, and extends above the level for 30 feet and below for 20 feet. A similar stope, 30 by 20 feet and 25 feet high, begins 50 feet south of the shaft. One hundered feet north of the shaft a chamber 20 by 20 by 20 feet has been made. The values did not warrant further stoping at these places, and development is in progress.

MARY ANN MINE.

This mine is located near the north end of the Mary Ann claim, near the Joe Dandy mine, northeast of the summit of Raven Hill. The property is owned by the Mary Ann Mining Company. The production could not be learned, but it is very small. The development consists of a shaft 275 feet deep and three levels representing 800 to 1,000 feet of drifting and crosscutting. Breccia is the only rock encountered in the mine.

The Mary Ann vein as seen on the first level just east of the shaft has a direction N. 5° E. and dips 75° to 80° E. It is 3 to 4 feet wide, and consists of a series of approximately parallel oxidized seams, some of which carry kaolin. Thirty feet south of the shaft it is cut by an oxidized flat vein striking N. 30° W. and dipping about 35° NE. It is a much-sheeted, considerably oxidized zone, 8 to 12 inches wide. Along the intersection of these two veins a stope 15 feet long and 5 feet wide has been carried up for 25 feet on $30 ore holding rusty gold. A drift along the flat vein is being pushed to the southeast with the intention of striking the crossing of a vein approximately parallel with the Mary Ann vein and farther to the east.

On level 2 the Mary Ann vein is not very well defined. Sixty feet north of the shaft it is crossed by a 3-inch vertical oxidized vein, but no ore was found. A drift 15 feet to the east along the cross vein reaches a series of partially oxidized seams forming a vein 2 feet wide, which runs N. 5° W. and dips 80° W. At this point a flat vein also crosses which corresponds in position and direction to the ore-carrying flat vein on the level above. At this triple intersection a stope 10 by 5 by 20 feet high has been worked.

About 60 feet west of the shaft on level 2 a vertical 2-inch seam striking N. 75° W. is cut by a flat vein 6 inches wide striking N. 65° E. and dipping 4° NW. Both these veins are simply sheared oxidized zones in the breccia. At their junction a few tons of 2-ounce ore were taken from a stope, mainly above the flat vein, 15 feet long, 5 feet wide, and 10 feet high.

MOHAWK BELLE MINE.

The Mohawk Belle claim is situated at the head of the northern branch of Eclipse Gulch, between Bull and Raven hills. The west end of the claim is being worked through a shaft 120 feet deep. Three or four hundred feet of drifting and crosscutting have been done from the bottom. An east-west vein dipping 70° N. is being drifted on and has furnished a small bunch of ore at the surface.

The east end of the claim was worked some years ago and the Lottie vein, which was discovered on the Lottie claim, to the south, produced about $100,000. The ore was very rich in rusty gold, some shipments being reported to have yielded from $3,000 to $13,000 per ton.

IDA MAY MINE.

The Ida May property, located on the summit of Raven Hill and consisting of the Ida May, Little Clara, and Mountain Girl claims, is owned by the Ida May Gold Mining Company. The production up to 1900 was over $40,000.[a] There are

[a] Hills, Fred, Official Manual of the Cripple Creek District, 1900.

three shafts on the property, the deepest attaining 375 feet, with 800 feet of drifting. Very little work has been done lately. The general country rock is breccia. The old shaft, visited by Penrose in 1894, is about 200 feet deep and the upper level only is accessible. A basalt dike 1 foot wide and about vertical runs through the shaft with a course N. 5° W. Sixty feet north of the shaft the dike branches, one branch curving around to the east until it has a course of about N. 75° E. South of the shaft the dike turns N. 35° W., and a phonolite dike appears alongside the basalt. This phonolite dike is very small near the shaft, but widens to about 2 feet at the south face of the drift, about 80 feet south of the shaft. It is intersected by the basalt dike. The ore occurred in the basalt, particularly where fissures come in from the walls.

Northeast of the old shaft, near the road, is a new shaft, 400 feet deep, sunk by lessees. The basalt dike is here about vertical and is reached by short cross-cuts from the shaft. The average width of the dike is about 2 feet. It constituted an ore body above and a short distance below level 1, the ore occurring in the dike itself, usually richest on the west side. The average value of the ore was about $15. Tellurides occur in fractures, accompanied in many places by an obscure greenish mineral, possibly roscoelite, said to be indicative of good ore.

CHAPTER IV.—MINES OF BEACON HILL.

GENERAL INTRODUCTION.

Beacon Hill, like Guyot Hill, is merely a prominent knob on the general southwest spur of Raven Hill. The principal geological feature of the hill is a vertical plug of phonolite, elliptical in plan, which is intrusive into the Pikes Peak granite and has been described on page 34. This phonolite forms approximately the upper 150 feet of the hill, the lower slopes being granite. There are a number of prospects in the phonolite, but the productive mines are all in the granite. They lie in two belts parallel to the longer or northeast-southwest axis of the elliptical plug. One of these belts is on the northwest side of the hill and includes the El Paso, C. K. & N., Old Gold, Henry Adney, and other mines and prospects. The other is on the southeast side of the hill and embraces the Prince Albert, Gold Dollar, Zoe, Mabel M., Agnes, and St. Thomas mines. The general relation of the veins to the phonolite plug is shown in fig. 40 (p. 351).

The Beacon Hill mines are noteworthy as lying at a greater distance from the main area of breccia than the other productive mines in the district. Their relation to the phonolite plug strongly suggests a genetic connection between this intrusion and the formation of the veins.

EL PASO MINE.

INTRODUCTION.

The El Paso mine is situated on the northwest slope of Beacon Hill and is owned by the El Paso Consolidated Gold Mining Company. The original El Paso company, organized in 1894, with a capital of $900,000, owned the Orizaba No. 1, Orizaba No. 2, Fannie B., Vulcan, and Bryan Fraction claims, covering about 25 acres. Later the company was reorganized under its present title, with a capital of $2,500,000, and the Columbia No. 1, Columbus, Australia, Old Hickory, and Little May claims acquired.

PRODUCTION.

The gross production of the El Paso mine up to the end of the year 1903 was $1,698,576. The production for 1904 (with December conservatively estimated by the company) was $1,337,735, making a total of $3,036,311. The dividends paid in the same period amount to $506,250, besides which the company has added considerably to its holdings and has equipped the mine in a very substantial manner.

UNDERGROUND DEVELOPMENT.

There are two important shafts on the El Paso property—the old El Paso shaft, near the east end of the Orizaba No. 1 claim, and the present main shaft, on the Columbia No. 1 claim, 600 feet north of the old shaft. The former is no longer

used. The new shaft is 560 feet deep and the old shaft a little deeper, as it is higher up the slope. There are four levels connecting with the main shaft, designated as levels 1, 2, 3, and 4 and run at 190, 310, 440, and 560 feet, respectively, below the collar. The general trend of these levels, as well as of the upper drifts from the old shaft, is N. 30° E. There are also some important drifts in the northern part of the mine, which run generally N. 75° E. Levels 2 and 4 connect with the old shaft, and also with two of the great drainage tunnels of the district, level 2 being continuous with the Standard tunnel and level 4 with the El Paso drainage tunnel.

GEOLOGICAL FEATURES.

The El Paso workings are in granite on the western side of the Beacon Hill phonolite plug. The granite is of the coarsely porphyritic Pikes Peak type, is usually

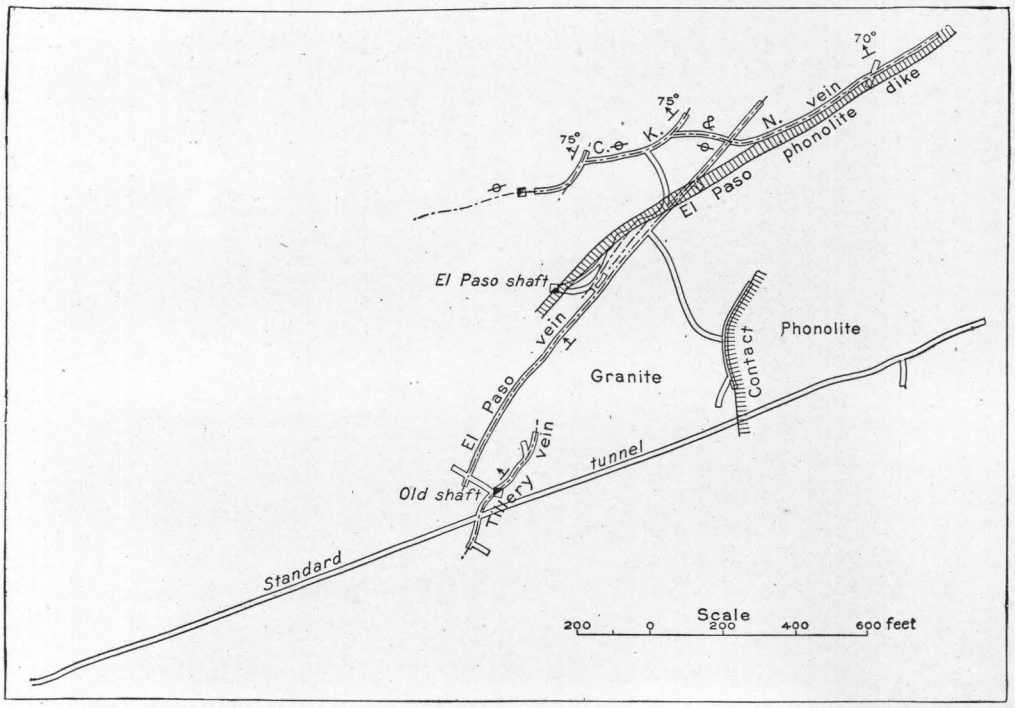
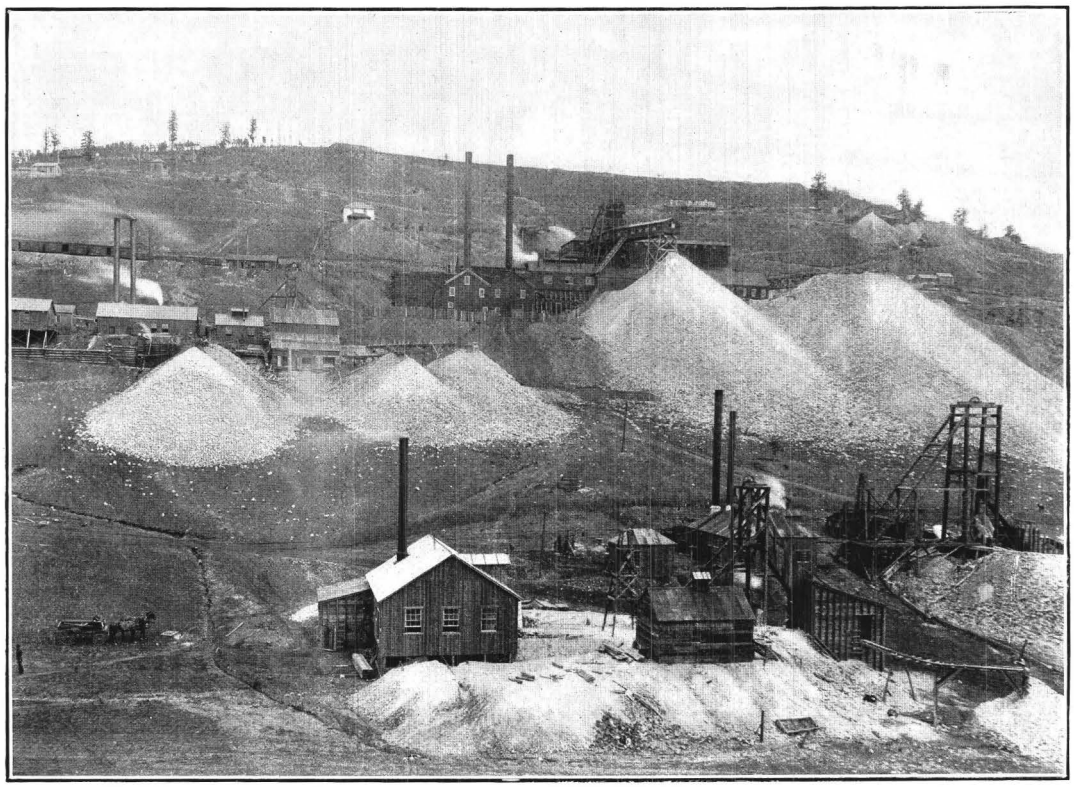


FIG. 39.—Plan of level 2, El Paso mine, showing relation of veins and ore bodies to phonolitic intrusions.

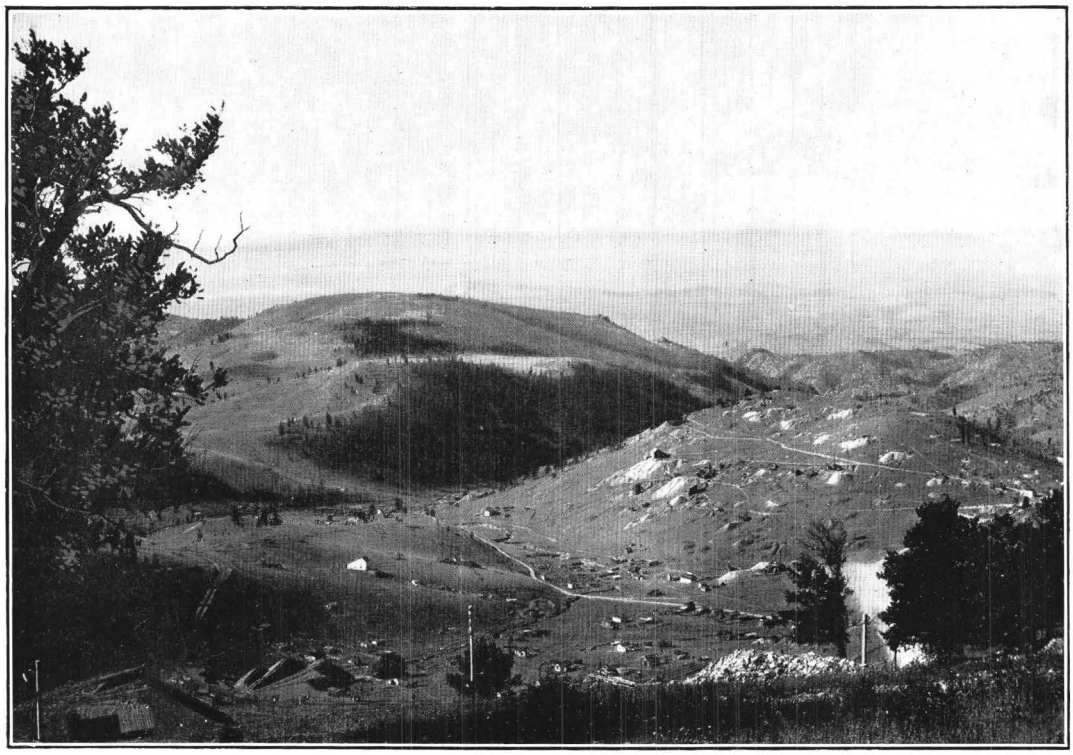
somewhat gneissoid, and contains numerous squeezed lenticular bodies of schist, which appear in some cases to have been derived from the granite by local shearing under great stress. The granite is cut by numerous dikes and sills of phonolite, many of which are clearly offshoots from the main phonolite plug. The most important dike is one striking about N. 55° W., shown in fig. 39, and also on the general geological map (Pl. II, in pocket). The dike dips from 55° to 60° NW., and is usually 15 to 20 feet wide. From its importance in the El Paso mine this dike may be conveniently referred to as the El Paso dike.

The contact between the phonolite plug and the granite is well exposed in the Australia tunnel and on levels 2 and 4 from the main shaft. It is a sharp, irregular



A. MINES ON BEACON HILL.

The El Paso is high up in the center; the C. K. & N. to left in the middle-ground; the Henry Adney and Old Gold in the middle and right foreground, respectively.



B. BEACON AND GROUSE HILLS, FROM RAVEN HILL.

intrusive contact, along which there has been occasionally a little local movement. Sills and dikes of phonolite are particularly abundant in the granite near the main phonolite mass, as may be well seen on level 2 and in the east branch of the new drainage tunnel. The contact dips steeply into Beacon Hill, usually at 75° or 80°. (See fig. 40.)

LODE SYSTEMS.

The principal lodes of the El Paso are the El Paso, Tillery, and C. K. & N. The El Paso and Tillery strike in general N. 35° E. Both dip northwest, the El Paso at about 70° and the Tillery at about 65°. They thus converge downward. At the

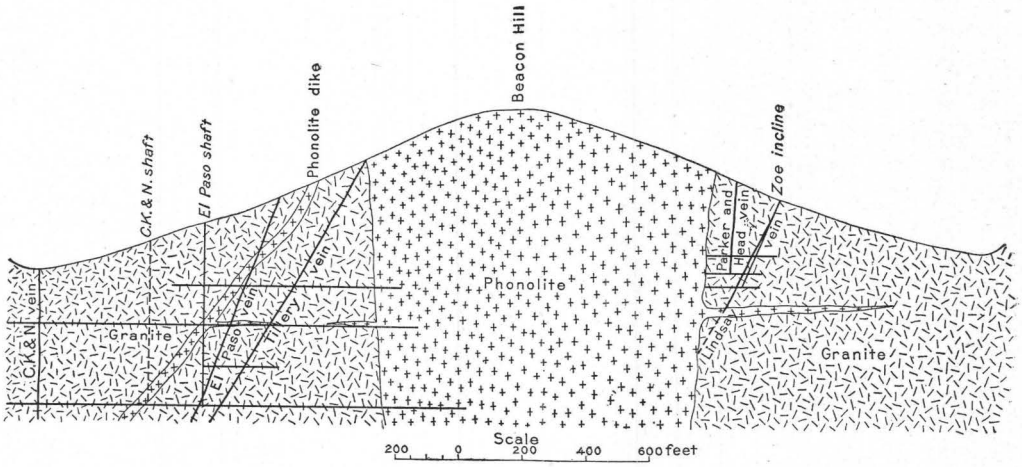


FIG. 40.—Diagrammatic northwest-southeast section across Beacon Hill, through El Paso and Zoe shafts.

surface, near the old shaft, they are approximately 150 feet apart, while in the southwest part of level 4 they are apparently together. They diverge, however, to the northeast, and at the new shaft are 70 feet apart on level 4. Both lodes are rather irregular in strike and dip. The Tillery is very indistinct north of the main shaft and has not proved important in that direction. An east crosscut on level 2 shows that the granite through which the Tillery lode would pass if it persisted so far north is too much shattered to allow the identification of the lode. The maximum explored length of the Tillery lode is about 700 feet, chiefly in the vicinity of the old shaft. The El Paso lode has been explored from a point about 450 feet southwest of the old shaft to a point 800 feet northeast of the new shaft, a total length of 1,850 feet. On level 1 the El Paso lode meets the El Paso dike just east of the new shaft. The lode follows the foot wall of the dike for about 175 feet, and then turns slightly northward across the dike and continues on to the C. K. & N. lode. On level 2 the lode and dike exhibit a similar relation, the crossing on this level being about 500 feet northeast of the shaft (fig. 43). On levels 3 and 4 the intersection occurs successively farther north and nearer the C. K. & N. lode, but the development in this part of the mine was not extensive enough at the time of visit to make clear all the details of the relation between the dike and the El Paso and C. K. & N. lodes. Near the dike the El Paso lode is rather irregular and changeable in dip and may be accompanied by considerable subsidiary fissuring. At the point

where the lode enters the dike from the southeast a zone of fissuring usually branches which continues northeast along the foot-wall contact of the dike. This is narrow and contains pyrite, but no ore. The C. K. & N. lode has a general strike of N. 75° E., but it is a rather curved and irregular zone of fissuring, part of this irregularity being due to a number of cross fissures, some of them having the same general trend as the El Paso and Tillery lodes. The dip of the lode varies, but is practically vertical.

The intersection of the El Paso and C. K. & N. lodes has been exposed on all four levels, but the exact relation of the two lodes is not decisively shown. On level 2 the C. K. & N. lode is offset about 10 feet at the intersection, but it is not certain from this that the El Paso is the younger lode. No corresponding displacement was noted on the other levels. On level 1 the C. K. & N. lode runs S. 83° W. for about 150 feet from the El Paso lode, the dip being vertical. The lode then turns S. 40° W. along an intersecting fissure zone, and follows this course for about 100 feet before resuming its normal strike. This cross-fissure zone dips 75° NW. The fissure zone continues beyond the C. K. & N. lode both to the northeast and southwest, containing some soft, gray gouge and rather crumbling pyrite. It might be regarded as a simple faulting of the C. K. & N. lode were it not for the fact that the ore of the latter lode continued without change along the faulting or intersecting fissures. The same fissure zone appears also on level 2, and has been followed for some distance in a drift (fig. 43). On this level, near the C. K. & N. line, the C. K. & N. lode is offset by a second cross-fissure zone, striking N. 30° E. This fissure zone also dips northwest about 75°. It is similar to the cross lode just described, but, unlike that fissure zone, contains no ore, and seems clearly to fault the C. K. & N lode. It is a well-defined sheeted zone in the granite, one of the fissures near the hanging wall containing a soft, gray gouge of sheared granite, with some pyrite. Similar cross fissures, usually containing a little soft gouge and pyrite, cross the C. K. & N. lode east of its intersection with the El Paso. They usually strike about N. 30° to 35° E. and dip about 75° NW. Some cross the C. K. & N. with no apparent displacement of the latter. About 100 feet east of the El Paso lode, on level 1, the C. K. & N. lode apparently ends at one of these fissure zones. Whether the C. K. & N. is actually faulted or merely terminates at this cross fissuring is unknown, as the continuation of the lode has not yet been identified. The same cross-fissure zone apparently cuts off the eastern part of the C. K. & N. on level 2, about 60 feet east of the El Paso lode. A few feet beyond this point the El Paso dike crosses the line of the C. K. & N. lode (fig. 39, p. 350), which is supposed to turn northeast and follow the dike. As there is a difference of only about 20° between the normal trend of the lode and the course of the dike, the fissuring was probably deflected along the dike contact in preference to taking an oblique course through the phonolite. In this part of its course it dips 65° to 70° NW., conforming to the usual dip of the dike. This change of dip was observed also at the east faces of the drifts on the C. K. & N. lode on levels 3 and 4, as these faces were at the time of visit. Developments on levels 3 and 4 had not then reached such a stage as to throw much additional light on the relation of the C. K. & N. lode to other structural features in the mine.

From the foregoing description it appears that the El Paso ground is cut by a number of fissure zones striking approximately N. 35° E. and dipping 70° to 75° NW. To this prevalent system the nearly east-west vertical C. K. & N. lode is a marked exception.

CHARACTER OF ORE.

The ore of the C. K. & N. lode consists of calaverite, which occurs chiefly in the vugs and narrow veinlets of the sheeted zone composing the lode. The calaverite is usually associated with quartz and fluorite, and locally with pyrite and sphalerite. The pyrite and sphalerite were apparently deposited before the calaverite and carry small values, $5 or $6 per ton being about the maximum. Free gold is rare in the C. K. & N., and the pay shoots contain practically no oxidized ore. Some low-grade ore in the C. K. & N. lode on level 4 shows an indistinctly banded vuggy aggregate of quartz and purple fluorite. The banding is apparently due to the replacement by these minerals of the very thin granitic slabs between the closely spaced fissures of the sheeted zone.

No ore was being taken from the El Paso or Tillery lodes at the time of visit. Specimens of Tillery ore from level 1 near the old shaft show the occurrence of both calaverite and tetrahedrite, associated with fluorite as implanted crystals on the drusy quartz lining the vugs and narrow fissures of the sheeted zone. Some of these fissures show a nearly solid filling of quartz and barite, with pyrite and sphalerite. These minerals belong to an earlier generation than the calaverite and tetrahedrite. None of the ore formerly mined from the El Paso lode near the old shaft was seen. The ore of the large pay shoot in this lode northeast of the new shaft consisted chiefly of shattered granite containing innumerable reticulating veinlets of quartz. These small, irregular fissures are seldom completely filled, but are vuggy or merely lined with drusy quartz. The valuable constituent of the ore is calaverite, which occurs in the vugs and on the drusy surfaces. Galena, stibnite, and chalcopyrite are said to be occasionally present in the ores.

The value of the El Paso ore ranges from about $8 to several thousand dollars per ton. In general $40 or $50 ore is considered good.

PAY SHOOTS AND LODE STRUCTURE.

The C. K. & N. lode is a typical sheeted zone in granite. The ore is rarely over 7 inches wide and is confined to one or more vuggy quartz veinlets. The ore forms practically one continuous shoot, which has been stoped from level 2 to the highest point at which pay ore occurs—namely, 100 feet above level 1 and 150 feet below the surface. On the east the pay shoot ends above level 1 at the zone of northeast fissuring already described, but between levels 1 and 2 it extends about 125 feet farther along the El Paso dike. Toward the west the pay shoot extends into the C. K. & N. mine, the upper limit of the ore pitching down at a somewhat steeper angle than the slope of the hill, so that at the C. K. & N. shaft it is about 200 feet below the surface. The length of the shoot on level 2 within the El Paso ground is nearly 800 feet. No stoping had been done on levels 3 and 4 at the time of visit, though recent work is reported to have shown large bodies of good ore

down to the bottom level. The extreme upper limit of the ore seems to be determined, at least in part, by a zone of nearly horizontal fissuring containing soft, crushed granite or gouge and some pyrite. At those points where the pay shoot follows fissures crossing the plane of the C. K. & N. lode it contains ore of the same character as in the C. K. & N. lode proper, but this ore is usually accompanied by a fissure containing soft gouge and pyrite (fig. 39, p. 350). Such soft material never constitutes pay ore. Some of the best ore on the C. K. & N. lode occurs near its intersection with the El Paso lode.

The old stopes on the El Paso lode near the old shaft are no longer worked, and no observations could be made on the occurrence of this ore. The pay shoot or shoots in this part of the lode appear to have had a total length of about 500 feet and come to an end near the new level 1, or approximately 200 feet below the surface. At this depth the lode shows a little oxidation, but only along some of the more open fissures of the sheeted zone. On level 2 the El Paso sheeted zone, while fairly distinct, contains no ore south of the main shaft. The principal pay shoot in this lode lies northeast of the main shaft, chiefly in the acute angle formed by the intersection of the lode with the El Paso dike. This ore formed an irregular mass, which extended from a point about 70 feet above level 1 almost to level 3. Near level 1 the pay shoot is only a few inches wide, and is a sheeted zone in granite at the under contact of the El Paso dike. The ore occurs as calaverite, mainly in the medial vugs of a veinlet of fluorite less than an inch wide. Above the level this veinlet finally pinches out. Below the level the main fissure diverges from the phonolite, and the granite between it and the dike is much fissured and mineralized, constituting on level 2 an ore body 40 feet wide. The irregularity of the fissuring at this point appears to be connected with an irregular sill-like offshoot from the phonolite dike into the granite and the presence in the latter rock of some streaks or inclusions of schist. The El Paso lode itself also splits into a number of fairly regular divergent sheeted zones as it approaches the under side of the dike. Granite, phonolite sill, and schist lenses are all traversed by reticulating fissures containing quartz and calaverite. Below level 2 the fissuring becomes less pronounced, the ore contracts, and on level 3 there is practically no ore where the El Paso lode and El Paso dike meet. The ore body has, roughly speaking, the form of a flattened ellipsoid lying against the under side of the phonolite dike, its longest axis pitching to the northeast with the general line of intersection of lode and dike. The ellipsoid has its greatest thickness of 40 feet near level 2, about 200 feet northeast of the main shaft, and decreases peripherally to zero. It is far from regular, however, as it contains several horses of unmineralized country rock, and the ore often extends for short distances along some of the more definite fissure zones.

Although the main contact between the granite and the Beacon Hill phonolite plug is not generally mineralized, it carries bodies of ore at several points, notably in the now idle workings of the Australia tunnel and Little May mine. In the El Paso workings some ore occurs along the contact on level 2, but only in one or more irregular sills in the granite, which connect with the main phonolite mass. There has been slight movement along the general contact since the phonolite solidified, and the sills are irregularly fissured. In one stope visited the sill was about 6 feet in thickness and contained ore for a maximum distance of 15 feet from the main contact. The ore occurs as calaverite in the minute fissures in the phonolite.

C. K. & N. AND OLD GOLD MINES.

INTRODUCTION.

The C. K. & N. mine adjoins the El Paso on the northwest, with workings on that part of the C. K. & N. lode lying within the Raaler claim. It is owned by the C. K. & N. Mining Company, of Colorado Springs, incorporated in 1894 and capitalized at $1,250,000. The authorized capital was afterwards increased to $1,500,000. Very little work was done on the property until the end of 1899, when it was leased for five years to Mr. Horace Granfield, the company receiving 20 per cent on the net value of the ore. Although the C. K. & N. lode was not then known in the El Paso mine and does not show at the surface, Mr. Granfield sank a shaft 300 feet in depth, practically on the lode, and discovered ore in the latter part of 1901. The mine has since produced steadily and is noted for the high grade of its ore.

The Old Gold mine lies immediately west of the C. K. & N., the workings being connected on the C. K. & N. lode. It is owned by the Old Gold Mining Company, of Denver, organized in 1895 and capitalized at $1,800,000, subsequently increased to $2,101,150. The property comprises isolated portions of the Old Gold, Buckeye, Genevieve, and Lonaconing claims not covered by earlier locations. One was first discovered in 1903 by the lessee, E. G. Taylor, superintendent of the C. K. & N. mine, at a depth of about 300 feet.

PRODUCTION.

The output of the C. K. & N. mine is as follows:

Production of C. K. & N. mine.

Year.	Gold.	Silver.
	Ounces.	*Ounces.*
1902	9,095	(a)
1903	19,390	510
1904	32,093	(a)
	60,578	510

[a] Silver for this year probably included with the gold.

The total gross value of the product is $1,211,553, and the company has paid from royalties twelve dividends up to December 31, 1904, amounting to $171,828.

The Old Gold mine produced up to May 1, 1904, 4,984.57 tons of ore, of a gross value of $207,412.18. The royalties to the company, on a basis of 15 and 20 per cent of the net value of the ore, amounted at the same date to $29,909.65, and the first dividend, $10,505.75, or $5 per thousand shares, was declared in March, 1904.

UNDERGROUND DEVELOPMENT.

The C. K. & N. is a small mine, with very simple workings along the one lode. The main shaft, situated close to the El Paso line, is 498 feet deep and connects with three levels, level 1 being 300 feet below the surface, while the other levels are at intervals of 75 feet. These levels run diagonally across the Raaler claim, following

the C. K. & N. lode, which strikes N. 76° E. They end on the northeast against the El Paso and on the southwest against the Old Gold properties, giving a total stoping length along the lode of about 400 feet. The Old Gold shaft, sunk on the C. K. & N. lode 400 feet southwest of the C. K. & N. shaft, is also about 400 feet in depth. The main level is 250 feet below the surface, and consists of a drift about 125 feet in length along the C. K. & N. lode, with a northeast-southwest drift on the Old Gold lode. The bottom level, 80 feet lower, consists of a similar drift on the C. K. & N. to the Old Gold lode. The collar of the Old Gold shaft is 98 feet lower than that of the C. K. & N. shaft.

GEOLOGICAL FEATURES.

The C. K. & N. and Old Gold workings are in the same granite as the El Paso mine. This granite is cut by a number of small, irregular sills and dikes of phonolite. In the Old Gold ground there is a prominent phonolite sill or dike 30 or 40 feet in thickness, which dips to the northwest at about 45°. Thickness and dip, however, are both variable, and in some places the sill is divided into an upper and lower sheet by a slab of schist. Similar schist overlies the phonolite, which apparently was intruded along a schistose streak or inclusion in the granite.

LODE SYSTEMS.

The principal lode is the C. K. & N., which strikes N. 76° E., and is approximately vertical. It extends from the El Paso ground across the Raaler claim, and into the Old Gold ground until it meets the phonolite sill. Northwest of this sill no trace of the C. K. & N. lode has yet been found, and it probably does not cross it. The Old Gold lode is a nearly vertical fissure zone in the sill, striking, like the latter, N. 35° E. It is known only on the 300-foot level of the Old Gold, as it is not discoverable as a distinct lode in the schist and granite above and below the phonolite. There are a few small cross fissures in the C. K. & N. mine, striking about N. 30° E., and thus, like the Old Gold lode, corresponding to the general system of northeasterly lodes represented by the Tillery and El Paso veins. They do not perceptibly displace the C. K. & N. lode.

CHARACTER OF ORE.

The ore of the C. K. & N. lode consists of calaverite in a gangue of quartz associated with varying amounts of fluorite, and, as shown by concentrating at the Dorcas mill, with some barite. The calaverite sometimes projects as implanted crystals into small quartzose vugs, but probably the greater part of it is completely inclosed by the gangue. Occasionally nests of stibnite have been found in the lode, carrying up to 300 or 400 ounces of gold per ton. Chemical examination of such stibnite by Doctor Hillebrand shows that the gold exists as a telluride, probably mechanically included in the stibnite. None of the ore seen showed any sign of oxidation, and free gold is unknown. Some of the ore is remarkably rich, small quantities carrying as much as 3,000 ounces of gold per ton, while one lot of 1,586 pounds netted $19,000, corresponding to about 1,200 ounces per ton. The average proportion of silver in the ore is 1 ounce to 8 or 10 ounces of gold. Some of the ore contains as much as 300 ounces of silver per ton. The ore of the Old Gold lode,

occurring in fractured phonolite, sometimes shows considerable pyrite, in small pyritohedrons lining the little vugs and fissures, and often accompanied by sphalerite.

PAY SHOOTS AND LODE STRUCTURE.

The principal pay shoot in both mines is that of the C. K. & N. lode, which has already been partly described in connection with the El Paso mine. The lode is a narrow sheeted zone cutting through granite and phonolite, the ore occurring in both rocks, though it is usually wider in the granite. The fractures are partly open, particularly the principal fissure of the zone, and show no gouge or slickensiding. The main fissure is rarely more than 4 inches wide. It is sometimes solidly filled with quartz and calaverite,. but more often shows an open vuggy structure, the calaverite occurring both as implanted crystals in the vugs and within the quartz lining the walls of the fissure. Occasionally the main fissure contains nearly loose slabs of country rock, a few inches in thickness, coated on all sides by crystals of quartz and fluorite. Calaverite occurs also in the smaller less regular fractures on each side of the main fissure, as is indicated by the fact that the screenings from a width of 3 or 4 feet are usually of high grade. According to Supt. E. G. Taylor, the calaverite (or some other gold telluride) sometimes occurs alongside the principal fissure in granite that is not perceptibly fractured. Such granitic ore is grayish or greenish in color and somewhat porous, showing metasomatic alteration, whereas the unaltered granite is reddish in color and dense in texture. This pay shoot has been stoped from the El Paso line into the Old Gold ground and from the 370-foot level to within 165 feet of the surface. No ore is known above this, though the lode is said to have been followed for about 30 feet above the point where the ore ended. Toward the west the pay shoot continues to the Old Gold phonolite sill. In the phonolite the lode splits into a few small, irregular fissures and is soon lost. The ore does not extend into the phonolite and has been found to fall rather below the average grade as the sill is approached. On level 3 of the C. K. & N. no stoping had been done at the time of visit in January, 1904, and it was a little doubtful whether the C. K. & N. lode had been found. The fissure followed in the drift was very indistinct, showing only a little pyritic mineralization in granite alongside a small phonolite dike. No calaverite and nothing resembling the open, vuggy C. K. & N. lode as known above were seen on this level.

The Old Gold pay shoot was first encountered on level 1 of the Old Gold as a small, rather irregular, vuggy fissure in the phonolite sill, accompanied by some irregular fracturing. The best ore occurs in the main fissure, but the irregular fractured phonolite is also ore to a maximum width of 10 feet. As this ore proved to be of high grade and showed such a width on this level, chutes were put in and the drift timbered preparatory to carrying up an extensive stope. It was soon found, however, that the ore extended only 15 feet above the level, being limited to the phonolite. Later developments on the level below have shown also that this pay shoot does not extend below the bottom of the phonolite.

UNDERGROUND WATER.

A considerable quantity of water finds its way into the mine through the open portions of the C. K. & N. lode and through cross fissures, but is kept down by natural drainage into the El Paso mine. By working above the water level maintained by its larger neighbor the C. K. & N. mine is able to avoid pumping.

GAS.

An abundant flow of gas, in part carbon dioxide, issues from some of the fissures of the C. K. & N. lode, so that a candle held to such an opening is immediately extinguished. Owing to the connections with the El Paso and Old Gold shafts, the mine was well ventilated and the gas was causing no particular inconvenience at the time of visit.

PRINCE ALBERT, GOLD DOLLAR, ZOE, AND MABEL M. MINES.

INTRODUCTION.

The Prince Albert, Gold Dollar, Zoe, and Mabel M. mines are all situated on the southeast side of Beacon Hill, near the contact between the granite and the phonolite. The Prince Albert mine includes the Prince Albert, Beacon, and Eureka claims and is owned by the Prince Albert Mining Company (Limited), incorporated in 1895 with a capital of $3,000,000. It represents a consolidation of the Prince Albert, Beacon, and Ida Etheleen companies. Both the Prince Albert and Beacon mines began shipping ore in 1893 and attracted much attention to Beacon Hill. In 1896 the Prince Albert was shipping 20 tons of $40 ore a day. Most of the work in the last few years has been done by lessees.

The Gold Dollar mine lies immediately northeast of the Prince Albert and with the Mabel M. mine is controlled by the Woods Investment Company. The Zoe mine occupies a narrow strip of territory between the Gold Dollar and Mabel M., with a maximum stoping length along the lode of about 60 feet. The Gold Dollar, Zoe, and Mabel M. properties are all portions of the Arequa town site and were not laid out as mining claims. The Gold Dollar mine began to ship in 1897 and the Mabel M. at about the same time. Both are now operated by lessees.

UNDERGROUND DEVELOPMENT.

All of the mines lie approximately on a line running N. 35° E., the principal drifts having nearly the same trend. The workings of the Prince Albert mine are practically all at the northeast end of the property, near the Gold Dollar line. They comprise several shafts and adits, some irregular levels, and extensive stopes and open cuts. The deepest shaft is 250 feet and most of the workings are within 100 feet of the surface. Beneath the Prince Albert workings proper the ground has been explored at a depth of about 300 feet by the Gold Dollar adit.

The Gold Dollar shaft is a little over 420 feet in depth, with six levels. Of these, level 4, 221 feet below the collar, is the most extensive and connects directly with the Gold Dollar adit from Arequa Gulch. The Zoe shaft is an incline, of which the bottom level is level 5 of the Gold Dollar. The Mabel M. shaft is about 475 feet deep, with five main levels. The total length of ground exploited in the four mines is about 1,500 feet.

GEOLOGICAL FEATURES.

The workings are nearly all in gneissoid granite, near the contact with the main phonolite mass of Beacon Hill. In this respect the geological conditions are similar to those in the El Paso and C. K. & N. mines on the other side of the hill. The contact between the granite and the phonolite is very irregular, as may be seen from fig. 41. It dips, as a rule, steeply into the hill, the average angle being probably about 75°. In places the granite is only slightly brecciated near the contact. Elsewhere the two massive rocks are separated by as much as 15 feet of breccia, composed of mingled fragments of phonolite and granite. There is usually much pyrite along the contact, impregnating both massive and brecciated rocks, but no ore. In the open cut and stopes in the Prince Albert mine bodies of similar breccia are inclosed in the phonolite. It is probable that an explosive eruption first shattered and pierced the granite of Beacon Hill and that the phonolite magma subsequently rose in the volcanic neck already partly filled with the phonolite and granite fragments produced by the explosion. In the open cut of the Prince Albert the phonolite cuts the breccia with a well-defined intrusive contact.

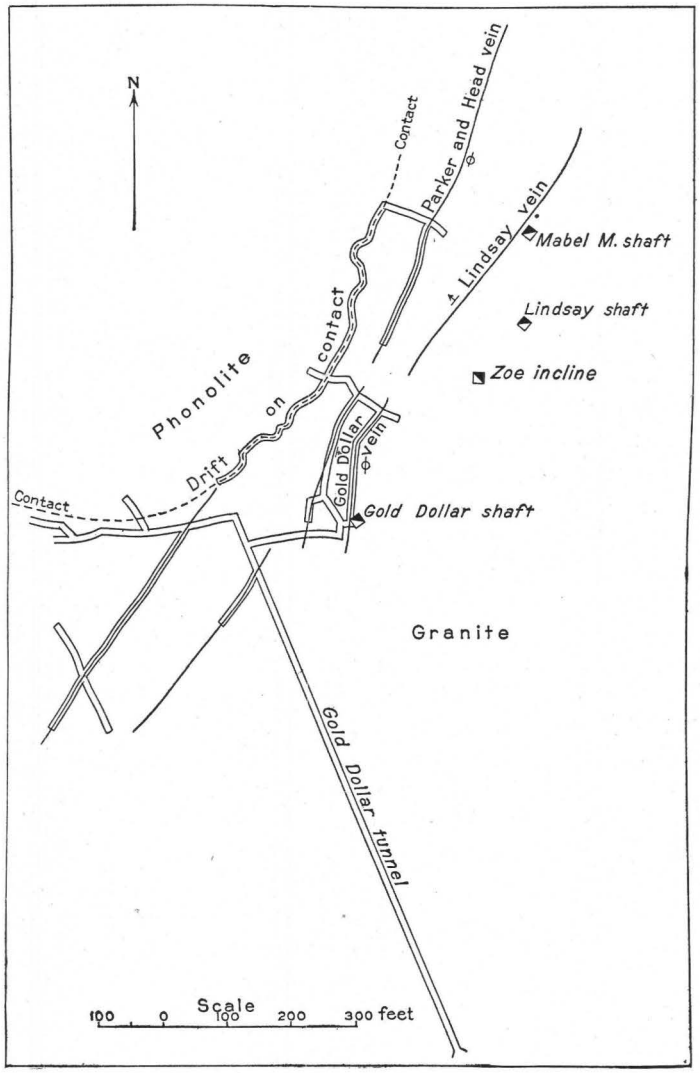


FIG. 41.—Sketch plan of level 4, Gold Dollar mine, showing relation of fissures to the phonolite plug of Beacon Hill.

The granite is traversed by several irregular dikes and sheets of phonolite, some of which are clearly offshoots from the main phonolite neck or stock.

LODE SYSTEMS.

The granite for a distance of about 200 feet from the main phonolite mass is cut by a number of fissures which, for the most part, strike about N. 35° E. This strike is roughly parallel with the longer axis of the Beacon Hill phonolite intrusion and with the numerous fissures in granite in the El Paso workings on the other side of the hill. The individual lodes composing this general fissure zone range in strike from N. 10° E. to N. 40° E. They dip usually to the northwest, the angles ranging from 60° to 90°. The principal lodes are the Prince Albert, Gold Dollar, Lindsay, Mabel M., and Parker & Head. Owing to the irregular and disconnected character of the underground workings the mutual relations of these lodes are not clear. It is possible, for example, that the Gold Dollar and Lindsay are really parts of one lode, but the connections through the Zoe mine are not such as to establish this identity. The Gold Dollar lode has a dip of about 70°, while the dip of the Lindsay is 60°. In general the fissure zones are not very persistent and where they do not contain ore are not always distinguishable from other fissures of similar trend, but of no known economic importance. The fissures frequently branch and intersect one another, but, so far as known, none of the intersections show faulting.

The Gold Dollar and Lindsay lodes constitute practically the southeastern boundary of the known zone of productive fissures. The other lodes lie between these two and the Beacon Hill phonolite and are usually more nearly vertical.

CHARACTER OF ORE.

The ore in these mines occurs as calaverite or sylvanite associated with quartz. No fluorite was observed in the ore seen at the time of visit. A specimen of ore from the Prince Albert mine was obtained by Penrose in 1894, and the telluride within it was examined by Hillebrand and Penfield. It proved to be calaverite.[a] Palache[b] more recently has described a telluride from the Mabel M. mine, and has shown it to be sylvanite. The ore, as a rule, is unoxidized, though traces of oxidation can occasionally be detected along some of the more open fissures even in the deepest levels.

PAY SHOOTS AND LODE STRUCTURE.

With the exception of the main Prince Albert ore body and some small pay shoots in phonolite in the Beacon claim, the ore in these mines occurs in narrow sheeted zones in granite. The Lindsay lode lies on the east side of a phonolite dike, but the ore is all in the granite. There is usually one main fissure, less than an inch in width, in which occur quartz and calaverite or sylvanite, the tellurides being found in the vugs of the quartz veinlet. This main fissure is often accompanied by minor, less persistent fractures, which may also contain quartz and tellurides. The pay shoots are comparatively small, being rarely over 50 feet in length and not extending to great depth. The known ore in the Parker & Head and Lindsay lodes all occurs at less than 300 feet in depth. In the Mabel M. and

[a] Cross, Whitman, and Penrose, R. A. F., jr., Geology and mining industries of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 133–136.

[b] Notes on tellurides from Colorado: Am. Jour. Sci., 4th ser., vol. 10, 1900, pp. 419–422.

Gold Dollar lodes the ore goes deeper, but even in these lodes little ore has been found below 350 feet in depth. The pay shoots occur irregularly in the lodes and are not, so far as observed, related to cross fissures or intersections.

The main ore body of the Prince Albert occurs at the intersection of the Prince Albert lode with an intrusive sheet of phonolite. This sheet is about 8 feet thick and dips north-northeast at an angle of 30°. It is clearly an offshoot from the main phonolite mass of Beacon Hill. The ore body, most of which has been stoped out, was about 200 feet long and had a maximum width of 40 feet. The general relation of the ore to the Prince Albert fissure zone and to the phonolite sill is shown in fig. 15 (p. 208). It extended from the surface southwest of the Prince Albert shaft down to level 1 of the Gold Dollar mine and is said to have produced over 10,000 tons of good ore. This ore occurred entirely in the granite, the fissures being practically barren within the phonolite. A little low-grade ore only has been found in the granite on the under side of the phonolite sheet. From a maximum width of 40 feet, where it rested upon the phonolite, the ore seems to have contracted rather abruptly 20 or 25 feet above the phonolite to the narrow width of the Prince Albert lode proper, which carried ore up to the surface.

In the Beacon claim a little ore has been obtained from fissures in the main phonolite intrusion. This however, is exceptional, the bulk of the Beacon Hill ore occurring in the granite.

UNDERGROUND WATER.

These mines were formerly much hampered by water, even at a depth of 200 feet. The levels were drained by the Standard tunnel and now by the El Paso tunnel, though at the time of visit there was stagnant water in the sump of the Mabel M. shaft.

CHAPTER V.—MINES OF BULL HILL.

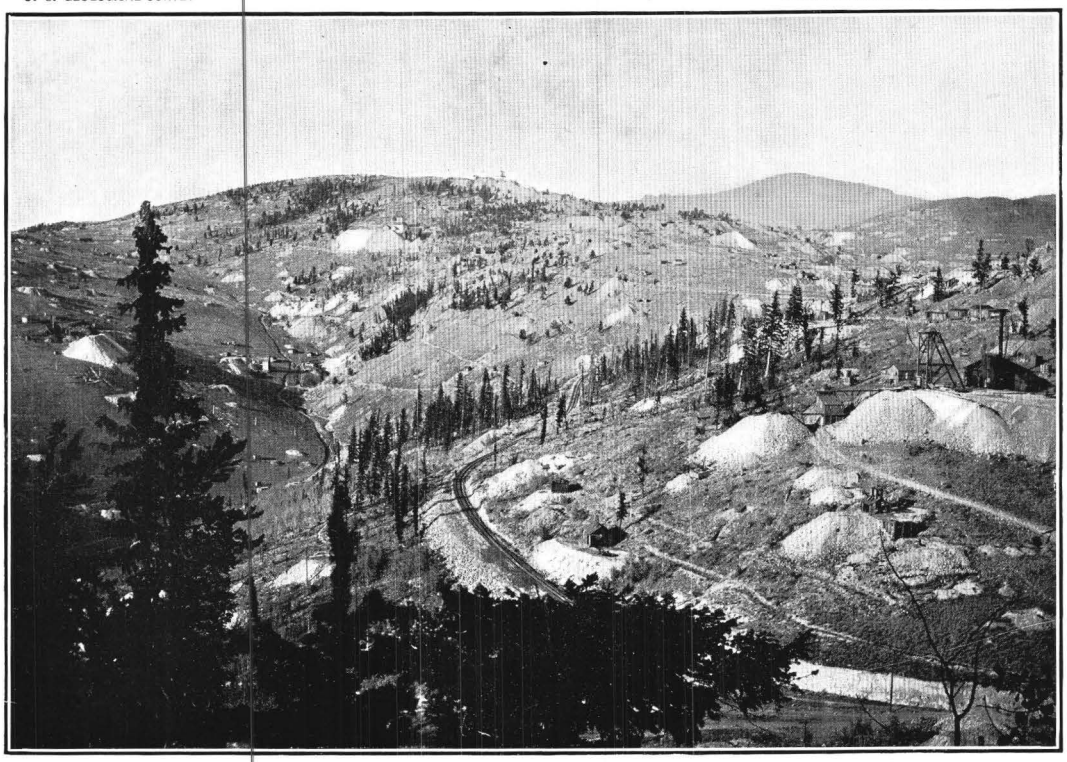
GENERAL INTRODUCTION.

Bull Hill occupies a central position in the complex of volcanic hills and many important mines are located on its southern slope. An isolated area of brecciated granite occupies its western slope, while over the eastern and southern parts breccia prevails. Several bodies of latite-phonolite appear in the breccia. As shown by mining developments, these masses as a rule form flat intrusive sheets. In the southern area especially the various shafts sunk in it have everywhere shown that breccia appears below latite-phonolite at a depth of 300 or 400 feet. Several basic dikes with a northwest or northeast trend cut across the southern shoulder of Bull Hill, and at least one phonolite dike with northwest trend is prominent in the Logan and Dante mines.

The Wild Horse lode outcrops near the summit and follows approximately the contact between granite and breccia, though in lower levels it is entirely in granite or granite breccia. On the south or southwest slope a general shattering has occurred, as shown by the complicated veins of the Dante, Gold Sovereign, War Eagle, and other smaller mines. The strongest fissures appear on the prominent south or southeast shoulder of the hill in the northerly trending Blue Bird, Orpha May, and Mineral Rock lodes. The Orpha May lode is traceable as a closely linked and very productive system for three-fourths of a mile from the Modoc mine, by the Last Dollar, Rubie, and Orpha May veins. A basic dike with a north-northwest trend cuts across the Orpha May and has in places proved very productive. The nortneast slope of Bull Hill contains few lodes of importance.

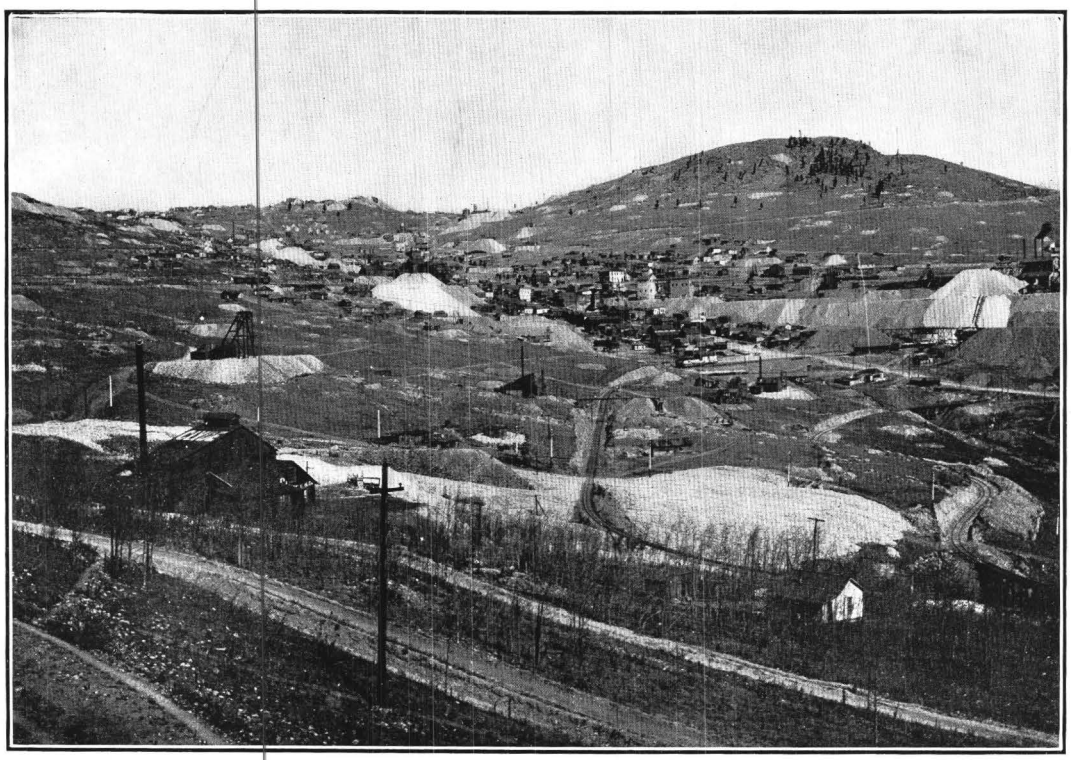
WAR EAGLE AND RAMONA MINE.

The recently opened War Eagle and Ramona property is situated on the southwestern slope of Bull Hill, about 250 feet below the summit. It is worked by lessees, who in 1903 extracted a considerable amount of ore from a surface pit and in 1904 opened a vein system found below this surface ore. The production from April, 1903, to April, 1904, is stated to be about $45,000. The developments consist of the War Eagle shaft, 58 feet deep and connecting on that level with the 150-foot Ramona shaft, situated 300 feet to the northeast. The elevation of the collar of the War Eagle shaft is about 10,528 feet. The workings are chiefly contained in the somewhat shattered granite of Bull Hill, but also reach, near War Eagle shaft, the breccia contact, which here is sharply defined. A drift has been run on this contact for about 100 feet northwest of the shaft. All of the rocks are very much oxidized.



A. SOUTH SLOPE OF BULL HILL, FROM SQUAW MOUNTAIN.

Pikes Peak in distance.



B. BULL CLIFF AND TOWN OF INDEPENDENCE.

Vindicator mine to right.

The veins so far as developed are the War Eagle, striking northeast and dipping steeply northwest; the Ramona, striking north-northwest and dipping steeply east-northeast; together with several flat seams or small veins. The War Eagle vein would seem to be the extreme southern continuation of the Wild Horse vein described below, or is at least closely parallel to it. At an elevation of 10,100 feet the New York tunnel should have intersected the vein, but if it did so the vein has not proved profitable. The veins appear as clay seams, the vein matter consisting of soft brown gritty clay with small masses of pure white kaolin. Along the flat veins crusts of smoky comb quartz are not uncommon.

The occurrence of the ore presents several interesting features. A large mass was found on the surface somewhat below the vein and almost on top of the granite-breccia contact. This body of thoroughly oxidized ore, which contained values of about $25 per ton, had horizontal dimensions of 30 by 40 feet and was not more than 25 feet deep. A small bunch of ore yielding 200 tons occurred on level 1, on the granite-breccia contact.

The War Eagle vein has been drifted on for a distance of 400 feet, chiefly northeast of the shaft, but does not itself contain any ore. The ore occurs for a horizontal distance of 200 feet along the intersection with a flat clay vein dipping about 20° NW. The shoot followed the intersection closely, the gold occurring chiefly in the flat vein, which at most was 8 feet wide, but not extending far from the War Eagle vein. The flat vein, which at first was 10 feet above the level, finally dipped under foot. At the Ramona shaft, on the War Eagle vein, another flat vein comes in, also dipping 20° NW. and carrying good values at the intersection. The gold in the flat veins is comparatively coarse. The central clay seam may assay $300, while the adjacent rock for a foot or two in width contains about $18 to the ton.

The Ramona vein, which is 2 to 4 feet wide and very clayey, contains a pay shoot with very fine gold which begins 8 feet east of the intersection with the War Eagle vein and continues for 123 feet west-northwest, being suddenly cut off by a partly open watercourse which cuts across the vein. Diminished values continued for a few feet beyond it, but the ore soon became unprofitable. It is believed that a fairly large amount of oxidized ore containing about $6 per ton is available along these veins.

RAMONA NO. 2 MINE.

This mine is situated on the southeastern part of the Ramona claim, just east of the War Eagle mine. Its workings consist of an incline shaft about 200 feet deep and three levels, making a total development of about 800 feet. The production of the mine could not be ascertained, but it is not large.

The workings have been driven on a basalt dike which strikes a few degrees west of north and has an average dip of 80°. It varies considerably in course, dip, and thickness, and here and there pinches out entirely. A short distance north of the shaft the dike crosses the breccia-granite contact, the latter lying to the north. The change of rock has little apparent effect on the dike. The breccia contains much granite and is thoroughly oxidized; the granite is shattered and altered, so that the contact between the two rocks can not be exactly located. It appears, however, to dip steeply to the north, or in other words the granite seems to overhang the breccia.

On the third or bottom level the dike is followed northwest from the shaft for about 100 feet, becoming here much pinched and shattered. Just north of this point the drift crosses a well-defined zone, 3 to 4 feet wide, approximately vertical, and striking northeasterly, which contains fragments of granite and phonolite. It may be a brecciated-phonolite dike, but the presence of basaltic fragments in the zone 50 to 60 feet northeast of the point where the basalt dike was last recognized indicates that this may be a plane of faulting.

All the ore has been extracted from the basalt dike or the accompanying fissure. A little ore was taken from the dike at the surface. On level 1 the granite-breccia contact is approximately 20 feet north of the shaft. A little stoping has been done above and below the level north and south of the shaft. The vein on this level is simply a shattered oxidized zone, holding kaolin, and the basalt is not recognized. On level 2 the basalt becomes distinct. The contact is in about the same relative position as on the level above. Here also a little stoping has been done just south of the shaft, above and below the level. Along and to the south of the contact on level 3 a fair-sized stope of ore has been mined along the dike, the values being mainly along the sides of the dike. The ore was oxidized and of good grade.

The position, size, and value of the ore shoot seems to be independent of the granite-breccia contact, though occurring near and roughly parallel to it. No cross seams were observed.

SHERIFF MINE.

The Sheriff mine, the property of the Sheriff Gold Mining Company, is located on the Sheriff claim, on the saddle between Bull and Raven hills. There are several shafts from 100 to 200 feet deep on the property. The principal shaft and the only one that was being worked in the spring of 1904 is 300 feet deep and connects with about 600 feet of drifting and crosscutting. The production of the mine is not very large.

The shaft is sunk in breccia just outside the Bull Hill granite area. In general the rock is fine grained and dense, and appears to be largely phonolitic. A basaltic dike is encountered about 30 feet southeast of the shaft, on the 45-foot level. It is 18 inches wide, strikes N. 38° W., and dips about 80° SW. On the 165-foot level the dike is seen 100 feet southeast of the shaft with the same dip and strike, but with a width of 4 feet. Ten feet away and parallel to it is a brecciated and oxidized zone containing many fragments of basalt. One hundred feet northwest of the shaft a 4-foot basalt dike strikes N. 15° W. and dips about 75° E.; it is probably a branch from the first-mentioned dike.

Well-defined continuous veins are not shown by the workings, though several narrow seams partly filled with quartz are found in the upper levels.

The values occur principally in minute seams and veinlets in the dense, unoxidized breccia. These seams are filled with carbonates and carry tellurides. The average value of what has been mined is probably $40.

A small ore shoot descends approximately vertically from the surface. The shaft was sunk on it and for a depth of 25 feet extracted practically all the ore of the shoot. To the south of the shaft the body expanded and a chamber 20 feet

high, 20 feet east and west, and about 30 feet north and south was stoped out, furnishing about $6,000 of $30 to $40 ore without sorting. One of the flat quartz seams was reached at the bottom of this chamber, and the values extended only a few inches below it. In the shaft, however, the quartz seam was not recognized, probably having pinched out, and there the shoot continued down as above. About 60 feet from the surface it widened out toward the west. At 70 feet the second flat quartz seam was reached and the values went only a foot or two below it. Ore was stoped out 20 feet above the quartz seam for a width of 20 feet. About 25 feet west of the shaft a vertical quartz seam was encountered. This seam formed the western limit of the ore, but at the junction of the flat and vertical veins a small pocket of rich ore was opened toward the south. All the ore from this intersection gave returns of $500 per ton and a small shipment assayed 500 ounces. This intersection was stoped for 20 feet, and the vertical vein carried values for 14 feet below the flat vein; then pay ore gave out.

The central part of this ore body averaged $30 per ton as broken, and the coarser wall rock, running $12 to $15, was also mined and shipped.

A little ore was taken from the 300-foot level, but this was inaccessible at the time of visit, and the mode of occurrence was not ascertained.

BOGART MINE.

Adjoining the Sheriff mine on the northwest is the Bogart mine of the Mountain Boy Gold Mining Company. It has not been worked for some time and was not examined. The shaft is 260 feet deep and the workings expose the basalt dike which enters the Sheriff ground. Ore is said to have been found where this dike splits, and $13,000 was taken from two pockets, the ore averaging $30 to $40 per ton.

HAPPY YEAR MINE.

The Happy Year mine is a short distance north of the Bogart, and contains what is without doubt the same basaltic dike. The shaft, which is said to be about 500 feet deep, is in granite, but most of the workings were inaccessible. A tunnel farther down the hill follows the basalt dike and cuts the shaft at about 200 feet. The dike is much decomposed, varies from 6 to 30 inches in width, and is about vertical. Just north of the shaft a second basalt dike is seen a few feet west of the first and nearly parallel with it. The two dikes are said to come together above and at the junction to have made a considerable body of ore of rather low grade. About 100 feet southeast of the shaft the approximate contact of granite with breccia is seen. Both rocks are much altered and the contact is not at all sharp. The first-mentioned basalt dike is drifted on perhaps 300 feet south-southeast from the shaft. The production of the mine was not ascertained.

NEW YORK TUNNEL.

The portal of the New York tunnel, which penetrates Bull Hill, is situated at an elevation of about 10,100 feet, close to the eastern branch of Squaw Gulch, about 1,800 feet southwest of Midway. The tunnel is 1,500 feet long, with a direction of S. 65° E. The rock is granite, but is much shattered and in places holds fragments of volcanic material. Several kaolin-filled fissures and seams have been encountered and some of them have been drifted on, but, it is stated, without success.

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ALBANY TUNNEL.

The Albany tunnel, on the northwestern slope of Bull Hill, starts about 1,200 feet southwest of Midway station and is at an elevation of about 10,170 feet. Its course is S. 68° E. and it runs for about 1,400 feet in brecciated and oxidized granite. Shattered zones carrying kaolin and manganese are frequently seen, running in various directions. About 700 feet from the portal an 18-inch basalt dike strikes N. 40° W. and dips about 80° SW. The dike is much broken up, and the rock decomposed as usual. No ore has been found in the tunnel.

The Happy Year tunnel was described under the Happy Year mine.

WILD HORSE MINE.

The Wild Horse mine, which is controlled by the Woods Investment Company, is situated on the northern side of Bull Hill. Ore was discovered in it in 1897, and it was actively worked until 1903, when development in depth ceased. At the present time the upper levels are leased and low-grade ore for direct cyaniding is extracted. It is stated that the production has somewhat exceeded $1,000,000, and that about one-fourth of this amount has been disbursed in dividends.

The developments are very extensive; the vein has been followed for a distance of 2,400 feet on various levels. The mine is opened by the Wild Horse shaft, the elevation of the collar being 10,653 feet. The lower levels are principally opened from the Gleason shaft, which has the same elevation of collar and which is 1,250 feet deep, level 10 being turned at that depth. Drifts and crosscuts will aggregate between 2 and 3 miles in length. The mine never had any water, general drainage having preceded exploitation.

The Wild Horse vein outcrops near the eastern contact of the isolated area of more or less shattered granite which occupies the western part of Bull Hill and the southern part of Ironclad Hill. Fragments of phonolite are sometimes found in this granite and may be due to dikes wholly crushed by secondary movements. The rock is oxidized to a depth of 1,150 feet below the surface. As shown in the crosscut on level 10, the fresh rock is a loosely cemented breccia, the fragments being usually a few inches in diameter and containing plentiful disseminated crystals of pyrite. In places a little fluorite may be noted. The contact between granitic and volcanic breccia is more or less indistinct on the surface and is not exposed in the mine; however, the volcanic breccia usually contains a large amount of granitic detritus. Schist begins to appear in the hanging wall of the vein on level 4, underneath the Midway station, according to Messrs. Finch and Purington, and there are also one or two dikes of phonolite in the older rocks.

The Wild Horse vein is remarkable in several respects. It is curved, striking north-northwest in its northern portion, between Midway and the Wild Horse shaft. South of that point it assumes a north-northeast course, and has been traced for 1,000 feet to a point not far from the Ramona shaft. Near the Wild Horse shaft the apex of the vein lies practically on the contact between granitic and volcanic breccia, though it does not follow this contact in depth, but north of this point it enters the granitic area. The vein has been traced to a point underneath the gap at Midway. The dip is generally steep toward the west. South of

the shafts it is 60° or 70°, but the vein straightens northward to an almost vertical position. A small portion of level 2 is said to be driven in volcanic breccia, while the workings generally are contained in more or less oxidized granite.

The vein is ordinarily well defined, with two or more fairly regular walls, which, however, are apt to bulge out into swells at places where the ore body is wide. Some of the stopes are 25 feet wide. The ore consists of a thoroughly oxidized clayey mass, with some pure-white kaolin and a moderate amount of limonite, apparently not much more than in the surrounding granite breccia. There is very little quartz and the ore can be followed only by assays. The best pay is contained in the kaolin seams, some of which run up to $300 per ton, while the hard bowlders contain little of value.

The ore shoot which came to the surface a little south of the Wild Horse shaft was very well defined and pitched about 45° N. on the plane of the vein. Near the surface the ore was low grade and much of this material, suitable for direct cyanidation, remains in the upper levels. The length of the shoot along its pitch was 1,200 feet, while the horizontal dimension along the levels varied from 200 to 600 feet, the greatest length being attained on level 5. Good and poor parts were irregularly distributed; the richest stope, yielding $200,000, was near the bottom, above level 9, 970 feet below the collar; this was 40 feet long and 27 feet wide. Between levels 8 and 9 the ore became stringy and thin.

Level 10, turned 1,250 feet below the collar, showed the rock unoxidized; the crosscutting to the vein was greatly interfered with on account of gas, which sometimes filled the whole mine for days. At the end of the crosscut the vein was found, it is stated, but consisted chiefly of a loose mass of iron pyrites of little value. It was not, however, extensively explored. The pyritic granite breccia in the crosscut contained values up to $4 per ton. The lower levels have remained closed since 1903.

LONDONDERRY MINE.

The Londonderry mine is located on Ironclad Hill close to Midway. It has not been worked for many years, and very little ore has been extracted from it. The shaft is 300 feet deep, and its collar has an elevation of 10,550 feet. It is sunk in granite and schist and some drifts run on a vein presumably parallel to and west of the Wild Horse. The workings also extend a few hundred feet east to the Wild Horse vein.

GOLD SOVEREIGN MINE.

The Gold Sovereign Mining and Tunnel Company owns several fractional claims on the southwestern side of Bull Hill. The company has produced ore from two localities, viz, the Lovett vein and the Whisper block. The latter occurrence will be described in connection with the Dante mine, as the two properties here exploit the same set of veins. The total production to 1904 was $300,000, of which $100,000 was contributed by the Whisper part of the property. A new and very rich shoot was exploited in 1904 near the Lovett vein.

The developments consist of the Gold Sovereign tunnel, driven for 640 feet in a northeasterly direction, the elevation of the portal being about 10,001 feet, and the Jackson shaft, which opens the Lovett vein and is at present leased to the

Cripple Creek and Gold Temple Company. The elevation of the collar of this shaft is about 10,150 feet and the depth 645 feet. Seven levels have been turned, the seventh and deepest being 550 feet below the collar. The total extent of drifts and crosscuts is over 2,000 feet.

The country rock along the Lovett vein is latite-phonolite. Breccia occurs only on the southwest side of the vein, in the stope north of the shaft on the third level. A basic dike with a north-northwest strike follows the trend of the vein for the entire distance developed—about 600 feet; it also appears to the north in the Maggie prospect and to the south in the Trilby mine. It is not well shown on the surface. The width is rarely over 4 feet. In places it splits into two parallel dikes. While ordinarily much decomposed, fresh rock is obtainable in places. The dark, fine-grained rock contains large foils of biotite and the microscope shows it to be a monchiquite. A narrow phonolite dike also follows the trend of the vein and lies generally on the east side of the basic dikes.

The so-called Lovett vein is rather an ill-defined, almost vertical zone of fracture up to 50 feet wide than a single clear-cut vein. The trend is N. 40° W. It is crossed by the Fox vein, trending N. 60° E. and dipping steeply to the southeast. The Fox vein first appears 300 feet west of the Lovett, where it is exposed by a short tunnel, and is next cut by several drifts from the Jackson shaft, but has not been found on the lowest or seventh level. It continues for several hundred feet toward the northeast and is also exposed in the Whisper block. In character it is a narrow sheeted zone, 1 or 2 feet wide, carrying fluorite and quartz along its central fissure. Besides these two principal veins there are a number of flat seams, generally dipping southwest and exercising a decided influence on the ore bodies.

The ore occurs chiefly where flat seams intersect the Lovett vein or near the intersection of the Lovett and the Fox veins. It does not occur in the basic dike nor in the phonolite dike, but may be found on either side of them. Most of it is entirely oxidized, but on the lowest level calaverite is contained in the narrow seams.

Ore was found along the apex of the Lovett vein from the croppings of the Fox vein southward to the Lovett shaft, a distance of 200 feet. On the third or 250-foot level, 100 feet northwest of the shaft, there was a large ore body having dimensions of 100 by 100 by 20 feet. The stope was opened on a flat vein at the intersection with the Lovett vein, chiefly on the northeast side of the latter. There are two basalt dikes here 10 feet apart, but no ore occurs in them. Little else of value is found on this level. On level 4, 300 feet below the collar, the drift follows the basic dike south to the Fox vein, which seems to be locally interrupted by the dike; there is no proof, however, that the dike is really later than the vein. A good shoot 20 feet long has been stoped on the Fox vein up to the surface; it lies between the basic dike and the parallel phonolite dike. Two hundred feet south of the Jackson shaft the basalt dike crosses over to the west side of the Lovett vein. At this place is a stope in latite-phonolite about 35 feet long on the level and 2½ feet wide with particularly rich streaks, changing in position from one wall to another. This stope extends nearly to the surface.

The continuation of the same stope has been opened from level 7, 550 feet below the surface. Here the phonolite dike, 12 feet wide, lies on the east side of the basic dike. Very rich ore was found in 1904 in latite-phonolite between these dikes; the ore

body is at least 8 feet wide and contains calaverite in little fissures and spaces of dissolution. In the center of this ore body appears a flat fluorite seam, 6 inches wide, with a central veinlet of quartz. A few feet west of this point, near the basic dike, wholly oxidized ore has been stoped 100 feet high. Several hundred carloads were taken from this part of the shoot. Many small flat seams of great richness occurred in this stope, all dipping northwest.

TRILBY MINE.

The Trilby mine is situated on the western slope of Bull Hill, just south of the Gold Sovereign. It is owned by the Moose Gold Mining Company and is located on the Trilby fraction, which contains only four-tenths of an acre. The shaft is 585 feet deep, with 500 feet of drifts and crosscuts. Development work is in progress. The production is estimated at about $30,000. The mine is now being operated under lease by the Bayard Mining and Leasing Company.

Weathered latite-phonolite with its characteristic pitted appearance is disclosed in surface workings. The short upper levels of the mine were not visited. The country rock of the 400-foot level and below is breccia, in general only slightly or not at all oxidized. A basalt dike which shows no well-defined outcrops at the surface, but is exposed in the Trail workings on the south and the Gold Sovereign on the north crosses the property near the shaft. It appears to be irregular, and while only one dike is seen on the 400-foot level, there are three with corresponding position, direction, and dip on the 480-foot level.

Between the eastern and middle basalt dikes on the 480-foot level is a shattered mass of phonolite fully 15 feet wide. It contains a few fragments of breccia, but probably represents the phonolite dike which parallels the basalt in the Gold Sovereign workings. This phonolite was not observed on the 400-foot level.

On the upper levels some ore was stoped from pockets in the basalt dike. Thirty feet west of the shaft, on the 400-foot level, the narrow basalt dike appears striking N. 15° W. and dipping 85° W. It is drifted on to the north for 20 feet to the Gold Sovereign line, where the dike has widened to 6 feet. Near the line a stope has been made 6 to 12 feet wide and 20 feet high, at which height the values gave out. A 15-foot winze 15 feet from the line is in good ore.

Between the 400-foot and 480-foot levels the shaft cut a narrow oxidized seam which is vertical and strikes a little east of north. Just above the 480-foot level its dip changes to about 75°. Just south of the shaft on this level the vein widens and 1 foot of basalt comes in. The dike is said to be good ore at this point. Another basalt dike, 15 or 20 feet west of the shaft, has a steep dip to the west and strikes N. 15° W., corresponding in direction with the dike on the level above. It is being stoped to the south and gives $30 to $60 ore. When visited the stope was 20 feet high and 30 feet long. Toward the south the basalt narrowed and at last pinched out completely, and in the breast a 3 to 4 inch quartz vein, characterized by druses and vugs and carrying values of $300 to the ton in tellurides and free gold, had taken the place of the basalt. This quartz seam may be the same as that noticed on the level above.

Between this dike and that at the shaft is a dike-like zone of shattered phonolite. In the numerous minute seams tellurides occur, with occasionally free gold also, making this an ore body worth $20 to $50 per ton.

Thirty feet west of the shaft is a 1-foot basalt dike parallel to the second one; it is not drifted on as yet, but is said to constitute ore. No developments had been made on the 580-foot level.

The values seem to be intimately associated with the dikes, but no other conditions, such as cross veins or junctions, seem to influence the distribution of the pockets and pay shoots in these dikes.

TRAIL MINE.

The Trail mine is situated on the southwestern slope of Bull Hill, just south of the Trilby. It is at present controlled by the Woods Investment Company. The mine has not been regularly worked for some time, but formerly received considerable exploitation, though the production has not been great. The workings consist of a vertical shaft about 500 feet deep and several levels, of which only the two tunnel levels are accessible.

Both breccia and latite-phonolite occur in this mine. As in the Blue Bird, Gold Sovereign, and Trilby, the latite-phonolite appears to flatly overlie the breccia. The contact between the two is usually indistinct through brecciation of the latite-phonolite, but in the lower Trail tunnel the contact is sharply defined and dips flatly southwest. Numerous phonolite dikes, economically unimportant, are encountered in the various workings. Their direction is variable, but usually is between north and west. Three basalt dikes of a general northerly course are cut in the lower tunnel. One of them corresponds in position, strike, dip, and width to the basalt dike which passes through the Trilby and Gold Sovereign mines.

Each tunnel follows a nearly north-south vein which dips steeply to the west. It is said and seems probable that they are on the same vein, though the vein in the lower tunnel has a 4- to 10-inch streak of dense fluorite, while that above appears as only a narrow crack in oxidized rock. There are short stopes, timbered so that their height can not be ascertained, in several places along each tunnel. Eighty feet south of the shaft, on the upper tunnel level, a "mud vein" dipping steeply west and striking a little east of north crosses the main vein and is said to have made the best ore in the mine. The stope is not large. A stope 50 feet long, 25 feet deep, and 20 feet high has been opened just north of the shaft on the main vein. The ore was of medium grade.

DANTE MINE.

The Dante mine, together with the Whisper block of the Gold Sovereign mine, is situated near the High Line track on the southwestern slope of Bull Hill, at an elevation of about 10,350 feet. The Jackson shaft of the Gold Sovereign mine is located about 700 feet southwest of the Dante shaft. The Dante Gold Mining Company, owning the Dante claim, is controlled by the Reed Investment Company, of Colorado Springs, but the property is worked by a number of lessees; sometimes as many as eight sets are at work. The production is considerably over $100,000, and a similar amount has been produced by the adjacent Whisper block.

The developments consist of the Dante shaft, 450 feet deep, from which six levels are turned. The various veins are opened by a complicated network of drifts and crosscuts, probably aggregating 4,000 feet on both properties, but not extending beyond a circle with a diameter of 400 feet. The Whisper block of the

Gold Sovereign is developed by the Whisper shaft, 475 feet deep, and now being deepened further. It is 175 feet north-northwest of the Dante shaft. There are seven levels, the lowest 390 feet below the collar. The elevation of the lowest level is thus only 9,960 feet, while the Jackson shaft is down to an elevation of 9,505 feet.

On the surface latite-phonolite prevails, much of it in the form of loose slide rock, at least for 70 feet below the ground. The lower levels are generally in breccia, but this contains much latite-phonolite, and the line between the two formations is not distinct. A phonolite dike 25 feet wide and striking a few degrees west of north traverses the property between the two shafts and is exposed on several levels. This dike continues on the north into Logan ground. On the second level of the Whisper an equally wide dike of a peculiar latite-phonolite adjoins the phonolite on the east.

The veins as a rule are narrow, consisting of a central seam with quartz, calaverite, and a little fluorite; on both sides of this seam there are usually a few less distinct parallel cracks. The northeasterly trending Fox vein contains more fluorite than the others. The ore is mainly oxidized, but calaverite begins to appear in the lower levels. At least nine veins have been found on the property. Their relative positions are illustrated in fig. 42. Trending north or north-northwest are the Parallel, Whisper, and Blue Bird veins. The Parallel strikes north-south and stands nearly vertical. The Whisper strikes N. 30° W. and dips 60° SSW. The so-called Blue Bird has the same strike, but dips 70° NNE. Among the northeasterly trending veins the Fox strikes N. 60° E. and dips steeply south-southeast. The Moffat and the East veins, neither of which carry much ore, strike N. 40° E. and stand about vertical. The Fox, Whisper, and Parallel are the principal productive veins known from all levels.

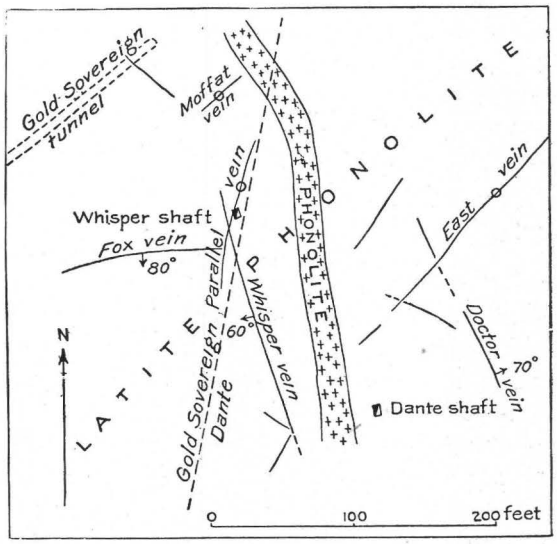


FIG. 42.—Vein systems in Whisper and Dante mines, chiefly on level 4, 240 feet below the surface.

The occurrence of the ore is strikingly dependent upon vein intersections. One of the principal shoots occurs along the intersection of the Parallel and Whisper veins, a line descending at a moderate angle toward the south and crossing the Whisper shaft at about level 4. Most of the ore was found on the Parallel vein. On level 7 the intersection is found 140 feet south of the Whisper shaft on the line separating that property from the Dante mine. Smaller stopes have also been opened on the Whisper vein at some distance from the line of intersection. Another ore shoot lies along the line of intersection of the Fox and Whisper veins, which dips southwest. At the intersection of the Fox and an unnamed vein parallel

to the Whisper ore occurred between levels 6 and 7. Some ore occurs in the dike of latite-phonolite on level 2 of the Whisper shaft. Along the west side of the phonolite dike on level 6 of the Dante lies another vein which has produced a little ore. Ore has also been extracted from the Blue Bird vein on levels 4 and 5. In its prolongation this vein would enter the Blue Bird claim a short distance southeast, but it is not one of the main Blue Bird veins.

BLUE BIRD MINE.

The Blue Bird Gold Mining and Milling Company owns the Blue Bird claim, on the southern slope of Bull Hill. The developments consist of one main vertical shaft 1,350 feet deep, with the elevation of collar 10,397 feet, several smaller shafts, and about 8,000 feet of drifts and crosscuts. Fifteen levels are turned, the lowest or level 15½ having an elevation of 9,048 feet. The production is stated to be $300,000. The mine was located and worked at an early date. When Penrose visited it in 1894, it had already attained a depth of 300 feet.

The country rock on the surface and down to level 4 is latite-phonolite, but at about that depth it is replaced by breccia, so that the massive rock seems to form a horizontal sheet above the breccia. A phonolite dike about 20 feet wide, with the usual platy parting, cuts across the southern part of the claim. Its trend is north-northwest, and it is probably the same dike which has been noted from the Dante and Logan mines. A small northwesterly trending basic dike was observed near the southern face of level 4 and not far south of the phonolite dike. Active oxidation has penetrated along the veins down to level 4. On the ninth and lower levels there is not much oxidation.

The main vein strikes about N. 5° E. and dips 60° to 90° E. in the upper levels. Below level 9 the dip changes to westerly, soon, however, resuming its easterly inclination. Locally the vein changes abruptly in strike and dip and is associated with much irregular fracturing, dominantly north-south, but of various dips. Some east-west fissures occur which do not fault the vein and which carry no one. Two shorter, almost vertical veins parallel to the main Blue Bird vein have been developed in the northern and southern parts of the claim; each is 100 feet distant from the main vein, the one to the east, the other to the west. They have been opened only to level 4.

The ores of the Blue Bird have always contained much silver; in places assays will give several hundred ounces to the ton. Copper carbonates were found on the upper levels. The first appearance of tetrahedrite, which is the principal argentiferous mineral, was on level 10. Below the oxidized zone the gold appears in calaverite or sylvanite, which occur chiefly in cracks in the massive fluorite of the vein, or in vugs in the same material. Tetrahedrite occurs massive with fluorite or in quartz, sometimes intergrown with massive tellurides; it is also found in medial vugs in spar veinlets in the deeper levels. It carries both gold and silver and is locally accompanied by a little pyrite. Stibnite is mentioned by Penrose from the upper levels. Nests of white kaolin, while common in the upper levels, are not known below level 5. The vein material in the main fissure is a compact, fine-grained mixture of purple fluorite and quartz, which no doubt is formed by the filling of open cavities; it contains sharply angular inclusions of little-altered coun-

try rock. This material is sometimes 3 feet in width. Secondary fracturing with opal and drusy quartz is often noted, and the ore seems to be associated with these disturbances. In places, such as in level 10, the vein appears as a sheeted zone 6 feet wide, divided in slabs about a foot thick. On level 4 the fissures pass through the phonolite dike, but no values are contained in the dike. On the twelfth and lower levels the vein shows fine parallel sheeting, with a great number of veinlets of dolomite which carry fluorite and tetrahedrite. The slight developments on level 15 show again the large fluorite vein with sharply defined inclusions of breccia. It is seen here that the spar veinlets are younger than the compact fluorite.

The main vein is opened for 900 feet horizontally, but the deep developments are confined to the vicinity of the shaft and a few hundred feet south of it. The surface shoots on the main vein extended down to level 6, 400 feet deep. One part seems to dip about 45° N.; the maximum length along the levels was 400 or 500 feet.

A smaller, northerly shoot almost connecting with this seems to dip southward, but extended only to level 3. From level 11 down to the bottom ore is stated to occur again. Some very fine specimens of tellurides and tetrahedrite have been found in this part of the mine.

DEXTER MINE.

The Dexter mine, situated on the Dexter claim, lies to the south of the Blue Bird, on the southwestern slope of Bull Hill. It is owned by the Dexter Gold Mining Company and is being worked under lease. Sinking was in progress at the time the mine was visited, the shaft being then 560 feet deep. Four levels have already been turned and a station cut for the fifth. The elevation of the collar is about 10,300 feet. Three other shafts on the property, now abandoned, increase the total developments to about 3,000 feet. The production of the mine has not been very large.

The shaft starts in the pitted, oxidized latite-phonolite which is characteristic of this slope of Bull Hill. As in the near-by mines, this rock is found to overlie breccia as a flat sheet. Level 1 is closed. Level 2, 200 feet below the surface, is in breccia, but the top of a 40-foot stope above this level shows the approximate contact of the two rocks. Three hundred feet S. 15° W. of the shaft on level 2 the contact is again seen, breccia to the east and latite-phonolite to the west. The contact is by no means sharp and its dip and strike could not be determined. A dike of latite-phonolite 20 feet wide crosses the level about 145 feet south of the shaft. The remaining workings of the mine are in breccia.

The veins of this mine belong to one very well-defined system, apparently corresponding to the westernmost of the three Blue Bird veins, a short distance to the north. They trend slightly east of north and dip very steeply to the west. One of these veins just west of the shaft, called the Fluorite vein, is a sheeted, partially oxidized zone in breccia, with kaolin and a brownish-black manganese oxide in the seams and a 2- to 8-inch seam of dark-purple fluorite sometimes carrying quartz. Fifteen feet farther west is a nearly parallel vein carrying more manganese and no fluorite, but otherwise similar. This is known as the Manganese vein. About 100 feet south of the shaft, on the 280-foot level, these two veins come together and continue for 50 to 60 feet, when they finally cross and resume their former courses. A 50-foot crosscut, east from the shaft on the same level, reaches

another vein of this system. It is similar in character to the others and holds kaolin, manganese, and soft, muddy fluorite in the seams. A fourth parallel vein, with manganese and much kaolin in the seams, occurs 120 feet west of the shaft, on the third or 320-foot level.

North of the shaft, on level 2, the Fluorite vein carried ore, the values occurring principally in the seams as rusty gold. The vein is stoped at this place 3 to 4 feet feet wide, 40 feet long, and 40 feet high.

A small amount of ore was taken from the Manganese vein directly west of the shaft, on level 2. On level 3 this vein is good ore, but has not yet been much developed.

Where the Fluorite and Manganese veins unite on level 2 a good body of ore has been formed. The rock is oxidized and considerably shattered and the values occur in the seams. The rock is reported to average $14 as mined, and the screenings are of better grade. A stope 60 feet long and averaging 10 feet wide had been carried up 40 to 50 feet at the time of visit. The ore is said to continue to the surface. This is the main ore body of the mine, and it is the intention of the leasing company to erect a cyanide mill to treat it. The breast of the drift on the Fluorite vein on level 3 was about 130 feet south of the shaft, and good values were just beginning, probably indicating the proximity of the Manganese vein. These two veins have been cut on level 4, but have not yet been developed.

The vein east of the shaft on level 2 is crossed just north of the crosscut by a narrow vertical seam, which is not observed elsewhere. At the intersection a couple of carloads of ore were taken out.

LAST DOLLAR MINE.

PRODUCTION AND DEVELOPMENT.

The Last Dollar Gold Mining Company owns the Last Dollar and Combination claims, covering an area of 18 acres. The mine is working on veins which lie in the general southward continuation of the Orpha May and Rubie vein system, and which, south of the Last Dollar, appear in the Modoc mine. The total production from April, 1896, when the property was acquired by the present company, up to March 1, 1906, is $2,090,396. Early in 1904 the mine was hoisting 100 tons per day and shipping 30 tons of ore per day.

The developments consist of a main vertical shaft 1,268 feet deep (in 1904), the elevation of the collar being 10,278 feet. Twelve levels are turned, the lowest 1,218 feet below the collar. The total length of drifts and crosscuts is probably 10,000 feet. South of the main shaft are three inclines called A, B, and C. B is the deepest, reaching down to level 6. The developments are almost entirely confined to the Last Dollar claim. The mine had some water a few years ago, but in 1904 the bottom level was dry.

GEOLOGICAL FEATURES.

The country rock in which the Last Dollar vein occurs is chiefly a syenite, at many points going over into latite-phonolite by gradual transition. Phonolite dikes are not uncommon, especially on level 12. Breccia occurs on levels 4 and 5 on the west side of the Modoc vein.

LODE SYSTEMS.

The Last Dollar and the Modoc veins form on this claim a practically continuous system of linked veins, striking N. 10° to 25° W.; they are either vertical or dip very steeply westward. A number of short cross veins intersect the Last Dollar veins on both sides of the main shaft; their trend is N. 50° to 60° E., and their dip very steep, say 75° NW. Actual intersections were not seen, but Mr. Charles Walden, the manager, states that the Last Dollar veins cut across the sulphide veins, and would thus appear to be the later of the two.

ORES.

The principal gangue minerals are a slightly greenish dolomitic mineral, with some fluorite and quartz. Above level 8 the ore is entirely oxidized, but below it calaverite is probably the most important ore mineral. Tetrahedrite, rich in silver, occurs on the Modoc veins and on the short northeast veins crossing the Last Dollar veins. Pyrite, zinc blende, and molybdenite, with a little galena, also occur on these cross veins, while they are practically absent from the Last Dollar veins.

Some of the stopes are 20 feet wide; a width of 4 or 5 feet is, however, more common. The structure of the veins is that of sheeted zones, in which, within a space of a few feet, there are up to 20 or more narrow, parallel carbonate and fluorite seams on which the calaverite occurs. The ore extracted in the mine is screened and washed, the coarse part being rejected as waste, while the screenings are of high grade. The cross veins have a similar structure in which a central seam, with vugs and pseudomorphic quartz is often prominent. Sometimes the central fissure will be filled by fluorite, several inches wide. The Modoc veins contain little fluorite.

PAY SHOOTS.

The most important ore shoot follows the intersection of the cross vein with the Last Dollar veins at the shaft, and thus dips 75° N. on the plane of the latter. The most productive part thus far exploited occurred in this shoot, between levels 4 and 8, but the shoot has proved rich as far down as the present developments have been carried—that is, to level 12. The greatest horizontal length of this shoot is 250 feet. Rich bodies of ore also occurred at the intersection with the main vein of several other cross veins located farther south, near shaft C (fig. 43). On the cross veins sulphides and tetrahedrite prevail, but it is believed that in these, too, the principal value lies in the calaverite. Pay ore extends on these cross veins up to a distance of 40 feet from the Last Dollar veins.

On the Modoc veins a shoot was stoped from the surface down to level 6, and recently good ore has been found on the same vein system on level 10. Explorations in the northern part of the claim have discovered some bunchy ore, but no regular shoots.

DETAILS OF THE LAST DOLLAR VEIN SYSTEM.

The Last Dollar vein really consists of three branches, which appear to unite 300 feet north of the shaft. There are practically no developments north of the shaft above level 4. The easterly branch, 75 feet east of the shaft, stands practically

vertical, and is opened for 250 feet north and south of the shaft, between levels 4 and 8. A westerly branch, not known on the upper levels, then appears; it passes a few feet west of the shaft, and has been developed on levels 9, 10, 11, and 12. Between the two lies a shorter branch, chiefly known from levels 8 and 9. The two main branches seem to split about 250 feet south of the shaft. Beyond the junction, 300 feet north of the shaft, the Last Dollar vein has been developed only on levels 5 and 11. It is poorly defined, sometimes showing only as a number of tight slips in the rock, and has a tendency to turn off to the west. At a small stope 400 feet north of the shaft, on level 5, the vein shows as a seam of fluorite 2 to 5 inches thick, with several subordinate parallel cracks. On level 11, 550 feet north of the shaft, a fractured zone, which probably corresponds to the main vein, contains fluorite and dolomite carbonates with scattered values. One hundred and fifty feet east of this point the extreme workings on this level have opened a narrow seam, rich in spots, with fluorite and tetrahedrite.

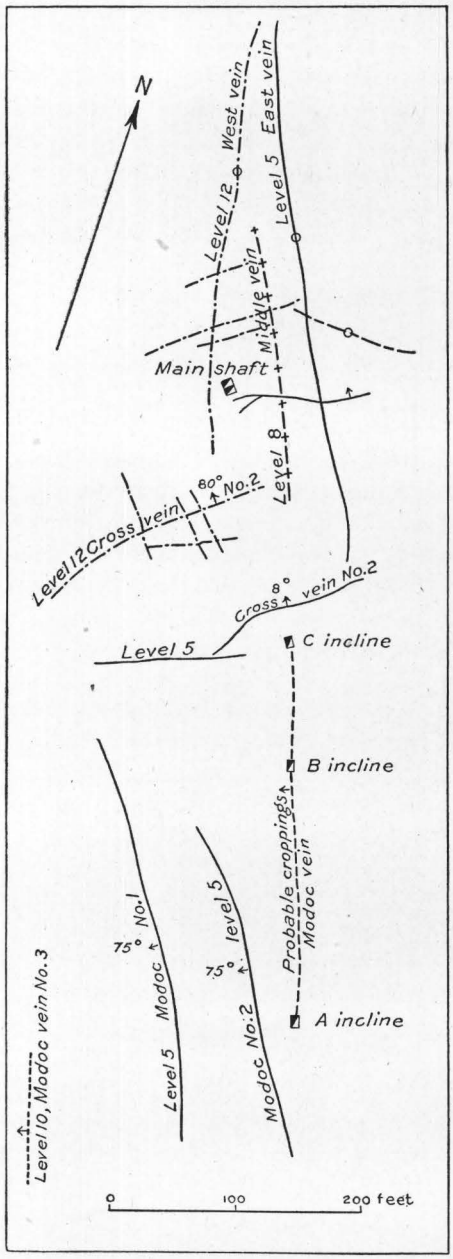


FIG. 43.—Vein system of Last Dollar mine, on levels 5, 8, 10, and 12.

On the Last Dollar veins the ore consists chiefly of tellurides, with dolomite gangue, also some fluorite and quartz, the whole forming a sheeted zone 3 or 4 feet wide. Open spaces are not common. Tetrahedrite is reported from a winze on level 12, on the main vein, but elsewhere seems largely confined to cross veins.

The cross veins are at least four in number. The first and most important crosses the shaft at about level 6 and is traceable from the surface down to the bottom level. It contains much fluorite in places, as well as vug holes along a central seam. On level 12 the second or south cross vein contains open spaces as much as 2 feet wide and 12 feet long. Secondary action by silica solutions, resulting in pseudomorphs of quartz after dolomite and celestite, is common. Massive pyrite, with zinc blende, tetrahedrite, and molybdenite, commonly occurs on the cross veins, but the values do not extend more than 40 feet from the main vein.

On level 12 a strong cross vein is cut 125 feet south of the shaft, being probably the same that appears on levels 5 and 6. Just west of the main vein this intersects a number of short veins trending a little more northwesterly than the main vein. This southerly cross vein has been followed out to the side line of the claim, but the values soon decrease, though pyrite and zinc blende still occur in its seams. On some of the levels the cross veins south of the shaft are not well developed.

Aside from some small ore bodies on levels 5 and 11, north of the shaft, the principal pay shoots occur at the intersections of the main vein with the first and second cross veins. The shoot at the main shaft has been followed 1,200 feet down; on the various levels it is up to 250 feet long along the main vein, and pay extends out on the cross veins for a distance of 40 feet at most on both sides. On the bottom level ore is said to extend for 180 feet north and 240 feet south of the shaft, establishing in fact a connection between the shoots on the north and south cross veins. Ore has been found also on various upper levels at the intersection of the cross veins south of the shaft, but it does not form as well defined a shoot as that near the main shaft.

In the upper three levels, now inaccessible, the main shoot lies just south of the shaft and at the intersection of the cross vein with a vein of the Modoc system, between the two branches of the Last Dollar vein. From levels 4 to 8 it jumped across to the intersection with the easterly of the Last Dollar veins, while from levels 8 to 12 it was transferred to the intersection with the westerly branch of that vein system.

DETAILS OF THE MODOC SYSTEM.

The Modoc veins are at least three in number and lie in the general continuation of the Last Dollar veins, but have a more decided westerly dip of 75°. The easternmost is opened on level 5 at the south end line of the claim, but is here unprofitable. It is the same as No. 2 vein in the Modoc mine, on which pay ore occurs. A central vein, the same as No. 1 or the principal vein in the Modoc mine, cropped on the surface for 400 feet and is opened by the three incline shafts A, B, and C, the second being the deepest and extending to level 6. This vein contained, between the surface and level 3, an ore shoot of fair proportions, which below level 3 becomes smaller and shows a tendency to pitch south. Between levels 5 and 6 the ore contained much copper and silver, indicating a partly oxidized tetrahedrite. The vein shows large vugs in a central seam, filled with loose material and coated with quartz and dolomite. Alunite, a secondary mineral, fills the medial seam in places.

The developments on level 10, the next one below level 6 in this part of the mine and the deepest at present, have shown the existence of rich ore with some tetrahedrite on this narrow vein. A third of the Modoc vein system has been opened in the extreme southwest corner of the claim.

MODOC MINE.

PRODUCTION AND DEVELOPMENT.

The Modoc mine, on the Ocean View claim, is owned by the Modoc Mining and Milling Company, and is situated a few hundred feet south of the Last Dollar, on the eastern slope of the broad gap separating Bull Hill from Battle Mountain. The property has been worked constantly since 1897 and has been a steady producer and dividend payer. Efforts to ascertain the total production have failed, but the mine has probably yielded approximately half a million dollars.

The shaft, which is situated near the north end of the claim, is vertical for the first 110 feet and then changes to a steep incline down to level 11, a total vertical depth of 675 feet. From level 11 a winze 400 feet deep extends down to level 15, which at present is the deepest. The elevation of the collar is about 10,150 feet, and the total depth 1,075 feet. Developments aggregate about 6,000 feet. Levels 7 and 9 extend practically through the entire claim, while those above and below are confined to the north end, except level 15, which is 800 feet long. At present (1904) work was carried on only from level 9. The mine has no water in the bottom, but gas fills the winze 200 feet and sometimes 400 feet deep.

GEOLOGICAL FEATURES.

The syenite area of the Last Dollar mine changes to breccia near the north end line of the Modoc property, and breccia continues as the principal country rock until the southern part of the claim is reached. The rock is of normal appearance and often contains much phonolite, but on the bottom level it is said to be loose and sandy, with open caves in places. A phonolite dike not more than 20 feet thick has been followed for 300 feet on level 9, 600 feet south of the shaft. A large and irregular mass of the same rock appears on the same level 200 feet farther south; it seems to be about 100 feet wide and extends at least 148 feet below level 9; possibly it is connected with the first-mentioned dike. The southern face of level 9 is in breccia.

VEIN SYSTEM.

The Modoc vein No. 1 is followed underground for 1,300 feet, almost from one end of the claim to the other. It is a narrow sheeted zone about 4 feet wide; the foot-wall seam is usually well defined, as is sometimes also a hanging-wall seam. Where the vein traverses phonolite, it seems less sharply defined, but the ore widens considerably. The vein curves slightly eastward, so that while at the north end the strike is N. 20° W. it has changed to N. 10° E. in the southern part of the property. The dip is constantly 75° to 80° W. A shorter and parallel vein called No. 2 is opened on the east side near the shaft on level 9 and on several of the upper levels. Many short seams cross the main vein, trending northeasterly near the shaft and southeasterly in the southern part of the claim. No faulting was observed at the intersections. A distinct but barren vein follows the first phonolite dike, 600 feet south of the shaft; its strike is northwest, its dip 70° NE.

ORE.

The general character of the Modoc ore is like that from the main vein of the Last Dollar. The narrow seams in the vein contain quartz, with a little dolomite, and are coated by tellurides. There is very little fluorite. The oxidation extends in places down to the bottom level, while some fresh tellurides were found as far up as level 2. In many places the veins contain a contact seam filled with a hard white substance which proves to be impure alunite, a potassium-aluminum sulphate, probably formed by oxidizing influences. There is little silver on the upper levels, but more on the lower; some tetrahedrite was found on level 15. In the southern shoot the ore contains as much as 28 ounces of silver per ton. A little zinc blende occurred on one cross vein, but the strong development of sulphides on these veins, so prominent in the Last Dollar, seems absent here. More pyrite occurred in the lower levels, but was here, too, associated with calaverite. The ore is of the usual high grade. At present a wide body of ore is mined at the south end of the claim, being taken out 18 feet wide in places. The screenings only are kept, but these run upward of 4 and as high as 8 ounces per ton. The ore in the phonolite is as good as that in the breccia.

ORE SHOOTS.

The ore in the Modoc vein, as in the Last Dollar, seems to depend on its intersection with cross veins or with joint systems having a northeast or southeast strike. The ore extends only a few feet on these from the main vein. Some ore has been mined from vein No. 2, but the most important part of the production has been derived from the main vein near the shaft. The stopes on the main vein extend to within 100 feet of the surface and to all of the lower levels except 14 and 15. On level 9 they are 150 feet long. A parallel shoot lies on the No. 2 vein, a short distance east of the main vein. To the south, on level 9 there are three smaller shoots, all occurring at intersections with cross joints; one is now being mined in phonolite from a winze 150 feet below level 9 and 850 feet south of the main shaft.

RUBIE MINE.

The Rubie property, adjoining the Last Dollar on the north, has been exploited under lease by the Princess Alice Gold Mining Company. Work was discontinued a few years ago.

The Rubie shaft is located 1,450 feet north-northwest of the Last Dollar shaft. It is about 800 feet deep, with drifts extending 300 feet north and 500 feet south. Three hundred and fifty feet to the south a winze has been sunk to an approximate depth of 400 feet. The main drifts follow a vein with occasional bunches of ore which lie in the direct northward continuation of the Last Dollar vein. The vein is vertical or dips very steeply to the east. At the winze mentioned a northeasterly trending cross vein intersects the main vein, and here a narrow pipe or chimney of good telluride ore was found, averaging in value about $60 per ton. This narrow shoot extended through a vertical distance of 400 feet. It had a rounded cross section, with a diameter of from 7 to 30 feet; was contained in breccia, and seemed to represent an old water channel. The gangue consisted of quartz, chalcedony, and fluorite.

STRATTON PROPERTIES ON BULL HILL.

SITUATION AND DEVELOPMENT.

The holdings on Bull Hill of the Stratton Cripple Creek Mining and Development Company, or of Stratton's estate, as it is commonly designated, form an irregular area reaching practically to the summit and covering parts of the southern and eastern slopes of that prominent point; irregular projecting points include the Longfellow claims on the southeast and the Los Angeles mine on the south. On the northeastern side the property includes the Zenobia mine, which adjoins the Pharmacist. The total area is approximately 200 acres.

The production was derived chiefly from the Orpha May, Mineral Rock, and Shurtloff No. 1 veins; accurate figures have not been obtained, but the total amount is considerable. From Hills's Manual the following data are obtainable; they extend only to January 1, 1900, but very little ore has been mined on the properties in question since that date.

Approximate production of certain claims of Stratton mines.

Los Angeles	$100,000	Zenobia	$141,000
Lucky Guss	327,000	Orpha May and Pikes Peak (Union Gold Mining Company)	1,000,000
Sacramento	10,000	Favorite	75,000
Specimen	125,000		

The production of Shurtloff No. 1, Logan, and Mineral Rock mines has not been ascertained.

During the first part of 1903 the Shurtloff No. 1 was worked to some extent through the American Eagle shaft, but in the early part of 1904 the entire system was idle. Work on the Shurtloff is reported to have been resumed in the latter part of 1904. Most of the following notes, except those on the Zenobia, are from reports of men formerly connected with the various mines, from a study of the surface, and from data obtained from the underground maps.

The developments are very extensive and comprise a total length of drifts, crosscuts, and shafts of at least 60,000 feet. Aside from a great number of smaller shafts there are three deep ones—(1) the John A. Logan, 1,400 feet deep, elevation of collar 10,472 feet, of sump 9,097 feet; (2) 950 feet east by south of this is the Orpha May, 1,264 feet deep, elevation of collar 10,538 feet, of sump 9,274 feet; (3) 1,200 feet north by west of this is the American Eagle, 1,500 feet deep, elevation of collar 10,750 feet, of sump 9,249 feet. All of these are connected by a remarkable system of crosscuts and drifts, developed according to the far-reaching plans of W. S. Stratton. Level 15, the deepest in the American Eagle, corresponds to level 12 of the Logan and level 17 of the Orpha May.

WATER AND GAS.

The bottom levels of the mines are dry. Gas has proved very troublesome in the Logan mine, especially in a crosscut on level 12, 500 feet northwest of the shaft, where it issues in large volumes. It is also said to be bad in the long east crosscut on level 13 in the Orpha May mine.

GEOLOGICAL FEATURES.

Volcanic breccia in places containing much latite-phonolite occupies the largest part of the area; but, as may be seen from the map, the area of massive latite-phonolite which covers the surface at the Gold Sovereign, Blue Bird, and Dexter mines throws out a wide branch northward on the west side of Bull Hill, almost reaching its summit at the Zenobia mine. This body of intrusive rock rests like a thick sheet on breccia, in which are most of the underground workings. A short distance east of this latite-phonolite, which may be called the Blue Bird area, appears another which is designated as the Altman area. This seems to reach down as far as the underground workings in the Findley mine have penetrated—1,500 feet. Whether the Shurtloff No. 1 vein is in breccia or latite-phonolite on level 15 of American Eagle has not been ascertained. At any rate, latite-phonolite must begin a short distance east of it.

A very prominent phonolite dike about 25 feet wide traverses the Logan workings with a north-northwest trend; it lies 200 feet west of the shaft and is cut by levels 3, 5, 10, and 12. A parallel dike is stated to lie 50 feet west of the shaft. The main dike continues through the Dante workings and is probably continued through the Blue Bird and possibly into the Colorado City mine. It forms part of the great phonolite-dike system of the Portland mine and may be identical with the Rigi dike crossing the southern part of the Modoc mine. In the Logan it is not reported to carry values.

Two persistent basic dikes cut through the central part of the properties in the Orpha May mine, and one of them at least is traceable on the surface for 2,000 feet. The western dike is exposed in the Favorite workings, where it dips steeply east-northeast; then in various crosscuts between the Eagle and Logan shafts, and finally in the Orpha May workings, where it is very productive and is intersected at an acute angle by the Orpha May vein. The other dike lies 200 to 300 feet farther northeast and is exposed by long drifts on Orpha May level 13 and Logan level 5. This does not seem to carry much ore.

The Isabella dike of dark trachydolerite is said to be intersected by the American Eagle shaft between levels 2 and 3.

VEIN SYSTEMS.

Several important vein systems traverse the property and at least three of them appear to converge toward a point from 500 to 800 feet north of the American Eagle shaft. Nearly all the veins trend north-northwest to north and stand vertical or dip a few degrees to the west. The Zenobia is the only one of importance which strikes northeast.

Beginning from the west the productive veins are as follows:

LOGAN VEIN.

The Logan vein is exposed on various levels near the shaft and trends north-northwest. It is said to have carried ore for 200 feet below the surface. The lower workings disclosed many veins in various directions like those of the Dante, but no ore shoots of importance are recorded.

The "Basalt" vein following the Orpha May dike trends about N. 32° W., but with considerable local deviations. The dip is nearly vertical or, in the Favorite mine, 75° E. In the latter ground it proved productive at least down to level 5. A nonproductive interval follows, and then, just northwest of the intersection with the Orpha May, good ore again occurred on it. Much ore was stoped from levels 9, 10, and 11, probably also on higher levels, but from 11 to 17 little ore is reported from this vein.

ORPHA MAY VEIN.

The Orpha May vein for 800 feet south of the American Eagle shaft trends due north; it then turns to N. 15° W. and continues with this strike through the Orpha May workings to the Lucky Guss and thence down through the Rubie to the Last Dollar and Modoc, a total distance of a little less than 1 mile. The vein is not continuous throughout, but is replaced at intervals by closely contiguous fissures. The dip is vertical or very steeply westward, as shown in the Porcupine shaft. The lode has been opened on several levels from the American Eagle shaft but is apparently not traceable far north of it; in this ground it is said to be nonproductive. It is next shown in the shallow Grouse shaft and 600 feet south of the American Eagle shaft, in the Porcupine incline, where it has been explored to level 6 and apparently produced ore. For 1,000 feet south of this point it has been developed by the Orpha May workings to a depth of 1,260 feet. Penrose describes the Orpha May vein as a fissured zone in massive volcanic rock, and shows four well-defined but short shoots on it down to the 97-foot level. The shoots are said to be more likely to occur where cross fissures intersect the main vein, which is interesting in view of the fact that the same holds true for the whole southern course of the lode through the Last Dollar and Modoc. The vein appears to have continued down to the bottom level, but little ore is reported on it below the upper levels.

MINERAL ROCK VEIN.

The Mineral Rock vein lies, with slightly divergent strike, a few hundred feet east of the Orpha May. It begins 550 feet north-northwest of the American Eagle shaft, where it strikes nearly north-south, as shown on level 5 of this shaft. From a point 300 feet north-northwest of the American Eagle shaft its course is very straight at N. 22° W. to the south end. It is opened by the following inclines, each about 500 feet deep, indicating an extremely steep westerly dip: Mineral Rock, Garfield, Pikes Peak, Orpha May No. 2, and Lucky Guss No. 2. Its northern part is also crosscut by levels 5 and 8 of the American Eagle shaft. It is opened by drifts on level 5 to a point 400 feet south of the Mineral Rock incline, and on levels 5 and 8 to a point 700 feet north of it. Levels 11 and 15 of the American Eagle crosscut it, but no drifts have been run. About 300 feet south of Lucky Guss No. 2 its continuation has been crosscut by level 11 of Findley shaft, but whether the same vein actually exists here is doubtful.

Penrose describes the Pikes Peak or Mineral Rock lode on page 196 of his report, saying that it consists of a zone of fissuring 3 to 4 feet wide; the vein itself is from 1 inch to 1 foot wide, wholly oxidized to the depth then attained—197 feet. The sheeted zone in places follows a phonolite dike from 1 inch to 18 inches thick. Near the surface it splits into three distinct veins.

There were several ore shoots along this vein, and some of them have been stoped to a depth of 500 to 600 feet. It is stated that little of value has yet been found below this depth. The best ore was obtained from Lucky Guss No. 2, which was opened to level 7 and was crosscut in two places by level 13, Orpha May shaft. The ore is stated to have continued down to level 6.

SHURTLOFF VEIN.

Shurtloff No. 1, a nearly vertical vein trending N. 36° W., has been opened for 800 feet by crosscuts from the American Eagle shaft on levels 5, 8, 11, and 15. Rich ore has been found on the latter three levels 900 feet east by south of the shaft. Tetrahedrite is reported to occur on the lowest level, which is 1,300 feet below the place where the vein should outcrop. The Findley veins lie a short distance to the east and have proved productive to at least 100 feet below level 15 of the American Eagle shaft.

Two veins which evidently lie in the same general zone as the Shurtloff vein have been intersected in the long Orpha May crosscut on level 13, 1,100 and 1,200 feet east of the shaft.

The Zenobia vein is described in connection with the Pharmacist and Burns mines (p. 401).

LOS ANGELES VEIN.

The old Los Angeles mine is situated between the Blue Bird and the Last Dollar; the Portland holdings adjoin it on the south. It has been idle for many years, but in 1905 several thousand tons of low-grade oxidized ore was extracted and treated by direct cyanide process.

MINES NEAR CAMERON.

The lower northern slopes of Bull Hill and Bull Cliff near Grassy Creek and the little town of Cameron are characterized by the prevalence of much comparatively fresh breccia of reddish-brown color and well-preserved fragments. The Isabella dike of trachydolerite extends down to Grassy Creek and has here been proved somewhat productive, though elsewhere it is entirely barren.

No great mines are situated in this vicinity, but the Pinnacle has a very creditable production, and blocks 8 and 10 have likewise proved profitable. The Morning Star, which is situated somewhat higher up on the slope, nearer to the Isabella, was worked in 1903 on a small scale by lessees, but closed later on. On the north side of Grassy Creek in this vicinity there are no developments of importance.

PINNACLE MINE.

The Pinnacle mine is situated on the northern slope of Bull Hill, above Cameron, at an elevation of 10,250 feet. Between 1897 and 1900 it produced about $250,000. The mine is developed by an incline shaft 100 feet deep, a vertical shaft 500 feet deep, and about 1,800 feet of drifts and crosscuts. It was closed in 1904.

The principal workings occur in breccia, but the contact with the latite-phonolite is reached in several places. The main vein of the mine is a sheeted fissure in breccia, striking northeast and dipping northwest. Another vein said to carry

quartz occurs to the southwest of this vein, with about parallel strike. A cross vein carrying fluorite intersects the main vein about 300 feet north of the vertical shaft.

The principal ore shoot began at the mouth of the incline shaft and extended southwesterly for 180 feet. It pitched to the southwest on the plane of the vein and crossed the vertical shaft at about the 96-foot level. At 140 feet the size and value of the ore body was very much diminished, but some work continued below that point. No ore was found below the 250-foot level. The richest part of the shoot occurred 125 feet below the surface, where the ore body was 25 feet wide and about 120 feet long. In most places the ore is about 4 feet thick. A small body of ore was taken out at the intersection of the main vein and the fluorite vein above the 173-foot level.

The ore was oxidized in all places except a small core where the ore body had its greatest width and where calaverite appeared. The value of the ore was high, running up to 76 ounces per ton. A 300-ton lot of 10-ounce ore was shipped at one time.

BLOCK 8, SCHOOL SECTION 16.

The tract of State land known as block 8, school section 16, is situated on the lower slope of Bull Cliff, near Grassy Creek, and east of Cameron. A lease on the property is being worked by La Montaigne Brothers, who in two and a half years have taken out about $85,000, which represents the total production of the mine.

A shaft 550 feet deep has levels turned from the 250, 350, and 550 foot points, the total development amounting to nearly 3,000 feet.

The principal rock of the mine is characteristic breccia, frequently pinkish or reddish, with remarkably little pyritization and alteration. In places, however, it is gray and more compact and can not always be easily distinguished from massive rock. Two basaltic dikes are exposed on the surface and appear in the underground workings. One of them, with a northeast strike, and dipping steeply northwest, passes about 150 feet east of the shaft. It can be traced down the hill to the creek and up the hill to the Isabella mine and corresponds in appearance to the dike seen there, being fresh and black, with noticeable phenocrysts of pyroxene. It is a trachydolerite and is 8 to 15 feet wide. The workings underground show that the course of the dike is not constant. It appears to veer more to an east-west course with increasing depth.

The other dike, which is seen about 75 feet north of the shaft, has an east-northeast course and a dip which is on the whole about 85° S., though it is slightly inclined here in one direction, there in the other direction, from the vertical. This rock is more decomposed, but where fresh is a dense black aphanitic rock, which the microscope shows to be probably in the class of monchiquites.

The crossing of these two dikes is not seen on the surface, but as they dip together the intersection is exposed on the 250-foot and again on the 450-foot level, and in both places the east side of the smaller dike is faulted about 10 feet to the north by the larger. This narrow basalt dike seems to have been intruded along a fissure earlier filled by a latite-phonolite dike. The width of the latite-phonolite is not

shown, but it is in several places cut and crossed by the basalt. It is seen on all levels but the first.

A second latite-phonolite dike 4 to 5 feet wide and practically parallel with the first is seen just south of the shaft on levels 2, 3, and 4.

Two hundred feet south of the shaft, on the 250-foot level, ore occurs in the larger basalt dike and for a foot or two on each side in the country rock. The values consisted of tellurides distributed in small seams and fractures. The rock was screened and the screenings, which formed a small proportion of the whole, shipped at $60 per ton. The stope at this place is 25 feet long, 15 feet wide, and about 45 feet high.

On the 350-foot level 150 feet south-southeast of the shaft a small pocket of similar ore occurred on the large dike, and a stope was carried 20 feet below the level 8 feet wide and 15 feet long. On the 450-foot level stoping above the level was in progress at the time of visit. The values here extend for a short distance out into the breccia.

No ore shoot of importance or persistence has been found on this dike. The ore occurs in bunches or pockets, at the edges of which the values decrease in all directions. No conditions influencing the concentration of gold-bearing minerals at these places were observed.

On the 250-foot level the workings explore the intersection of the two basalt dikes and the fault by which the larger one dislocates the smaller. On the west side of the fault plane a body of ore occurred along the small dike, which is here considerably decomposed. The ore carried both tellurides and free gold derived from them by oxidation. Although the sorted ore averaged 4 to 5 ounces, the valuable minerals were so disseminated that they could only rarely be seen. The stope is 35 feet long, 5 feet wide, and extends 20 feet above and 20 feet below the level. It yielded $4,000.

On level 2 another body of ore was encountered northeast of the main shaft. The values, mainly tellurides, occurred in the seams of the "basalt," and particularly near the latite-phonolite dike. The screenings were ore, and averaged about 20 per cent of the total rock broken in the stope. Their value was about $60 per ton.

The stope is 150 feet long, 5 to 6 feet wide, and extends from 40 feet above level 2 down to level 3, a total of 150 feet. Below level 3 the grade of ore was too low to be profitably mined.

On the bottom level a 250-foot drift on the small dike under the stope above encounters only $10 ore and no stoping has been done.

The latite-phonolite dike just south of the shaft has been drifted to the southwest, on level 2, and though some fair assays were obtained, no ore was found. On level 3 the dike is not prospected, but on level 4 it contains ore and drifting had just commenced at the time the mine was visited. The contact at each side is sharp and distinctly marked by a narrow veinlet. Small druses partially filled with comb quartz carry tellurides, which also occur in the seams of the dike. The surrounding breccia contains finely disseminated pyrite, but, except within an inch or two of the dike, does not carry values of importance.

BLOCK 10, SCHOOL SECTION 16.

A lease is being worked on block 10, school section 16, situated near Grassy Creek, just north of block 8. The workings consist of a vertical shaft 250 feet deep, with one level at the bottom representing 300 to 400 feet of prospecting.

A crosscut to the southeast reaches, about 50 feet from the shaft, the large dike seen in block 8. It is here 8 feet wide and about vertical. Parallel with it on the northwest side is a mass of phonolite, probably a shattered phonolite dike. Twenty-five feet farther to the southeast is a dike of dense reddish phonolite. Beyond it is the smaller dike seen in block 8, and just to the southeast of it is a 2-foot oxidized vein, with seams and stringers of manganese. Low-grade assays have been obtained from this dike. A drift runs southwest for 200 to 300 feet along the large basalt dike, and two crosscuts have been run southeast to the smaller dike and the vein. No ore has been found.

The shaft on block 7, which lies between blocks 8 and 10, was closed and not entered. It was worked under lease some time ago by the Woods Investment Company. They are said to have taken out $30,000 from a shoot between the two basalt dikes, which are here close together. The shoot pitches toward block 10, but the values gave out at a depth of 165 feet.

CHAPTER VI.—MINES BETWEEN ALTMAN AND GOLDFIELD.

ISABELLA LODE SYSTEM.

The first important lode system encountered when the Altman-Goldfield district is approached from the northeast is situated on the slope of Bull Cliff. The prevailing country rock is the usual fine-grained pyritic breccia, which, however, farther down on the north slope shows only a very slight degree of alteration. An intrusive area of latite-phonolite surrounds the veins in part. From the sections and descriptions given below its dike-like form, spreading near the surface to wider proportions, is clearly apparent. A very persistent dike of trachydolerite cuts across the lode system with a northeast strike (fig. 44).

The two mines described below, the Isabella and the Victor, were among the large earlier producers, and still continue to show a small output. Their northwesterly trending system of lodes is shown on fig. 44 and, like so many others, is characterized by a slightly divergent direction of individual veins. A depth of 1,200 feet has been attained in the Isabella and somewhat less in the Victor. The Buena Vista vein of the Isabella mine is especially persistent.

VICTOR MINE.

PRODUCTION AND DEVELOPMENT.

The Victor Gold Mining Company owns the Victor and Little Joe claims, on the northeastern slope of Bull Cliff. The total production is given as $2,216,671 to January 1, 1900, and the dividends paid to the same date $1,155,000. The last dividend was paid in December, 1898, and during the last few years the mine has been idle, except for a little leasing work in the upper levels. Shipping was resumed in July, 1904, and ore is reported to have been found on levels 5, 6, 8, 9, and 10.

The developments comprise the Victor vertical shaft, 1,800 feet southeast of the Lee shaft of the Isabella. The elevation of the collar is 10,547 feet, and the total length of drifts, shafts, and crosscuts between 2 and 3 miles. Fourteen levels are turned. Level 8 is only 429 feet below the collar. The lowest level is said to be about 1,000 feet below the collar.

GEOLOGICAL FEATURES.

The prevailing country rock on the surface and in the workings is a normal volcanic breccia, usually of fine grain. The trachydolerite which covers Bull Cliff does not appear in the workings. It is reported that a flat mass of phonolite was encountered on the lower levels.

VEIN SYSTEM.

The Victor veins trend northwest and show a tendency to diverge northward. The dip is 70° or steeper southwest. On level 5 the main vein is traced 550 feet

southeast of the shaft. Two hundred feet northwest of the shaft the vein branches. The East Victor vein continues, with a strike of N. 52° W. and dip of 68° SW., for 400 feet to the end of the claim, and then on level 3 for at least 400 feet farther into Isabella ground. The West vein is of less importance. Close to the Victor shaft is another junction from which diverges a connecting vein between the Victor and the Cheyenne system, at first with a strike of N. 80° W., but farther on in Isabella ground swinging about to a more northwesterly strike. The dip is steep to the southwest. It is developed on Victor levels 7, 8, 9, and 10.

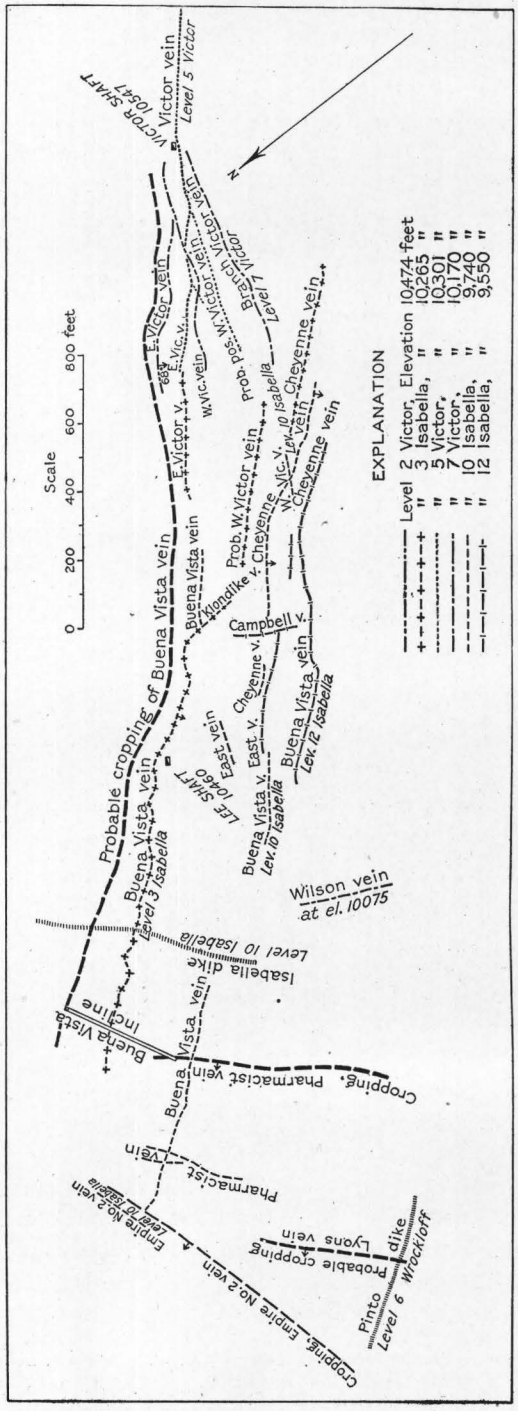


FIG. 44.—Map of the Victor and Isabella vein systems.

OCCURRENCE OF THE ORE.

The ore is said to have been oxidized throughout in the Victor workings, with the normal gangue of quartz, fluorite, limonite, kaolin, and manganese oxides. Little is known of the distribution of the ore. The most important shoot seems to have occurred within 400 feet on both sides of the shaft, near the point where the veins diverge. In depth the shoot became impoverished; it is stated that, like the Cheyenne shoot of the Isabella mine, a flat mass of phonolite was encountered which cut off the ore. At the northwest end line where the East Victor vein enters Isabella ground a very rich shoot occurred, the stopes of which were visited. It is in places 30 feet wide and extended down 40 feet below level 5, or 280 feet below the surface. There exists in the breccia at this point a system of flat joints which much resemble a rude stratification and which cut off the shoot at the depth mentioned. Crosscuts 120 feet below level 5 failed to find ore in Isabella ground.

ISABELLA MINE.

PRODUCTION AND DEVELOPMENT.

This property, owned by the Isabella Mines Company, consists of about sixteen claims forming an irregular area of 160 acres on the northern slope between Bull Cliff and Bull Hill. It was one of the most productive mines of the camp from 1895 to 1900. In 1899 the output reached the maximum, $968,000. The total sum is between $3,000,000 and $4,000,000, and dividends have been paid to the amount of $675,000. For the last few years the mine has been worked in a small way by lessees.

The mine is opened by the vertical Lee shaft, from which fourteen levels are turned. The elevation of the collar is 10,460 feet, and of the sump 9,332 feet. The first eight levels average 70 feet apart, while from 8 to 14 the distance between them is 100 feet. Level 3 is 202 feet below the collar; level 7, 438 feet; level 8, 520 feet; level 10, 720 feet; level 14, 1,120 feet. The Buena Vista incline is sunk on the vein 800 feet north-northwest of the Lee shaft, and follows it down to level 7. Level 3 corresponds with Victor level 5, and level 11 with Empire State level 11. The workings on the Pharmacist or Maloney and the Empire No. 2 veins are described on pages 393 and 395. There are several miles of drifts and crosscuts, chiefly on the Buena Vista and Cheyenne veins, which have been opened for a horizontal distance of 3,400 feet.

GEOLOGICAL FEATURES.

The croppings of the Buena Vista vein are chiefly in breccia, though between the Buena Vista and Lee shafts they run close to the contact of a southeastern projecting wing of the area of latite-phonolite which may be noted on the map on the northern slope of Bull Hill. For a few hundred feet southeast of the Lee shaft they cut through this dike-like wedge, and then continue into breccia to the Victor mine.

All the drifts from the Buena Vista incline and the ten upper ones from the Lee shaft show latite-phonolite, while breccia prevails on levels 11, 12, 13, and 14. These relations are roughly shown in figs. 45 and 46. From the latter it appears that the intrusive mass has really the form of a dike, gradually widening toward the surface and dipping steeply to the southwest.

The breccia is generally of normal character, with small but well-defined fragments of phonolite and latite-phonolite. It is apt to become harder and less pyritic some distance away from the veins, as shown in the long crosscut in the hanging and foot walls on levels 7 and 11. In the southeastern part of the mine the breccia is light colored, fine grained, and contains flat joints which in places clearly follow a rude stratification. The breccia near the phonolite sheet on the Cheyenne vein contains many fragments of that rock. Granitic fragments are said to be very abundant on level 14 (at present under water), and it was even stated that massive granite occurred on that level in the crosscut to the Cheyenne vein.

A thick sheet of phonolite with a flat northwesterly dip is encountered in the workings south of the Lee shaft on levels 10, 11, and 12. A smaller sheet, also

dipping northwest, is encountered on levels 10 and 11 below the projection of the Buena Vista incline. The same intrusive body is probably met in the long crosscut

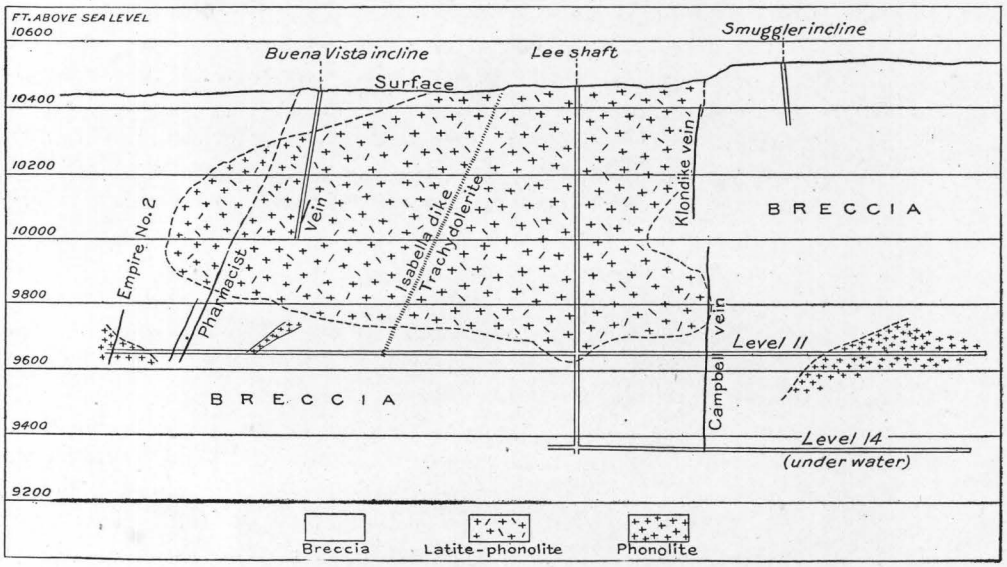


FIG. 45.—Longitudinal projection of the Buena Vista and Cheyenne veins of the Isabella mine.

in the foot wall on level 10, 250 feet southeast of the collar of the Buena Vista incline, at the point where the Isabella basalt dike cuts through it. A third very large body of the same rock, with a probable flat southeasterly dip, begins a short distance northwest of the Maloney vein on level 11, and is also shown on level 10 north of the crossing of Empire No. 2 vein, which cuts through it for a long distance. A very persistent but narrow dike of trachydolerite, called the Isabella dike, cuts through the workings between the Lee and Buena Vista shafts and is especially well exposed on level 10 in a long crosscut in the foot wall.

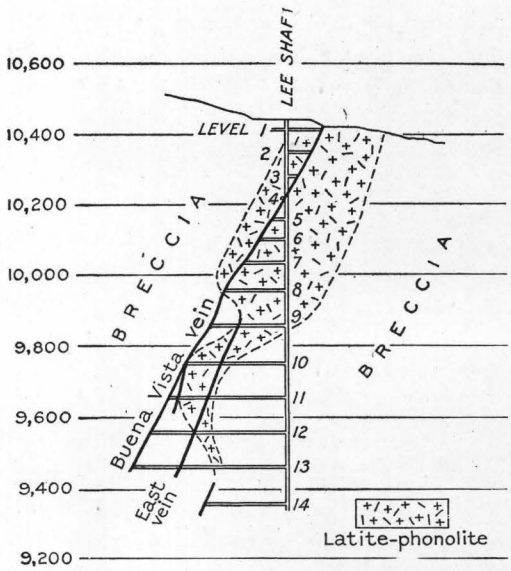


FIG. 46.—Cross section of the Buena Vista and East veins at the Lee shaft, Isabella mine, looking northwest.

VEINS.

The principal vein system trends N. 40° W. and the fissures dip southwest at 60° or steeper. This system is crossed by several northeasterly trending veins. The most important and most continuous of the northwesterly trending veins is called the Buena Vista; from the upper workings this vein would seem to be continuous with the East Victor vein, and it has been followed on several levels for

1,600 feet north and 500 feet south of the Lee shaft. The farthest point to which it has been traced is 1,550 feet northwest of the Lee shaft on level 11, but it is not known on the surface above this point. There is, however, in this vicinity a small vein dipping 30° N. on which the Comet incline, 100 feet long, has been sunk and a little ore obtained. The dip, as shown in fig. 46, is fairly regular, averaging 65°. Southeast of the Lee shaft, and on the lower levels, the Cheyenne veins join the Buena Vista, but farther to the southeast swings away from it, assuming a strike of N. 40° W. The Cheyenne is followed on many levels 1,200 to 1,400 feet southeast of the Lee shaft; in the lower levels it is steep, but flattens out above level 7.

The three branches of the Victor vein in the southern part of Isabella ground strike about N. 60° W. and the westerly branch practically intersects the Cheyenne on level 10, but they do not persist farther than a point 600 feet southeast of Lee shaft. The East vein lies 100 feet northeast of the Buena Vista and is opened near the Lee shaft on levels 9 to 13. A third parallel vein has been cut on levels 13 and 14, 100 feet nearer the shaft (fig. 46).

Among the northeasterly trending cross veins the Empire No. 2 intersects the Buena Vista on levels 9, 10, and 11 about 500 feet north of Buena Vista incline, but has not been followed far on the foot-wall side. The Pharmacist intersects on levels 9, 10, and 11, 250 feet north of the projection of the same incline. Its apex should cross the Buena Vista near the incline, but is not known here. A smaller cross vein was noted at the incline on level 5. The Klondike vein, striking N. 10° E. and nearly vertical, is known only on the seven upper levels, 400 feet southeast of the Lee shaft. On levels 10, 11, and 12 this is replaced about the same distance from the shaft by the vertical Campbell vein, which strikes N. 35° E.

With one exception no faulting is noted at intersections in the cross veins. At the Klondike crossing, however, south of the Lee shaft, the Buena Vista vein has been faulted from 20 to 50 feet, the southeastern part being thrown to the west.

OXIDATION.

The original water level was unusually low in the Isabella, 900 feet below the collar being the figure given. As a consequence oxidation has followed the veins down to the bottom level, 1,100 feet below the collar, though, in the lower levels, much calaverite was mined with the free gold. In the massive rock on both sides of the Buena Vista incline tellurides were found on level 2, and in places on lower levels of that incline the vein is almost free from oxidation.

ORE AND VEIN STRUCTURE.

The oxidized ores are of normal character—a soft mixture of ferruginous clay, pure kaolin, and quartz, with occasional seams of manganese, all carrying rusty gold. Fluorite is rarely abundant, the calaverite generally being contained in quartz-lined seams with occasional vugs. Tetrahedrite occurred in most of the levels of the incline from 2 down. It has also been found on the same Buena Vista vein at the junction with the Cheyenne on level 11, a short distance north of the crosscut from the Lee shaft.

All the veins show the usual type of narrow, sheeted zones, sometimes with only one prominent central seam. The Cheyenne on level 3 shows as a single seam of entirely oxidized ore. On level 7 the Cheyenne and West Victor veins lie closely together and two systems of seams appear, one dipping 70° SW., corresponding to the latter, and the other very steep, corresponding to the former. On level 10, where the Cheyenne vein was very rich, it appeared as a streak of brown mud 3 to 4 feet thick, composed of crushed quartz and limonite. On level 11 the well-defined vein with seams of fluorite dipping 60° SW. is a barren brecciated zone 2 to 4 feet wide. On the two lowest levels the oxidized vein remains well defined by several strong seams, but the mineralization seems less prominent than on the upper levels.

The Buena Vista vein on the various levels of the incline is a sinuous and narrow sheeted zone, at most 6 feet wide, and in many places very seamy and brecciated. Fluorite is present locally as a central veinlet, up to 6 inches wide. The seams are generally coated by quartz and more or less open. On the lowest levels this vein continues through breccia and phonolite as a system of narrow seams from 2 to 3 feet wide, but becomes less distinct toward the north. At the crossing with the Empire State No. 2 the Buena Vista vein is not well defined. There is a slight alteration of the country rock in the sheeted zones by the introduction of pyrite and dolomite, but it rarely masks the character of the rock. The East vein is similar to the Buena Vista. The Klondike and Campbell cross veins, about 400 feet southeast of the Lee shaft, are vertical sheeted zones with little evidence of mineralization. On level 12 the latter is very wide and carries values of low grade.

ORE SHOOTS.

On the Victor vein system, in Isabella ground, there are at least six well-defined shoots. The southernmost, the West Victor, carries a small ore body reaching to 250 feet below the surface and dipping 45° NW. On the East Victor vein in the same vicinity a rich shoot extended into the Isabella from Victor ground, also pitching northwest and attaining a width of 30 feet. It gave out 350 feet below the surface and is said to have stopped at flat seams in the breccia, some of which carried ore themselves.

Next follows the big Cheyenne shoot, on the vein of the same name. It begins on level 3, 1,200 feet southeast of the Lee shaft, and continues, pitching 45° NW., to a line 25 feet below level 10, where it encountered a large body of dense phonolite in which it rapidly impoverished. The richest ore was found at this point, and furnished a carload of 27½ tons which is reported to have yielded $219,000.

The Klondike and Campbell cross veins have yielded no shoots of importance, though small bunches of ore may occur on them close to the Buena Vista vein.

The shoots on the latter number three. The first is a narrow vertical chimney beginning on level 11, 400 feet south of the Lee shaft, and continuing to the surface, widening out here considerably and practically connecting northward on level 3 with the next shoot just north of the shaft. The second is also a vertical chimney at most 100 feet in length, the width of ore on all of the shoots averaging 3 feet. It begins on level 12 and, like the first, widens on level 3, connecting with the Incline shoot so that near the surface there is an almost continuous ore body 1,600 feet long. The Incline shoot also begins on level 11 and is stoped continuously with greatly

varying width to the surface. Near the surafce the stopes are very extensive, reaching 10 feet in width. On level 12 small spots showing values are encountered below the principal shoots. The East vein contains a few small stopes; one was seen on level 14, 500 feet south of the shaft.

Summing up, we have, then, on the Victor system in Isabella ground, three shoots dipping at 45° NW. and three others about 90°, on the plane of the vein. No definite laws governing their occurrence could be found. It is true that one of the vertical shoots nearly coincides with the crossing of the Campbell and Klondike veins, but no similar causation can be adduced for the remaining two. The ore almost invariably pinches when dense, normal phonolite is met.

MINES BETWEEN THE VICTOR AND VINDICATOR VEIN SYSTEMS.

GENERAL RELATIONS.

The two great systems of linked veins named respectively the Victor and the Vindicator both trend northwesterly and are separated by a space 1,500 feet in width. This space within a distance of 3,000 feet contains a number of smaller mines, most of which are working on veins with a northeasterly strike. Some of these veins continue up to the Isabella veins of the Victor system, but they are not as a rule productive on the northeast side of that system. The following mines, named from north to south, are described: Empire State, Pinto, Burns, Wrockloff, Pharmacist, Zenobia, Mercer, Murphy, Pueblo, Wacu Weta, Deadwood, Trachyte, Pearl, Deadwood No. 2, and Delmonico.

Two basic dikes, classified as vogesite, cross the Empire No. 2 and Pharmacist veins with northwesterly strike; one of them, the Pinto dike, has been productive in the Wrockloff mine and at the intersection with the Pharmacist vein. The same dike probably appears in the Deadwood No. 2 mine. The veins do not differ markedly from the ordinary type of sheeted zones; they often carry much fluorite. The country rock is breccia, with irregular masses of latite-phonolite and smaller bodies of phonolite. No marked influence of the inclosing rock is shown in the ore shoots, except that the veins often become less productive when entering the dense, normal phonolite. The most northerly of these veins is the Empire No. 2 or Emma No. 2, which continues with a strike of N. 78° E. and steep northerly dip for 1,200 feet west of the Buena Vista vein in the Victor system. The second is the Pharmacist vein, extending, with a strike of N. 50° E. and dip of 60° NW., from the Zenobia to the Isabella vein, a total distance of 1,600 feet. It has been very productive and is still actively worked. The third cross vein is the Wilson, which strikes N. 35° E. and is not known to intersect the Isabella. The fourth and fifth are the Klondike and Campbell veins, striking respectively due north and N. 30° E., both known only at the intersection with the Isabella vein. It is interesting to note that these veins all converge toward a point 900 feet northeast of the Buena Vista incline.

EMPIRE NO. 2 VEIN.

PRODUCTION AND DEVELOPMENT.

This vein is partly on Isabella, partly on Empire State ground; it also cuts through the northern part of the Pharmacist claim. The name Emma No. 2 is

sometimes applied to it. It will be more convenient to describe the deposit as a whole rather than each property separately. It has not been possible to ascertain the total production, but it is probably not far from $200,000.

The developments comprise three shafts, named the Edwards, Saunders, and Murphy, the last two 600 feet apart and respectively 475 and 450 feet deep, surface elevations ranging from 10,470 to 10,516 feet. In addition levels 10 and 11 of the Isabella have opened the vein at depths of 725 and 840 feet below the surface. There are probably 4,000 feet of drifts and crosscuts.

GEOLOGICAL FEATURES.

The croppings are near the contact of breccia and the mass of latite-phonolite which farther south, at the Buena Vista incline and the Lee shaft, narrows to dike-like proportions. The western part of the outcrop is in latite-phonolite. The old workings of the Murphy and Saunders shafts were not visited, but on level 10 of the Isabella a large mass of dense phonolite, not known on the surface, has been exposed. It is probably one of those flat intrusive bodies so common in this district. The phonolite begins a short distance north of the big stope at the intersection with the Buena Vista vein and continues for several hundred feet to the end of the drift, about halfway between the projection of the Saunders and Edwards shafts. A crosscut south connecting with an upraise to the Wrockloff workings passes into breccia 200 feet from the vein.

The same body of phonolite appears on level 11, where the impoverished vein at the crossing with the Buena Vista is in this rock. Phonolite appears again on this level for 200 feet east of the projection of Saunders shaft. Another mass of phonolite of more dike-like form was noted on the same level 1,000 feet from the Buena Vista intersection, where the drift leaves Empire No. 2 vein and turns into a south crosscut. A basic dike, probably the Burns dike, here crosses the vein and is locally contained in phonolite.

The Pinto dike is crosscut 150 feet east of the Burns dike. Both have been followed for some distance. At the intersection with the Empire No. 2 vein the Pinto dike has been faulted 10 feet, the southern part of it being thrown to the east.

The appearance of gneissoid granite on level 11 is of interest, as no older rocks appear on the surface above. The exact point where the Emma vein enters the granite on level 11 is 1,400 feet N. 80° W. from the Buena Vista incline, while on the surface it is a full half mile to the nearest outcrop of older rocks. For some distance back of the contact the breccia contains much granite; the contact itself is fairly sharp and stands very steep; the granitic rock is a somewhat sheared and gneissoid Pikes Peak granite, with large crushed orthoclase crystals. It is not brecciated like the isolated area on the west side of Bull Hill. The same rock continues for 400 feet west side of the contact to the end of the drift, and is said by Mr. L. S. Grant to continue 400 feet farther to the end of a south crosscut, which, however, it was not possible to enter.

THE VEIN.

As stated above, the Empire No. 2 vein strikes N. 78° W. and has been followed for 1,200 feet on one of the upper levels, as well as on Isabella level 11. The dip is very steep to the north; either it is somewhat irregular or there exist on

several levels fissures branching from the main one. Intersections with the Buena Vista vein at its extreme northwest end, where it is not very well defined, have been exposed on Isabella levels 5, 9, 10, and 11. The vein is a narrow sheeted zone, whether in breccia, phonolite, or granite. In the breccia near the Buena Vista vein it widens in places to 40 feet, but is ordinarily only 2 to 4 feet in width. In the fresh phonolite on level 11 it consists only of one central and three lateral seams filled with a little crushed quartz and tetrahedrite. Partial oxidation continues to level 11, though tellurides prevail in the ore on both 10 and 11. Tetrahedrite occurs in places either alone, as mentioned, or associated with calaverite; for instance, at the small stope on level 10 below Saunders shaft.

ORE SHOOTS.

The vein contains two shoots near the surface and at least two on levels 10 and 11. The Murphy shoot, 100 feet long and pitching steeply west, reached a point 350 feet below the surface. The Saunders shoot had about the same horizontal length and pitch, but pinched 200 feet below the surface; it yielded $40,000. On levels 9 and 10 a very rich shoot was found at or just east of the intersection with the Buena Vista vein; its length is 100 feet, and the greatest width 40 feet; on level 11 it had pinched in a mass of phonolite. A small body of payable ore was reached on level 10 below the projection of the Saunders shaft; still another kidney of ore was taken out on level 11 and just below it, in granite, 500 feet west of the Saunders shaft.

To sum up, the shoots on this vein pitch steeply west and have an elongated form. The big shoot on levels 9 and 10 is clearly dependent on the intersection with the Buena Vista, itself locally unproductive, at a point above a mass of dense phonolite. The Saunders shoot lies directly east of the Pinto basalt dike. No law was recognized governing the position of the other shoots.

PHARMACIST VEIN.

The Pharmacist vein was one of those worked in early times, and a description of it may be found on page 194 of Penrose's report. The vein is continuous for 1,000 feet from the Buena Vista vein, which it intersects in its lower levels, to the faulted crossing of the Zenobia, a short distance west of which it seems to die out. On the surface the country rock is chiefly breccia, but in depth the vein at many places enters the Altman area of latite-phonolite. The strike is northeasterly; the dip averages 60° NW. Ordinarily the vein is a normal sheeted zone containing tellurides and quartz. There is much fluorite in the eastern part, while on the western side this mineral is nearly absent. Instead, open spaces filled with smoky comb quartz prevail. Several shoots occur, chiefly pitching steeply eastward, while on the Empire No. 2 westward pitch is the rule. Most of them seem to be connected with intersections of other veins, and one occurs at the intersection with the Pinto basalt dike.

EMPIRE STATE MINE.

The Empire State Gold Mining Company controls the eastern part of the Pharmacist and Empire No. 2 veins near their intersection with the Buena Vista. The production is at least $600,000, of which $300,000 is stated to have been taken out from the big stopes at the intersection just mentioned.

The developments comprise the Empire State or Orphan shaft, which connects with level 11 of the Isabella (elevation 9,650 feet), called 7 of the Empire State, the elevation of the collar being about 10,550 feet; and the Maloney shaft, located 300 feet farther south and 400 feet deep. Drifts and crosscuts probably add up to 4,000 feet. The workings on the Empire No. 2 vein have already been described.

Both shafts are in breccia, as are the workings on lower levels near the Buena Vista vein, but on the western side of the crosscut from the Maloney shaft the drifts soon run into latite-phonolite through an indistinct contact. In one of the stopes 30 feet above level 4 the vein has a sharply defined central seam of fluorite, 2 inches wide, with several smaller seams on each side, and breaks with fairly well-defined foot and hanging walls. Twenty feet southwest from this place the same width is shown, but the vein consists of twelve very narrow veinlets of fluorite, with occasional small quartz vugs. On level 10 of the Isabella, at the east end of the stope, the vein shows a well-defined seam surrounded by silicified and pyritic breccia, gradually changing to normal rock within 1 foot on each side of the vein.

The principal shoot worked from the Maloney shaft appears to begin in Pinto ground, it is said at the intersection with the so-called Harrington vein, which was not, however, identified at greater depth. It pitches steeply eastward down to level 4; the maximum length is 200 feet. Probably the same shoot is found again on levels 5, 6, and 7 of the Orphan shaft, corresponding to 9, 10, and 11 of the Isabella mine, and lies chiefly on the west side of the Buena Vista vein, though on level 10 the stopes extend 30 feet north of it. Between level 9 of the Isabella and level 5 of the Maloney shafts 200 feet of backs should exist if the shoot really is continuous.

PINTO MINE.

INTRODUCTION.

The Pinto mine is situated on the saddle between Bull Cliff and Bull Hill, just north of the main street of Altman. It is owned by the Free Coinage Gold Mining Company. The production of the mine has been close to $1,500,000. The workings consist of a 575-foot shaft and about 5,500 feet of drifting and crosscutting. The elevation of the shaft collar is about 10,625 feet.

GEOLOGICAL FEATURES.

The principal rock of the mine is latite-phonolite. About 500 feet east-southeast of the shaft, on the 350-foot level, breccia begins and continues to the end of the workings. Three basaltic dikes are encountered in the mine. A large dike, 10 to 20 feet wide, nearly vertical and with an east-northeast course, is cut in two places south of the shaft on the fifth or 550-foot level. It corresponds in direction, and in appearance also, with the large dike which can be traced on the surface from the Eagle mine to the Isabella mine. It may be called the Isabella dike. Two hundred and fifty feet south of the shaft the same drift crosses a second dike, 4 to 7 feet wide, which strikes N. 25° W. and is practically vertical. This is known as the Pinto dike. It is characterized by the presence of brownish-black mica, and is

in most places considerably decomposed. The Isabella dike is seen to cut directly through the Pinto dike, and no evidence of faulting could be found. The latter dike has been opened in all levels. The third basaltic dike, known as the Harrington vein, is best seen in the southeast crosscut on level 5, about 150 feet from the shaft. It strikes N. 10° W. and dips steeply to the east. Basalt does not occur throughout the fissure, but alternately pinches out and comes in, everywhere much decomposed. The Harrington vein intersects the Pharmacist on several levels up to the 100-foot level.

VEIN SYSTEMS.

The principal vein of the mine is the Pharmacist vein. Its course is N. 60° E. and it dips on an average 62° NE. The shaft was sunk on the apex of this vein, and at the various levels crosscuts have been run to the north to reach it. So much stoping has been done that the vein can be examined in only a few places. On level 2 to the east of the crosscut it appears as a narrow crack, sometimes opening into small lenticular vugs holding quartz. The country rock is hard latite-phonolite, very little oxidized except close to the fissure. In places the fissuring is not confined to a single point, but spreads out into a zone 2 to 3 feet wide.

The Pinto basalt dike, which is itself of economic importance, is cut by this vein, and the Harrington vein or dike, which is elsewhere valueless, influences the richness of the ore at its intersection with the Pharmacist vein. The crosscut to the southeast on the 550-foot level reaches the Wilson vein 650 feet from the shaft. This vein consists of a series of parallel seams in silicified breccia, not much oxidized. It carries no ore on this level. Its course is about N. 35° E., and it dips very sharply to the northwest. Near the crosscut it is intersected by a sheeted zone which runs north-northwest and gives low-grade assays. The drift on the Wilson vein should cut the Pinto basalt dike about 750 feet from the shaft, but the dike apparently breaks up, for, though fragments of basalt are found about where the dike ought to be, no regularly defined body of that rock is encountered.

The Pharmacist vein carries values principally as rusty gold, but with here and there patches of tellurides in the crevices which make up the vein. The screened and sorted ore averaged about $40 per ton where mined, but in places it was of too low grade to be worked. The vein is stoped practically continuously from 250 feet down to 550 feet from the surface across the property. At the intersection of the Harrington and Pharmacist veins an irregular ore shoot 5 to 20 feet in diameter, was stoped from above the 100-foot level to the 350-foot level, at which point the shoot passed into Empire State ground. The average value of the ore from this shoot was 4 ounces. Where the Pharmacist vein crosses the Pinto dike occurred one of the rich ore shoots of the camp. The values were largely in the basalt and consisted of both tellurides and derived rusty gold, while the Pharmacist vein and the mineralized country rock near the dike were completely oxidized. The ore was shipped as mined, and gave returns of 7 to 8 ounces. This rich ore occurred in a body with a roughly circular horizontal cross section 6 to 15 feet in diameter, and reached from the surface to where it left the Pinto ground, 90 feet below the 550-foot level. At this point the shoot was impoverished.

On the Pinto dike ore occurred on level 2, 100 feet south of the Pharmacist vein. A pay streak 1 foot wide on the west side of the dike in the soft decomposed

basalt gave shipments of 2 to 3 ounce ore. A stope, 75 feet above and 60 feet below the level, has been made along the dike for 70 feet. At the south end the dike is cut off by a fault whose direction and displacement are not shown by the developments. On level 5 are two small stopes on the Pinto dike which gave $20 to $30 ore. A stereogram of the ore bodies of the Pinto mine is shown in fig. 18 (p. 211).

BURNS MINE.

The Burns mine, on the Burns claim, is situated in the western part of the town of Altman, between the Pinto and the Pharmacist mines. It is the property of the Acacia Gold Mining Company. The total production probably exceeds $200,000. Dividends were paid in 1903. The workings consist of a vertical shaft 350 feet deep and a 400-foot incline winze from level 4, 350 feet below the surface. Drifts and crosscuts at seven levels make the total development about 3,500 feet. The elevation of the shaft collar is about 10,625 feet.

So far as could be determined, latite-phonolite is the only rock encountered in the underground workings, though breccia appears on the surface. The Burns basalt dike has a course of N. 35° W. and dips steeply to the northeast. It is cut on all levels.

The Pharmacist vein outcrops about 120 feet southeast of the shaft, which it crosses at about level 3. The vein faults the Burns dike, the northern part of the dike being displaced 5 to 12 feet to the east wherever examined.

The Pharmacist vein is a brecciated, partially oxidized zone from a few inches to 8 feet wide. On levels 1 and 2 it shows narrow strips of white kaolin and bands of manganese. On level 4 the vein is much brecciated and holds a little fluorite, quartz, and opal. On level 6 vug holes with crystallized smoky quartz and fluorite and seams of kaolin are numerous, while for some distance southwest of the winze a 7-inch band of fluorite and quartz occupies the center of the vein.

The values occur chiefly in the joints and crevices between the brecciated fragments. In general, the tellurides have been oxidized to rusty gold, but in places they remain fresh. The values vary considerably. Where work is now being done, between levels 1 and 3, about one-half of the rock broken is saved and averages about $60 per ton.

An ore shoot began at the surface southeast of the shaft and went down to level 2, branching at level 1. Near the surface it is 150 feet long. At level 2 each branch is about 50 feet long. Work is now being done below level 2, on the northeast branch. A little stoping has been done on level 4, just north of the shaft. At the east side of the claim a stope averaging 70 feet long and varying from 3 to 10 feet wide reaches from 125 feet above level 4 down to level 7. It connects with the Pinto stope on the same vein. A large, irregular stope, 200 feet long and averaging 150 feet along the dip of the vein, runs from just below level 4 down nearly to level 6. It connects on the west with a stope in Pharmacist ground. A smaller stope from level 6 goes down below level 7 along the winze.

A little ore has been taken from the Burns dike on levels 5 and 6 south of the Pharmacist vein. The dike seems to have no special effect on values.

WROCKLOFF MINE.

The Wrockloff mine, situated on the north end of the Burns claim, is also the property of the Acacia Gold Mining Company. The production could not be learned, but it has been considerable. A shaft about 750 feet deep and 2,500 feet of levels comprise the underground development. But little work is being done at present. The elevation of the shaft collar is about 10,550 feet.

The workings are mostly in breccia made up largely of latite-phonolite fragments. Fifty feet southeast of the shaft on level 2 the poorly defined contact with latite-phonolite is seen. Both the Pinto and Burns dikes are opened in the mine. The former splits and branches and breaks up between levels 1 and 6. On it occur the principal workings of the mine. On levels 1 and 2 it is 4 to 6 feet wide, nearly vertical, and considerably decomposed. A cross vein which strikes S. 25° W. and dips 50° NW. is seen on level 2 about 100 feet north of the shaft. It is a narrow fissure partially filled with quartz, and carries a little fluorite and patches of kaolin. Three levels are opened on it from the Lyons shaft, situated 150 feet north-northeast from the Wrockloff shaft.

At the intersection of this vein and the Pinto dike an ore shoot begins 25 feet above level 1, at a point 30 feet north of the shaft, and continues to 20 feet below level 4. The values are in general confined to the seams in and at the edges of the basalt, but above level 2 the surrounding latite-phonolite is traversed by minute seams parallel to the dike, which silicify the country rock and make it ore for several feet on each side of the dike in the neighborhood of the cross vein. The values decreased below level 4, and the ore soon gave out. This ore shoot was on the east branch of the Pinto dike.

From level 4 to level 6 a body of ore 60 feet long was taken out along the Pinto dike, which here pitches very steeply to the west. This stope is 200 feet northwest of the shaft, and it is said that there is no cross vein.

On level 6 a considerable body of ore was taken out along the Pharmacist vein (below the Burns workings) at the point where it crosses the Burns dike. On level 8 (the bottom level) a crosscut was extended to the dike and to the Pharmacist vein below the deepest workings from the Burns shaft.

PHARMACIST MINE.

INTRODUCTION.

The Pharmacist mine, on the claim of that name, is situated at the west end of the town of Altman and is owned by the Pharmacist Consolidated Mining Company. One of the earliest mines to be opened on Bull Hill, it attracted much attention by being the first to declare a dividend. The production up to January 1, 1900, was $650,000, and of that amount $84,000 has been paid in dividends. Only small amounts have been produced since that date.

The underground workings consist of an incline shaft 650 feet long, with eleven levels about 50 feet apart, and a vertical shaft about 600 feet deep, with six levels, the collar elevation being about 10,625 feet. Level 5 of the vertical shaft corresponds to level 10 of the incline. Connection with the Zenobia mine is established

by level 2 of the vertical shaft, corresponding to level 5 of the Zenobia incline. The total development is about 6,300 feet. The property is worked on a small scale by lessees.

Latite-phonolite is the only rock seen in the mine, though breccia appears in the shallow pits at the surface.

VEIN SYSTEMS.

The Pharmacist vein here strikes N. 55° E. and dips about 60° NW. A vein with parallel strike, but steeper dip, is seen on level 1 of the vertical shaft, about 150 feet northwest of the Pharmacist vein. A third vein of about the same direction, but nearly vertical, occurs between levels 1 and 2, 150 feet north of the vertical shaft. These three form a general northeast-southwest system. The Zenobia vein, at the point where it enters the Pharmacist claim, has a north-northeast course, but soon changes to a practically north-south course, which it retains in most of the Pharmacist workings. It dips 70° to 80°. Another north-south vein, approximately vertical, crosses the Pharmacist vein at level 4 of the incline, near the shaft, and what is probably the same vein is encountered 80 feet southeast of the vertical shaft on level 1.

CHARACTER AND OCCURRENCE OF THE ORE.

The ore from the Pharmacist vein is an oxidized latite-phonolite, more or less impregnated with silica, and holding many little quartz seams, with vugs partially filled with crystallized smoky quartz. The values occur in the seams as rusty gold derived from tellurides. The vein is said to have been stoped practically continuously across the claim from the surface down to level 3 of the incline and down to level 4 for some distance northeast of the shaft. Work is now being done above incline level 4, 100 feet north of the shaft, in what was formerly supposed to be the hanging wall of the vein. The oxidized quartz-bearing portion of the vein is low grade at this point, but parallel fissures in the unoxidized, partially silicified latite-phonolite toward the hanging wall carry fluorite and sufficient telluride to make the value of the screenings about $30 per ton.

A second and smaller body has been found on the Pharmacist vein between levels 5 and 6 of the vertical shaft, near the Burns line. The character of the vein and the ore are much the same as in the body described above.

The ore from the Zenobia vein is in most respects similar to that from the Pharmacist vein. Quartz is perhaps more abundant, oxidation is a little more advanced, and narrow streaks of kaolin are frequently seen. Unoxidized fluorite-telluride ore is also met usually along the foot wall and outside of the zone of quartz deposition. The values in this vein also vary considerably, some of the ore being of high grade. A stope on this vein reaches from a considerable distance above level 1 of the vertical shaft down nearly to level 2. It begins just north of the shaft and is 150 feet long and 4 to 12 feet wide. The values and width of the ore are greatest near the shaft on level 1, where a north-south vein, nearly vertical, which is itself stoped south of the shaft, joins the Zenobia vein. Another rich bunch of ore occurred near the north end of the stope, between levels 1 and 2, where the vein appeared to branch again. The best values were found in the east branch, but just at the fork

a northeast-southwest vertical fissure came in and increased the value and size of the ore body.

A second ore shoot on the Zenobia vein occurs on level 2 from the main shaft, where a stope has been made from a point west of the shaft 60 feet to the Zenobia line, both above and below the level. Both rusty gold and tellurides were found here, and some pockets were very rich.

A body of ore of good grade was encountered about 80 feet southeast of the vertical shaft on level 1. A poorly defined vein of the northeast-southwest system is here cut by a north-south series of vertical fractures. The rock is unoxidized, and silicified along the openings. Carbonates are common in the seams and are associated with tellurides. A chamber 20 by 20 feet, 30 feet high, was stoped at this intersection, and the screenings were shipped.

ZENOBIA MINE.

The Zenobia mine belongs to Stratton's estate and occupies the northeasterly projection of the large area on Bull Hill, owned by this company. It was one of the earliest producers of the camp; its output is stated to have been $140,863. A few years ago W. S. Stratton reopened the mine, sinking a vertical shaft 500 feet deep. The explorations were not very successful, and in 1904 the mine was worked only on a small scale by lessee.

The developments comprise an incline, now abandoned, with seven levels, and located 225 feet southwest of the Pharmacist incline; also a new veritcal shaft 527 feet deep, with four levels, 215, 315, 415, and 515 feet below the collar, which has an approximate elevation of 10,675 feet. Level 4 is about 100 feet below level 7 of the old incline. The total length of drifts and crosscuts is 4,000 feet.

The few exposures visible on the surface indicate breccia, but in the upper levels latite-phonolite is the dominant rock. In levels 1 and 2 of the vertical shaft only latite-phonolite is exposed, while level 4 shows much breccia, chiefly consisting of fragments of latite-phonolite. Abundant granitic material is also contained in the rock in the northwest crosscut.

The veins worked are the Pharmacist, opened chiefly on the northeast side of the incline close to the Pharmacist claim, and the Zenobia, which is developed chiefly on the southwestern side of the incline. The Pharmacist vein here strikes N. 50° to 65° E. and dips 60° NW., while the Zenobia strikes from N. 20° E. to almost north-south, the dip varying from 60° to 80°. These two veins intersect along a line with northerly dip and are exposed down to level 5 of the incline. A fault takes place at the intersection, the eastern part of the Pharmacist vein being thrown from 10 to 20 feet to the south. West of the intersection the Pharmacist vein is not well defined. Development on the 515-foot level has disclosed three veins within 175 feet, which strike approximately like the Zenobia and which may be branches of that vein.

Both veins show unusually large amounts of smoky quartz, much of it well crystallized, occurring in fissures and in cavities formed by solution. Little fluorite is present, and the ore is oxidized to the deepest level. Large amounts of yellow opaline silica are present as the latest vein mineral, and at many points cover druses

of quartz as confused masses of tubular rods. The rock near the vein contains much fine-grained pyrite, and is said to carry values in places.

The veins exposed on levels 4 are oxidized sheeted zones with large vugs filled with smoky quartz. Much of the surrounding rock shows distinct silicification, and opal is probably being deposited at the present time.

The ore shoot is confined chiefly to the Pharmacist vein, east of the intersection, up to the Pharmacist line, though some ore was also mined on the upper levels of the Zenobia vein. Very little stoping has been done below level 5 on the incline; a small shoot was, however, found on level 8, 50 feet northeast of the foot of the incline. The veins exposed on level 4 of the vertical shaft contain poor values, though reports indicate that subsequent prospecting has developed ore of better tenor.

MERCER MINE.

The Mercer mine is located on the Wilson claim, just south of the main street of Altman. It lies between the Pinto and the Deadwood mines and is owned by the Free Coinage Company, though worked under lease to Mr. D. N. Mercer. The production is estimated at $200,000. The underground development consists of an incline shaft 350 feet deep and about 600 feet of drifts. The workings are entirely in latite-phonolite, though the 550-foot level of the Pinto mine, directly beneath, is in breccia.

The shaft is sunk on the Wilson vein, which strikes N. 35° E. and dips very steeply to the northwest, with local variations. A crosscut to the southeast on the 50-foot level discloses a vein of practically parallel strike 15 feet from the Wilson vein and dipping toward it. The two veins come together just above the 120-foot level, the junction being approximately horizontal. The two veins appear to merge into one and to so continue to the bottom of the workings.

A small bunch of ore was found on the main Wilson vein above the junction, the screened ore of which yielded 10 ounces per ton. No ore has been found on the branch vein. At the junction of the two veins a good body of ore was found. The united vein consisted of a 7-inch band of fluorite and many narrow seams in the oxidized latite-phonolite, all carrying rusty gold and a very little telluride. The fluorite decreases below and finally gives out, but the values continue. Near the junction some of the ore held gray copper and contained up to 15 ounces of silver per ton, but very little tetrahedrite was found below this point. About 10 per cent of the rock broken passed through a one-fourth inch screen, giving values of 13 to 62 ounces per ton. One-third of the total passed through a 1-inch screen and ran from 1½ to 5 ounces per ton. The stope averages 4 feet wide, 180 feet long, and 150 feet deep and continues to the line between the Mercer and Murphy mines. The deepest point is on the 300-foot level near this line, and the 550-foot level of the Pinto failed to find ore. In sinking the shaft from the 210- to the 250-foot point a rich pocket in the ore shoot was found, which produced $11,000 This entire ore shoot was taken out by underhand stoping, as in that way more fines were produced and a better saving of values effected.

A small stope is now worked on another ore body above the 250-foot level and 180 feet northeast of the shaft. The values here are confined principally to dark,

muddy streaks 1 to 3 inches wide, which occur at one side or the other of the sheeted zone. The material is completely oxidized and, when panned, proved to be very rich in gold.

MURPHY MINE.

The Murphy mine, also owned by the Free Coinage Company, is situated on the Wilson claim about 120 feet southwest of the Mercer mine. The production was not ascertained, but has been considerable. The workings consist of a 350-foot incline shaft and 7,800 feet of drifting.

The Wilson vein continues from the Mercer into Murphy ground and is the principal vein of the mine. Its character is much the same as in the Mercer, but no fluorite was seen. Another vein, practically vertical, of irregular strike, but averaging about S. 20° W., branches off on the east side of the main vein. There seems to be no crossing, and to the north of the point where the veins come together the two seem to unite as one vein. The junction is about 60 feet southwest of the shaft at the surface and pitches so that it is about an equal distance northeast at the bottom, becoming more nearly vertical with increasing depth.

The ore occurs in the seams and fissures and is almost wholly oxidized. By screening and sorting about one-fifth of the rock broken is saved as ore and runs $30 to $300 per ton. Underhand stoping improves the values of the ore saved, as in the Mercer mine. Ore on the Wilson vein was stoped from the Mercer line to a point where the values quickly decrease, 15 to 30 feet southwest of the junction. The stope reaches from the surface to the 350-foot level, where the shoot practically ends. Ore along the junction of the veins was better than elsewhere. The branch vein has been stoped 100 feet from the junction from about the 300-foot level up almost to the 70-foot level, and work is being done in good ore higher up. The occurrence and amount of the valuable minerals are practically the same as in the main vein.

Whether or not there is any relation between this branch vein and the one which branches from the Wilson vein in the Mercer workings it was impossible to determine.

PUEBLO MINE.

The Pueblo mine is located on the claim of the same name and lies well up on the western slope of Bull Cliff. It is the property of the Free Coinage Company and is being worked under lease. The production of the mine is not large. The underground workings consist of a 100-foot incline shaft and two levels representing about 150 feet of drifting.

The shaft is sunk on a vein striking N. 55° W. and dipping about 80° NE. It is 2 feet wide and is oxidized and brecciated. On account of the decomposition of the country rock its character could not be determined. The 50-foot level follows the vein on both sides of the shaft. A stope 15 to 20 feet high and 75 feet long above the level yielded $15 to $40 values in rusty gold after screening and sorting. On the 100-foot level the northwest-southeast vein is crossed 15 feet northwest of the shaft by a north-south vein dipping 45° W. Stoping is being done along both veins, and oxidized ore running $20 to $40 is being shipped.

WACU WETA MINE.

The Maroon Tunnel Company owns the mine which is situated on the Wacu Weta claim, on the northwest slope of Bull Cliff. It is being worked under lease. The developments consist of an incline shaft 308 feet deep and about 500 feet of drifting and crosscutting. The production of the mine is not large.

The rock at the surface is the Bull Cliff phonolite, but the shaft quickly passes into latite-phonolite, which continues to the bottom. About 80 feet southeast from the bottom of the shaft a sharply defined, vertical, apparently intrusive contact of latite-phonolite and breccia is exposed in a crosscut.

The shaft is sunk on a sheeted zone dipping about 80° SE. The vein varies from 1 to 4 feet in width and is not much oxidized. It is said to be the Klondike vein of the Isabella mine, but this seems very questionable. An ore shoot averaging 25 feet long and 4 feet wide was stoped from the surface near the shaft to the second or 150-foot level; it pitched steeply to the southwest, but did not continue below level 2. On level 4, at a depth of 300 feet, a small bunch of ore was encountered 30 feet south of the shaft, but gave out at an irregular mass of dense phonolite. A 1-inch manganese seam enters the phonolite and is seen to turn abruptly toward the east. In 10 feet it crosses a 3-inch seam of soft oxidized material, and at the junction a few carloads of $20 to $40 ore were mined.

DEADWOOD MINE.

PRODUCTION AND DEVELOPMENT.

The New Zealand Mining Company, controlled by the Woods Investment Company, owns the Deadwood claim, on which the Deadwood mine is situated. It lies south of the saddle between Bull Hill and Bull Cliff. The combined production of the Deadwood and Trachyte mines probably does not exceed $200,000. A number of shafts explore the country rock near the surface, and the main shaft, which is about 700 feet deep, has seven levels; the elevation of the collar is 10,545 feet. Drifts and crosscuts aggregate 7,000 feet. Only the first three levels could be examined.

GEOLOGICAL FEATURES.

The shaft and main workings of the mine are in a lobe of breccia reaching down from the north. The surrounding latite-phonolite is penetrated in several places. The contact is nowhere sharp, the indication being that the breccia has been locally derived from the massive rock. This contact is seen on level 1, 225 feet N. 40° W. from the shaft. It is in approximately the same relative position on level 3. On the same level, about 300 feet northwest from the shaft, the end of the crosscut just enters a soft, partially oxidized breccia, of which no indication was found on the surface. Latite-phonolite is again cut near the end of the drift on level 3, about 250 feet south of the shaft. A small mass of dense phonolite, which is probably a northwesterly trending dike, was observed in two places on level 1, 200 feet northwest of the shaft, but not elsewhere.

VEIN SYSTEMS.

Two definite systems of fissures occur in the mine. One strikes N. 20°–25° W. and has varying nearly vertical dips. The other has a course about N. 75°–80° E. and dips to the south at a high angle. The north-northwest system is represented by a number of veins of varying persistency and importance, while the east-west system consists of one well-defined vein. This vein, which lies about 60 feet north of the shaft on level 1, is about 3 feet wide and nearly vertical. It consists of a number of parallel fractures in dense, partially oxidized and silicified breccia. One hundred feet northwest of the shaft it cuts one of the principal veins of the north-northwest system, and on level 1 appears to fault it, the northern part being thrown about 10 feet to the west. There is no evidence of faulting at the corresponding points on levels 2 and 3. The veins of the north-northwest system are in general of similar character, but vein brecciation has often occurred, oxidation is frequently greater, and fluorite is a common vein mineral.

The east-west vein has been stoped from the surface down to 40 feet below level 1, about 250 feet long, the values occurring in the seams and fissures as tellurides and as rusty gold derived from them by oxidation. The screenings, which amounted to about one-third of the total vein matter, ran $60 per ton. At the point where this vein faults the north-northwest vein a stope 20 by 20 feet has been made in ore that is said to have been of very good grade. How far above and below the level this rich part extended was not ascertained. On the east side of the north-northwest vein the stope on the east vein is being continued down to level 2. On the west side it has gone down at least a considerable distance below level 3.

The north-northwest vein, which is faulted by the east-west vein, is similar to the latter except that it is a little more oxidized. It passes about 40 feet west of the shaft on level 1 and is approximately vertical. Small bunches of ore have been taken from it just west of the shaft and 70 feet south of the shaft. This may be the same vein which is being worked 150 feet south of the shaft on level 3. The latter vein, which is 2 feet wide and dips steeply to the east, is much brecciated, and the oxidized fragments are held by a filling of purple fluorite. Screenings carrying 20 ounces to the ton make up about one-fifth of the total ore; they contain rusty gold, with occasional tellurides. A mineral which is probably tetrahedrite is sometimes found with the telluride.

A vein of the north-northwest system dipping steeply to the west is reached about 250 feet north of the shaft on level 1. It has been stoped extensively, but is not encountered again on other levels.

Two other veins of this system have been drifted on for a short distance 200 feet northwest of the shaft on level 3. One is practically vertical; the other, 30 feet to the west, dips at a high angle to the east. A few small bunches of ore have been taken from these veins. Much ore is also said to have been extracted from a flat vein near the surface.

On the whole the occurrence of the ore seems to be connected with the intersection of the two vein systems.

TRACHYTE MINE.

The Trachyte mine, on the claim of the same name, lies 500 feet southeast of the Deadwood, is also the property of the New Zealand Mining Company. It is explored by a shaft 400 feet deep and four levels, representing a total development of 2,500 to 3,000 feet. The elevation of the collar is 10,462 feet. The country rock is latite-phonolite, oxidized in places. The basalt dike from Deadwood No. 2 passes not far west of the shaft.

Owing to accumulation of ice in the shaft below level 1, only that level was entered. A crosscut 120 feet to the north discloses a vein with a trend slightly south of east, and dipping about 65° N. It has been stoped from close to the surface down to at least level 2, for a distance of 200 to 300 feet along the vein. The character of the vein matter could not be seen.

PEARL MINE.

The Pearl mine is situated between the Trachyte and the Deadwood No. 2, and has some workings on the Deadwood No. 2 basalt dike.

DEADWOOD NO. 2 MINE

INTRODUCTION.

Near the south end of the Deadwood claim a shaft has been sunk and work done principally by lessees. It is called the Deadwood No. 2 mine, and is estimated to have produced $150,000. The shaft is 850 feet deep and has nine levels which represent about 4,000 feet of drifting and crosscutting. The elevation of the collar is 10,410 feet.

GEOLOGICAL FEATURES.

The shaft and workings are in latite-phonolite. Levels 2 and 9 appear to enter breccia 140 feet west of the shaft, but this point could not be definitely determined. A 3-foot vertical phonolite dike striking about north and south is exposed on level 2 about 150 feet west of the shaft. The important geological feature of the mine is a basaltic dike cut by the shaft at level 1, having a general course about N. 20° W. and dipping on an average 80° W. The dip varies considerably, however, as does also the strike. The dike is irregular in width, ranging from 1 to 5 feet, but becomes more uniform with depth. On level 1 it appears to branch south of the shaft. The drift leaves the dike and soon cuts another approximately parallel dike. On level 2 a similar occurrence is met with just north of the shaft. Twenty feet north of the shaft on level 1 the dike is faulted, the north part being thrown 1 foot to the west. A narrow seam with a strike parallel to the dike, but which dips every steeply toward the west, branches off from the dike just below level 1. On level 6 this seam, which is still at the shaft, carries 6 inches of decomposed basalt. It is cut again on the lower levels, where the dip becomes slightly less and the width of basalt increases to 15 inches on level 9. The main basalt dike shows a corresponding loss in width as the other widens.

CHARACTER AND OCCURRENCE OF THE ORE.

On the first level a northwesterly vein dipping about 75° SW. is reached by a northeast crosscut 100 feet from the shaft. It consists of a partially oxidized, shattered, and sheeted zone in latite-phonolite. A small bunch of ore was encountered just above the level. A stope 3 feet wide, 25 feet long, and 15 feet high furnished a carload of $15 screenings. What is probably the same vein was explored for a short distance on the second level, but showed no ore.

The principal amount of ore came from the basalt dike. This is everywhere very soft and at the sides lies a decomposed, more or less clay-like gouge, which is in places oxidized, and which varies in width from a very narrow seam to several inches. The values occur in this partly as tellurides and partly as rusty gold. Where the values are exceptionally high the near-by basalt and country rock also may constitute ore. But since in general the dike was worthless, it was carefully shot down and then the soft selvage was picked down and caught on sheets. The process is called stripping, and requires no sorting. The value of the material so obtained varied considerably, but was always good, the range being $80 to $3,000 per ton.

ORE SHOOTS.

Beginning at the surface about 50 feet north of the shaft, on the basalt dike, is an ore shoot 130 feet long, which pitches steeply to the south. At level 1 it has been stoped 120 feet along the dike, the value of the ore shipped being about $80. On level 2 the shoot is 60 feet long and nearly vertical, the pay streak at the side of the dike being 1 to 8 inches wide. A small lot of gold-bearing rock too low in grade to be profitably worked, was taken out 40 feet south of the shaft on this level. On level 3 the shoot has been stoped for 50 feet. Between this and the next level the dike flattens considerably, and the ore shoot turns from nearly vertical to a much flatter pitch to the south, narrowing up and finally pinching out just before reaching the fourth or 400-foot level. Below level 4 the dike steepens again, but no ore was found between the fourth and fifth (470-foot) levels. Between the 470- and 550-foot levels occurred the richest ore in the mine. The pay streak was wider and the values better than elsewhere. The ore shipped brought returns of $300 to $700 per ton. The stope here was almost 300 feet long. For 120 feet in the middle the main values were on the hanging wall, while at each end of the stope they were on the foot wall. Where the pay streak crossed the dike at the south a triangular body of very rich ore was formed, the screenings from which shipped at $1.37 per pound. At the north end, however, only a narrow seam crossed from the hanging to the foot wall. Below level 6 the ore was of good grade, but was confined to a narrow strip on the hanging wall, directly under that which occurred on the hanging wall above. Between levels 7 and 8, 650 and 750 feet, respectively, from the surface, the pay streak was exceedingly narrow. A stope 120 feet long is continuous with that on the two levels above, and a stope 40 feet long was made about 50 feet to the north of the main ore. Stoping is in progress upward from level 9 in a corresponding position to the main stopes above. The values are contained in a soft greenish-black material one-half inch to 3 inches wide, mainly on the foot wall. Its value is about $275 per ton.

To summarize, there are two principal ore shoots on the basalt dike. One begins at the surface 130 feet, pitches steeply to the south, and gradually shortens till it pinches out about 385 feet below the surface. This shoot is fairly regular in form and the values are pretty evenly distributed through it. The second shoot, which is directly below the first, begins at the 470-foot level and has been proved to the 850-foot level. It is irregular in form and the values which it carries vary greatly in different parts.

DELMONICO MINE.

The Delmonico claim, on which the mine is located of the same name, lies on the western slope of Bull Cliff, just east of Deadwood. It belongs to the Stratton estate and is worked by lessees. The development consists of a shaft 600 feet deep, 300 feet of which have recently been completed, and three levels at 100-foot intervals. Development in the lower part of the mine is in progress. Drifts and cross-cuts probably aggregate 2,500 to 3,000 feet.

The principal rock of the mine is latite-phonolite, but phonolite breccia is reached on level 2, 350 feet south of the shaft. Ninety feet south of the shaft on this level the basalt dike from the Deadwood No. 2 crosses the north-south drift.

Only one vein of any importance has been encountered. It has a north-south course, dips steeply to the west and lies just east of the shaft. It consists of an oxidized and shattered zone 2 to 5 feet wide in latite-phonolite. Fifty feet south of the shaft a body of oxidized ore was encountered which was shipped as broken, and contained 1½ to 2 ounces per ton. A stope on this ore shoot is 4 to 5 feet wide, 35 feet long, and 100 feet high. The southern limit of the shoot is the basalt dike, which is also being stoped near the vein. This was the only shoot that had been found in the mine at the time of visit.

VINDICATOR LODE SYSTEM.

The depression between Bull Hill and Bull Cliff contains one of the most important and productive lode systems of the camp. While the general country rock is breccia showing the usual alteration, there are in this vicinity two large intrusive masses, the northern one consisting of latite-phonolite and the southern one of syenite. A smaller intrusion of latite-phonolite adjoins the syenite on the south near the town of Goldfield. The mining developments show that these are not flat masses, but rather deep batholiths extending to the greatest depths yet attained. The syenite borders in places with sharp contacts against latite-phonolite, while other exposures present all kinds of transitions between the two rocks. There are few basic dikes and few phonolite dikes in this vicinity; none of them is of economic importance.

The lode system is traceable for nearly a mile, the individual veins diverging slightly northward, as is well shown in the Vindicator and Golden Cycle mines. The dip is usually very steep. The following mines, taken from north to south, are located on this system: Shurtloff, Findley, Hull City, Lillie, Vindicator, Christmas, and Golden Cycle. All of them are producing mines of importance except the Christmas and the Lillie, on which little work is now being done. The total production of the system is approximately $10,000,000.

A depth of 1,500 feet is attained in the Lillie, 1,400 feet in the Findley, 1,200 feet in the Vindicator, and 1,000 feet in the Golden Cycle.

FINDLEY AND SHURTLOFF MINES.

PRODUCTION AND DEVELOPMENT.

The Findley and Shurtloff mines, which are owned by the Findley Gold Mining Company, are situated on the southeastern slope of Bull Hill just above the town of Independence. On the south the property adjoins the Hull City mine, while the Stratton estate holdings lie on the west. The principal production has been during the last few years. The output of ore of the Findley mine for the two years previous to 1904 was 11,850 tons; during earlier years 5,000 tons were produced. The total production of the two mines to April, 1904, approximated $700,000.

The developments on the Findley consist of a vertical shaft, with collar elevation of 10,398 feet and depth of 1,387 feet. Fifteen levels are turned, while at station 16 the vein has not as yet been crosscut. The numbering and elevations of levels are shown on fig. 50 (p. 414); the bottom level (15) having attained an elevation of 9,119 feet. Drifts and crosscuts aggregate about 2 miles in length. The Shurtloff shaft is situated 800 feet north-northwest of the Findley, and its collar is 129 feet higher; it is 900 feet deep, with ten levels at various intervals down to the 800-foot point. Level 10 lies 25 feet above Findley level 9; Findley level 11 extends underneath the Shurtloff workings without making connection with them. Drifts and crosscuts amount to 4,500 feet.

GEOLOGICAL FEATURES.

On the surface in the south end of the property the veins are contained in breccia, though the contact of the Altman area of latite-phonolite is only a few hundred feet distant to the northeast. Near the Shurtloff shaft the veins enter this rock and the shaft is said to have passed through over 400 feet of it before entering breccia, which continues down to the bottom. The Findley shaft is sunk in breccia. A crosscut to the northeast on level 11 reveals a sharp contact with syenite or coarse-grained latite-phonolite, 130 feet from the shaft; this probably represents the downward continuation of the Altman area. Moreover, though all accessible crosscuts from shaft to vein showed breccia, there is certainly latite-phonolite on level 11 for several hundred feet south of the shaft and for 600 feet north of the shaft to a point just north of the cross vein described below. The same rock is prevalent on level 14 along the vein, though the crosscut is in breccia, so that it would seem as if there existed a dike-like mass of latite-phonolite following the vein, at least on the lower levels. Level 15 was not accessible, being covered with water in April, 1904.

The breccia contains abundant fragments of latite-phonolite, and at the end of the east drift on the cross vein 600 feet north of the shaft much granitic material is present. Smaller masses of phonolite—dikes and sheets—are found in various parts of the mine, but have little practical importance A small northeasterly trending basic dike was cut on level 14, 450 feet south of the shaft.

A crosscut 1,100 feet long, which extends west-southwest underneath Mountain Beauty ground, reveals only breccia; neither the latite-phonolite nor the two basalt dikes seen on the surface were observed here 1,150 feet below the surface.

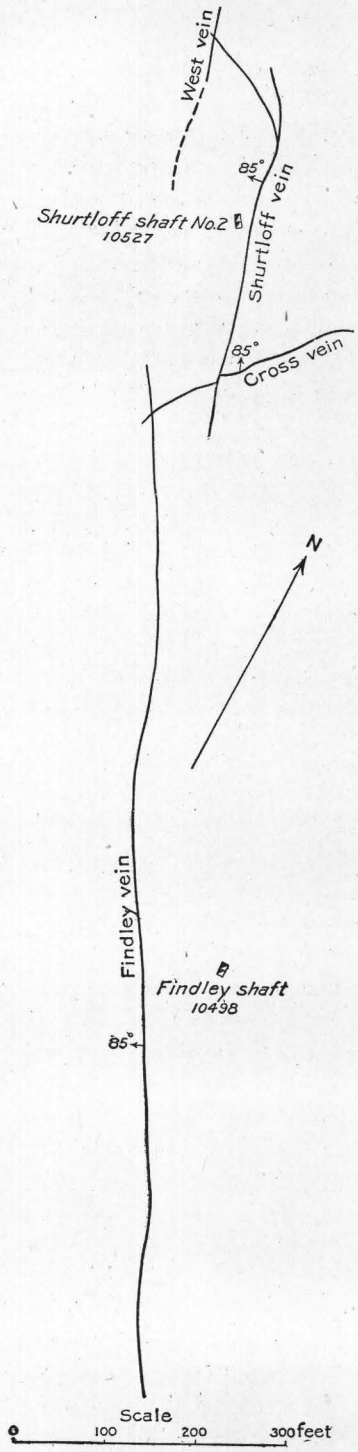


FIG. 47.—Vein system on level 11, Findley mine; elevation 9,525 feet.

VEINS.

The two principal veins are the Findley and the Shurtloff No. 2, the latter lying 80 feet east of the Findley. Both form, together with the Shurtloff No. 1 on the adjacent Stratton property, the most northerly extension of the great Vindicator system of linked veins. The Findley is the northerly continuation of one of the Hull City veins; its strike is N. 31° W., which it maintains for a distance of 1,000 feet; its dip, shown on fig. 47, is extremely steep to the west-southwest. The Shurtloff No. 2, striking N. 18° W. and also very steep, is first noted near the cross vein, 600 feet north of the Findley shaft, and has been followed for 500 feet northward to a point where it exhibits a tendency to split and turn to the northwest. Two parallel veins have been opened for a short distance, 100 feet east of the Shurtloff shaft, and another lies on level 11, 150 feet west of the Findley vein. An important cross vein intersects the Findley and the Shurtloff on levels 10 and 11, 600 feet north of the Findley shaft; its trend is N. 37° E., and its dip very steep to the northwest.

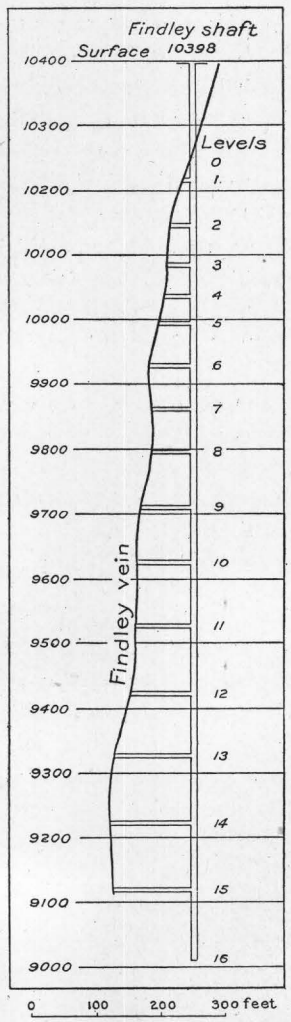


FIG. 48.—Cross section of Findley vein through Findley shaft looking northwest.

The main veins are narrow sheeted zones, usually with one central seam, containing vugs coated with dolomite, quartz crystals, and tellurides, and several subordinate seams on each side, the total width being usually less than 3 feet. The rock is, as a rule, almost

fresh close up to the fractures. There is little fluorite and a very small quantity of pyrite, the latter disseminated in the rock. Bunches of molybdenite were found on level 13, and a little tetrahedrite on level 14.

The cross vein contains a central band of fine-grained fluorite, up to 15 inches thick, with several parallel seams on each side. While free gold is practically absent on the lower levels of the main veins, this cross vein shows some, doubtless due to incipient oxidation. At the intersection with the Findley no faulting is visible, but the northeasterly trending vein cuts through the former and would thus seem to be somewhat more recent. On the other hand, the Shurtloff vein faults or deflects the cross vein, the eastern part being thrown 6 feet northward.

A crosscut to the west-southwest, 1,100 feet long, explores the Mountain Beauty ground just south of the Stratton estate holdings, and begins on level 11, 350 feet south of the shaft. Two veins were found in the general southern continuation of the Pikes Peak or Mineral Rock vein and about 300 feet south of the Lucky Guss No. 2 shaft, but which of them represents the vein mentioned is uncertain. Their distance from the beginning of the crosscut is 630 and 790 feet. Both veins show tellurides on tight seams.

ORE SHOOTS.

The shoots of the Findley mine do not appear at the surface. The principal ore body begins between the Findley shaft and the Hull City line, about 150 feet below the surface, but is rather small and irregular down to a point 500 feet below the surface, where it widens to 400 or 500 feet and occupies both sides of the shaft, extending to the Hull City line on the south. In the deepest levels it splits into two bodies south and north of the crosscut from the shaft; these were stoped on level 14 at the time of visit. The greatest width is 6 feet, and, as a rule, only the screenings constitute ore.

North of the cross vein, in Shurtloff ground, the Findley is called the West vein; it is here generally poor, but has been stoped for 50 feet some distance above level 8. The Shurtloff vein splits near its north end 100 feet north of the shaft of the same name, and a branch connects with the Findley. The northwest branch of the vein is stoped on level 8 from the fork to the point where it meets the West vein and upward for 70 feet. The north-northwest branch is stoped for 50 feet beyond the fork. Just at the junction of the two branches is a good body of ore; it begins north of the shaft above level 7 and has been stoped down to level 10, 800 feet below the surface. From a length of 70 feet at the top it increases to 350 feet at level 10, the north end of the stope being about vertical, while the south end pitches south. The stope varies in width from 5 to 12 feet. At level 9 the vein consists of two principal seams, with minor ones on each side, and the whole width is stoped. The ore from this stope is screened and sorted, and one-fifth to one-third is saved. The value of the ore shipped is 2 to 2½ ounces.

The northeasterly trending cross vein, which is probably identical with the Wilson vein on Pinto ground, presents some important features. A large body of ore, up to 30 feet in width, was found at its intersection with the Findley, 600 feet north of the shaft, on Findley levels 10 and 11, 725 and 825 feet below the surface. This cross vein carries fair ore all along for 225 feet northeast of its intersection

with the Findley; but at the crossing with the Shurtloff vein, which is barren on level 11, it proved valueless for 10 feet on each side of the intersection. Near the end of the drift on this cross vein values were suddenly cut off by a northwestward-trending seam.

To sum up, no ready explanation can be given for the occurrence of the main shoot, while the Shurtloff shoot seems dependent on the split in the vein, and the large body on the cross vein conditioned by the crossing with the Findley. It is remarkable that the next crossing with the Shurtloff should be attended by a decided impoverishment.

HULL CITY MINE.

PRODUCTION AND DEVELOPMENT.

The Hull City mine is owned by the Independence Consolidated Mining Company, and consists of an almost square area of 39 acres, except for two claims of Vindicator property which project into it from the southeast. The total production approaches $2,000,000, of which $900,193 was extracted up to the end of 1899 and $999,174 during the three years from January 1, 1901 to January 1, 1904. During 1904 the mine was worked on a smaller scale by lessees.

about 1½ miles N20E of Victor

The developments consist of a main vertical shaft 1,265 feet deep, with eleven levels turned. The elevation of the collar is 10,279 feet. The levels are somewhat irregularly placed, as shown on fig. 54. Level 11 has an elevation of 9,029 feet. Six hundred feet to the southeast, near the southern boundary, is the King or Vaughn shaft, also known as the Glorieta, with a collar elevation of 10,204 feet and a depth of 860 feet. This has twelve levels, the upper ones being close together; level 4 corresponds about to main level 1, and level 12 to main level 8. There are also many small shafts less than 400 feet in depth. The developments have a total length of several miles. On level 11 the crosscut has not yet reached the vein. In April, 1904, water stood 1,055 feet below the collar, and the two lowest levels were inaccessible. During 1903 the pumps kept the mine dry, raising 300 gallons a minute.

GEOLOGICAL FEATURES.

The principal rock on the surface, as well as on all lower levels, is a normal breccia in which latite-phonolite usually predominates. The change to latite-phonolite, which occurs both near the Findley line and at the south end of the workings, is gradual. A very prominent dike of latite-phonolite traverses the property for a distance of 1,000 feet from the Findley to the Vindicator boundary. Its strike is northwest or north-northwest, its width from 9 to 15 feet, and it stands nearly vertical. Southward it merges into the latite-phonolite of the Vindicator, while northward it seems to disappear shortly before the Findley line is reached. The dike is prominently porphyritic by large orthoclase crystals and more nearly approaches the trachytes in appearance than most of the latite-phonolites of the district. It occurs on all the levels below 3, but as the upper workings are inaccessible, its continuation to the surface could not be shown. A crosscut on level 4 extends 500 feet to the northeast and passes through two dikes of phonolite and two of latite-phonolite; at its extreme end it cuts a basic dike.

THE VEINS AND THEIR ORE.

The vein system in this mine is somewhat complicated. The present description follows the views of Mr. F. G. Willis, who some time ago undertook a careful geological examination; figs. 49 and 50 illustrate these relations. Near the surface a principal vein, pretty well defined and nearly vertical, called the "C" vein, seems to pass from the Findley shaft close by the Minnie Bell and Tompkins shaft to the main shaft, and thence down to the Vaughn or Glorieta shaft across by the Vindicator No. 2 shaft, a total distance of 1,300 feet, with a strike of N. 40° W. Three or four hundred feet below the surface two other veins appear on the northeast side of the shaft, while the "C" vein, with more decided southwesterly dip, crosses the big dike. Another vein, called the "D," follows the northeastern side of this dike. On level 10 three veins are exposed—the Winze vein, the "D" vein, and the "B" vein. The "A" vein is known only on levels 3, 4, and 5 (fig. 54).

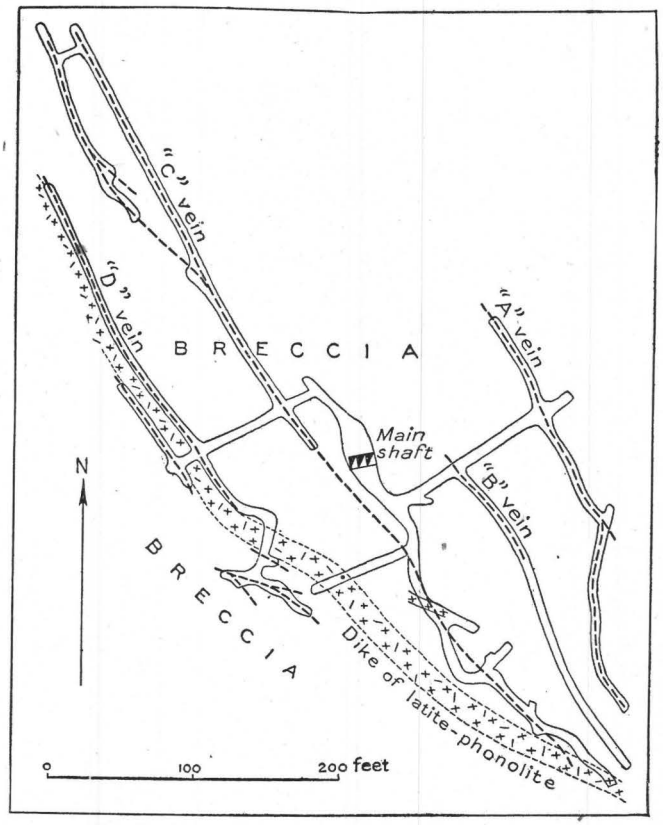


FIG. 49.—Map of fourth (550-foot) level, Hull City mine.

The veins show the usual structure and consist of several tight seams, in places separating brecciated material, or of a central seam, with small vug holes coated with quartz and fluorite, surrounded by several less distinct cracks. Dolomitic carbonates and pyrite are disseminated through the rock in the vein at many places, also outside of it, and crystallized carbonates may often be seen coating the seams.

The stopes on the "D" vein along the dike on level 4, north of the shaft, showed a very much crushed, nonoxidized dark-green breccia, in which much replacement by fluorite and pyrite, apparently also by calaverite, has taken place. The vein was stoped 2 feet wide and all of the material sacked. The "A" vein on this level is 3 feet wide in the pay shoot, with about six parallel and oxidized seams. On level 7 veins "C" and "D" lie close together, and "C" appears to cross the dike, which contains small streaks of stibnite and galena. The veins are partly oxidized on this level.

The principal ore is calaverite, occurring as usual, coating narrow seams in the vein, but also to some extent as replacement. In the lower levels tetrahedrite began to appear, especially in the "B" or shaft vein, from a point 850 feet below the collar to the bottom. This vein generally assays comparatively high in silver. Gold accompanies the tetrahedrite, but this particular ore is not of high grade. Assays gave, for instance, gold, $8; silver, 8.5 ounces; copper, 0.2 per cent. Galena occurred in the "C" or Winze vein; on level 9 a mass was found 1½ feet wide, consisting of galena, zinc blende, and pyrites, with good values of gold. Similar ore occurred on the "D" vein, 250 feet south of the shaft. On the other hand, the breccia close to the vein on level 7, at the Vindicator boundary line, contained much massive pyrite and zinc blende which proved practically barren. On the same level a seam with much stibnite occurred. Molybdenite occurs frequently in the ore. Partial oxidation extends at least 850 feet below the collar.

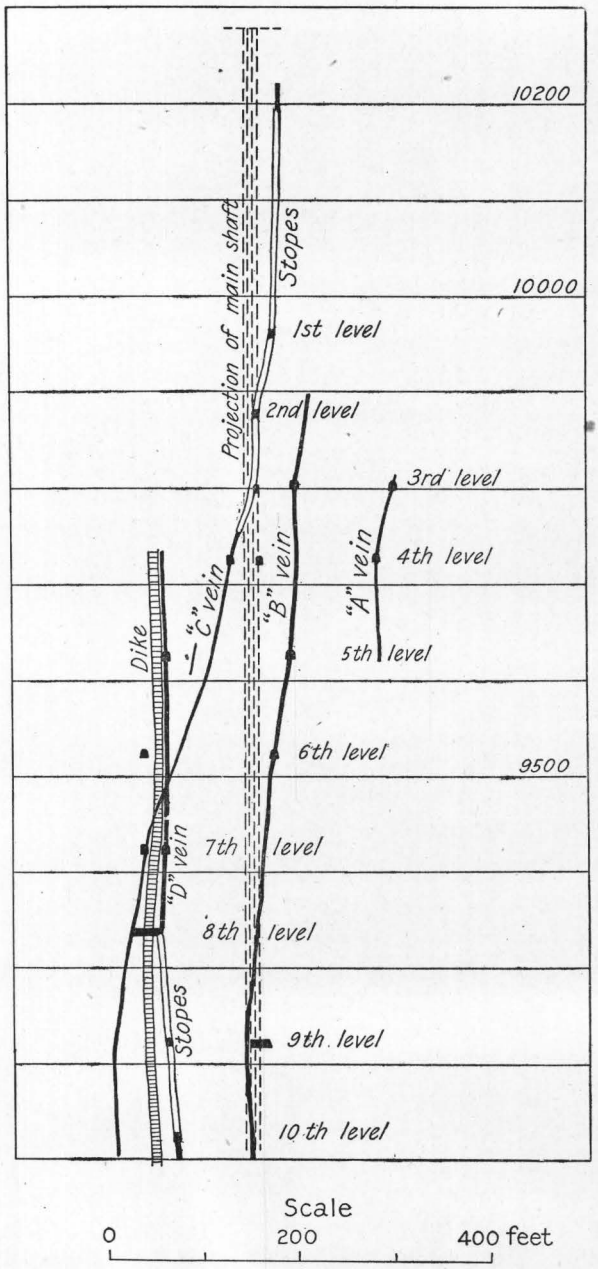


FIG. 50.—Cross section of Hull City mine, looking northwest (after F. G. Willis).

ORE SHOOTS.

The stopes on the "C" vein were very large and extended from near the surface to level 4, and in places somewhat below it. Three hundred feet below the surface the maximum horizontal length of 600 feet was attained, and the shoot practically connected with the south body of the Findley mine. Smaller stopes down to level 10 were opened on the Winze vein, which is assumed to be the "C" vein after having crossed over to the west side of the dike. On the lower levels the most important ore body occurred on the "D" vein, lying

just east of the dike. These stopes began near the Findley boundary line on level 4, where the "D" vein begins to split off from the main vein, and continued widening down to level 10, where they are 500 feet long. The shoot continues, though the best values were found between levels 8 and 9.

A third shoot follows the projection of the Glorieta shaft down to Hull City level 8. It connects on the south side all along with the ore body in the Vindicator No. 2 on the Wallace vein, and will be mentioned in more detail when that mine is described.

VINDICATOR MINE.

PRODUCTION AND DEVELOPMENT.

The Vindicator Consolidated Gold Mining Company owns an irregular area of 30 acres on the southern slope of Bull Cliff, above the town of Independence. The property extends from the Hull City line on the northwest to the Lillie, Christmas, and Golden Cycle boundaries on the southeast, a distance of 1,400 feet. Most of the ore shoots lie on the Wallace and Trotter claims, which have a general north-northwest direction. The mine was opened in 1895 and has been actively worked since then. The total production up to January 1, 1895, is about $4,600,000, from which dividends to the amount of $1,225,000 have been paid. The output for 1903 and 1904 has been as follows:

Output of Vindicator mine.

	1903.		1904.	
	Amount.	Assay value.	Amount.	Assay value.
	Tons.		*Tons.*	
Smelting ore	7,700	$418,230	8,980	$521,566
Milling ore	4,728	74,929	6,364	103,121
	12,428	493,160	15,344	624,687

The main or No. 1 shaft is located close to the Lillie boundary line in the western part of the property. The elevation of the collar is 10,209 feet and sixteen levels are turned, the lowest (1,200-foot) level having an elevation of 9,009 feet. The relations of the levels are shown in fig. 52. Those most important for the purposes of this description are levels 8, 10, 12, 13, 14, and 16, corresponding to depths of 502, 650, 804, 904, 1,003, and 1,201 feet. Level 16 connects with level 12 of the Lillie.

No. 2 shaft lies close to the Hull City line, 800 feet west-northwest of the main shaft. Its collar is 23 feet lower than that of the main shaft, and only seven levels are turned. Of these, level 6 is 500 and level 7 about 600 feet below the surface. Drifts on all levels from the main shaft explore pretty thoroughly the space between the Hull City and Lillie mines, while long crosscuts on levels 8, 12, and 14 open the south end of the property. The total length of shafts, drifts, and crosscuts on all levels is stated to be 12 miles, to which a considerable amount is added each year.

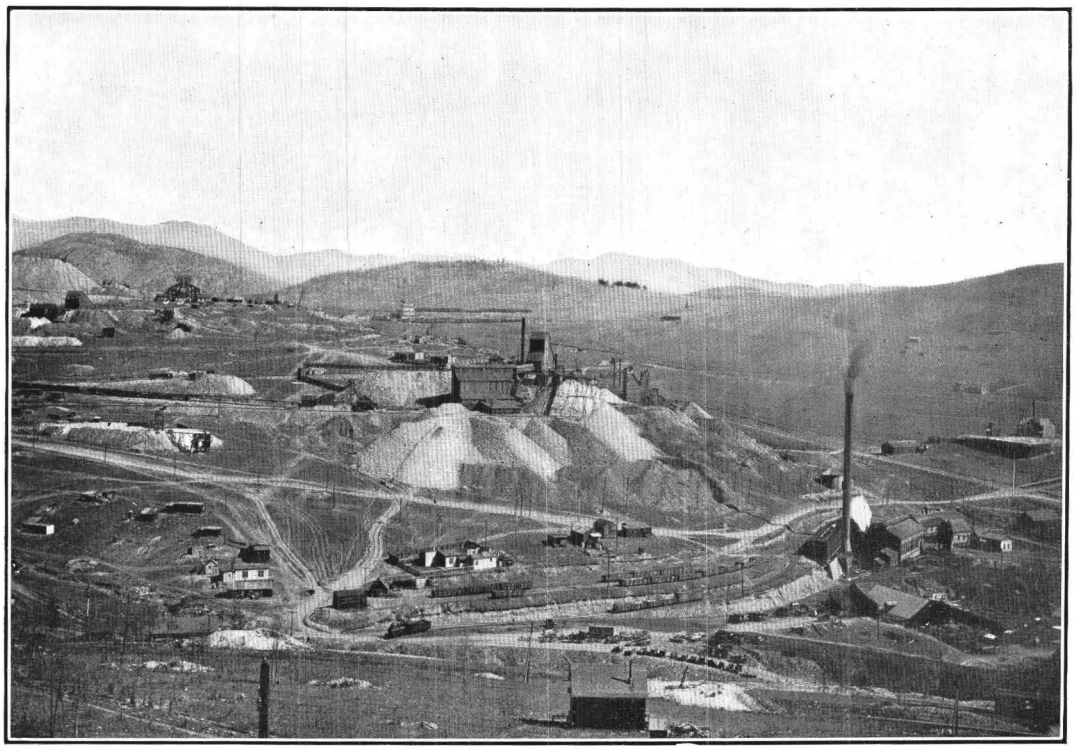
WATER LEVEL AND OXIDATION.

The Vindicator mine forms part of a drainage basin, in which are included the Findley, Hull City, Lillie, and Golden Cycle. First water was found on the 500-foot level, where at one time 100 gallons a minute were pumped. At 1,200 feet below the collar it was necessary to pump 500 gallons a minute. At the present time (1904) no pumping is done and the water stands a little below the 900-foot level. The shaft between the 800 and 1,200 foot levels was entirely dry, even dusty, and so were the drifts until the veins were crosscut, when a big stream issued. The water is potable, and for some time the supply for the town of Victor was drawn from the Vindicator pumps. All the veins are oxidized down to the 500-foot level, and part of the rock is reddish brown and soft. Even on the 800-foot level some of the veins are still oxidized.

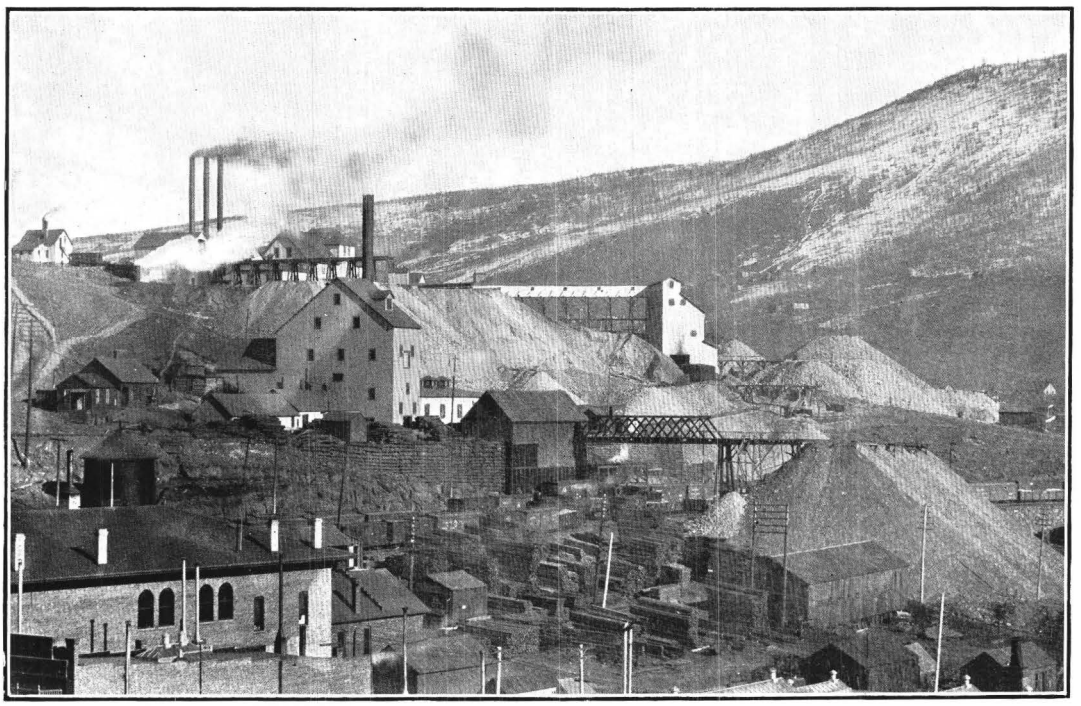
GEOLOGICAL FEATURES.

As may be seen on the geological map, the Vindicator mine lies in the northeastern part of a rounded area of syenite surrounded by breccia, and this syenite in its northern part connects by gradual transition with a branch of the Altman area of latite-phonolite. Short crosscuts to the northeast on the 500-, 650-, and 725-foot levels show that the breccia lies almost in the foot wall of No. 1 vein near the Vindicator and Lillie shafts, as it does near the surface. At the Sigel vein, in the extreme southeast part of the property, the rock is a very much brecciated latite-phonolite. A main contact between the massive rock and the normal breccia lies very close to No. 2 shaft and the Hull City line. A rock from level 6 of No. 2, 30 feet west of the shaft, proved to be a breccia, as is all of the country rock in the adjacent part of the Hull City property. Examination of rock sections has shown that some of the supposed massive latite-phonolite from level 12, a few hundred feet south of the shaft, is really much brecciated. The same applies to some specimens from level 16, northwest of the shaft. In fact, the normal breccia in this part of the district is very apt to contain a large amount of latite-phonolite, and it is often impossible to draw a well-defined line between solid rock and breccia.

The principal rock appearing in the workings from one end of the mine to the other is a latite-phonolite of normal type, with large porphyritic feldspar crystals, while syenite occupies relatively small areas. To distinguish between these closely allied rocks is often difficult, and in many places they are connected by transitions. Still it is somewhat surprising, in view of the prevalence of the syenitic rock on the surface, to find such small bodies of it in depth. The best known mass of syenite is exposed on several levels at and just west of the shaft. On the eighth (500-foot) level there is a sharp contact between latite-phonolite and syenite 50 feet southwest of the shaft. The latter rock continues for 100 feet southwest and then appears to gradually change to latite-phonolite. On level 10 syenite, with transitions to fine-grained types, appears between the shaft and the Vindicator vein, 30 feet southwest, but the crosscut does not extend farther in that direction. On level 12 a very fine-grained latite-phonolite appears at the station, but changes with sharp contact to syenite, which continues for 300 feet southward and there again borders sharply on latite-phonolite. On level 14 a similar contact is well exposed



A. GOLDEN CYCLE MINE AND PART OF GOLDFIELD.



B. STRATTON'S INDEPENDENCE AND STRONG MINES.

and trends almost due north. The syenite is here 100 feet wide, as shown by the south crosscut. At the La Bella vein on level 8 a little syenite is exposed, and likewise on levels 8 and 12 along the western boundary line of the property, in both cases with fairly sharp contacts, but neither of these bodies appears to connect with that at the shaft. It would thus seem as if the latite-phonolite contained several intrusive masses of syenite which have a very irregular shape.

There are very few phonolite dikes. One was noted on level 8 along No. 3 vein, 350 feet northwest of the main shaft. Two basic dikes have been opened by the workings, both trending north-northwest and dipping very steeply west-southwest. One of these, which is more closely defined as a monchiquite, is reached by a crosscut northeast from the shaft on level 10 and lies in unproductive territory. The other lies about 200 feet west of No. 2 shaft, and is exposed on levels 11, 12, and 13, as well as on level 7 of No. 2 shaft. In the latter place it flattens somewhat and changes its strike.

VEIN SYSTEMS.

The trend of the main fissure near the surface is S. 60° E. from shaft No. 2 to the main shaft and to the Lillie shaft, a short distance east of which it seems to die out. The workings disclose, however, the same tendency as in the Hull City mine to throw out branches on both sides of the main fissure. The detailed structure in the Vindicator is very complicated, and there is considerable uncertainty as to the correct connection of the veins between the various levels, an uncertainty which can often be settled only by actual stoping operations. The difficulty is increased by the very tight character of the veins and the general absence of well-defined walls.

At No. 2 shaft the principal vein is called the Wallace. Below level 5 this vein soon separates from that trending toward the Lillie shaft. It assumes a direction of N. 30° W. and a dip of 80°, and has been followed for 400 feet south-southeast of the shaft down to level 13. In the southward widening angle between the Wallace and the Main or No. 1 vein lie several other veins of less importance, as shown on fig. 55. No. 1 vein is practically continuous to the Lillie shaft by the main shaft and gradually straightens up, so that at the Vindicator shaft it is almost vertical.

No. 2 vein branches from No. 1 a little east of the Lillie shaft, and at the Vindicator shaft on level 8 lies 100 feet southwest of No. 1. A small and rich branch, the Vindicator, here lies between No. 1 and No. 2. It then seems to cross No. 1 vein, 200 feet northwest of the main shaft, and continues diverging with a strike of N. 30° W. up to the boundary line of the property. It is possible, however, that there is no real crossing, but that No. 2 vein north of the shaft is simply a diverging branch like the Lillie No. 2 vein on the south side of the same shaft. No. 3 vein branches from No. 2 and lies a short distance east of it. These two veins, also known as the Campbell and Wood veins, are not definitely known above level 8. On level 16 No. 1 vein can not be definitely recognized, and the whole vein system seems to be materially different.

In the southern part of the property lie the La Bella vein, known from the Christmas and Golden Cycle mines, and the Sigel and New veins, also opened in

the latter mine. These southern and less important systems are opened by long crosscuts on levels 8, 12, and 14. Their trend is northwest or north-northwest and their dip very steeply southwest. They have proved productive for only a distance of 200 feet from the southern boundary of the Vindicator.

The absence of cross veins is noteworthy. The two basic dikes in the northern part of the property carry no values and have no enriching influence. One of them, on the other hand, cuts off the ore shoot on No. 1 vein.

The veins are generally sheeted zones of an average width of 3 to 6 feet, but in places swell to 20 feet. Well-defined walls are rarely seen. The country rock has an irregular roughly blocky structure, and the tight seams of which the veins usually consist seem scarcely better defined than the joints in the surrounding latite-phonolite. On some veins a central seam with vugs is characteristic, but the cavities are very small. In the vicinity of the veins the latite-phonolite contains a little more disseminated dolomitic carbonates and pyrite than elsewhere, but even in the vein itself the percentage of these replacing minerals is small and does not greatly affect the appearance of the rock. Fluorite is sparingly present. As usual, the values are in the seams and, below the oxidized zone, consist of finely divided calaverite, often scarcely visible by the naked eye, loosely coating the thin quartz seams of the joints. Few other metallic minerals occur. Blende and galena are found in places, especially in the Sigel vein; molybdenite is likewise pretty generally distributed and was specially noted from the stopes on No. 3 vein. Tetrahedrite occurred in an unnamed vein on the deepest (1,200-foot) level, 200 feet northwest of the shaft.

The ore, which is sometimes shipped as taken out, but more frequently screened and hand picked, is of high grade and for the years 1901 and 1902 averaged a little over $40 per ton.

The smelting ore, which constitutes the larger part of an average daily output of 43 tons, contains about $58 per ton, while the milling ore, amounting to about two-thirds of the total ore production, averages $16 per ton. Very little silver is present.

ORE SHOOTS.

The most valuable ore body in the mine is that on No. 1 vein, which enters Vindicator ground from the Lillie between levels 5 and 11, and with a northwesterly pitch of 50° ceases somewhat below level 14.

Another shoot continues from the Lillie No. 2 vein into Vindicator ground, but the richest part of it occurred on a spur from this vein called the Vindicator from levels 12 to 14. Excellent shoots have been found 400 to 500 feet north-northwest of the shaft and in the deepest levels, on No. 2 and No. 3 veins, which here lie on the northwest side of No. 1 vein.

The Wallace vein or spurs close to it have carried a large stope practically from the surface down to level 13, the deepest from which it has yet been opened. It connects with the Glorieta shoot of the Hull City mine and pitches steeply northward. Shoots of smaller size have been opened on the La Bella, Sigel, and New veins.

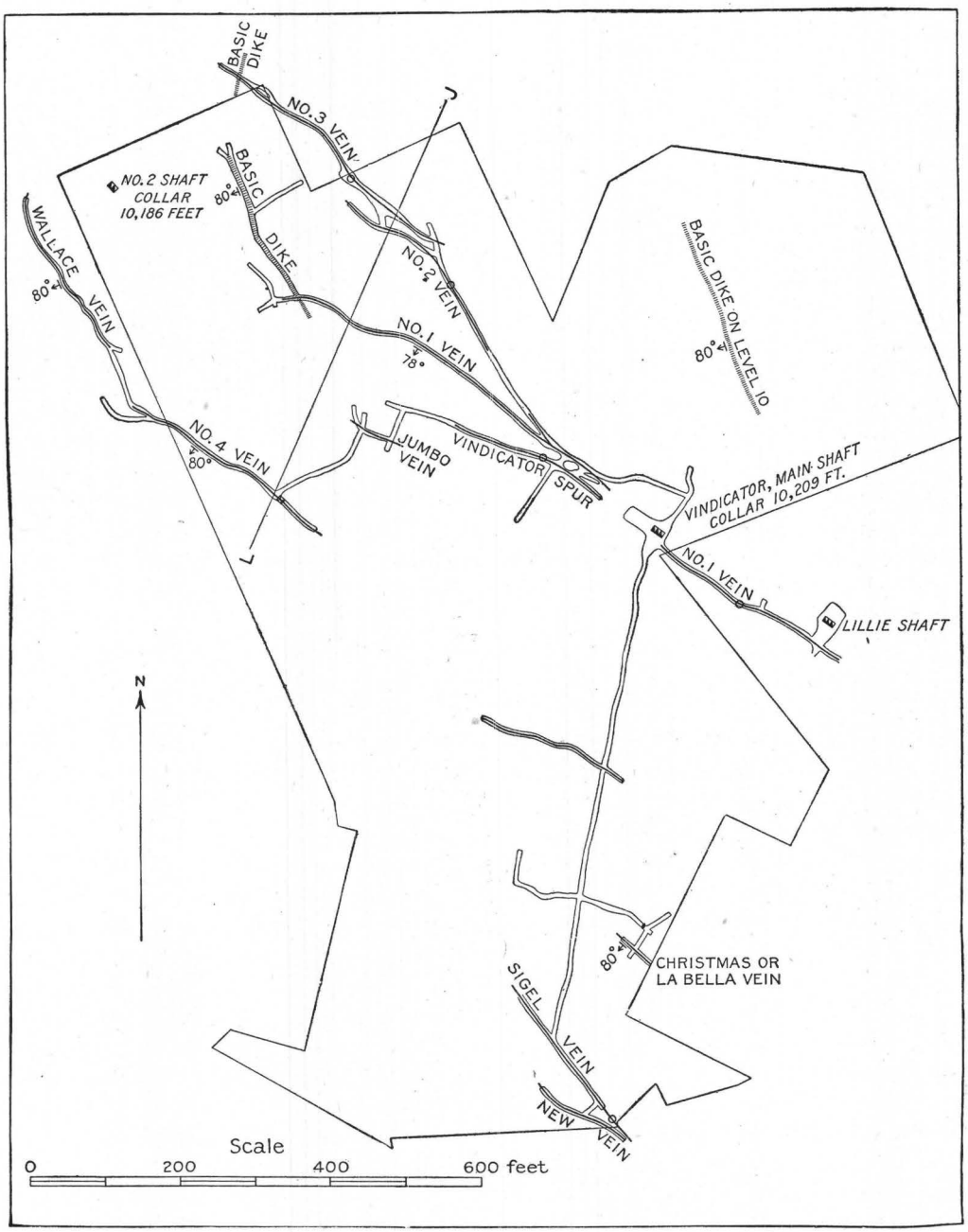


FIG. 51.—Map of level 12, Vindicator mine, showing vein system; elevation, 9,405 feet.

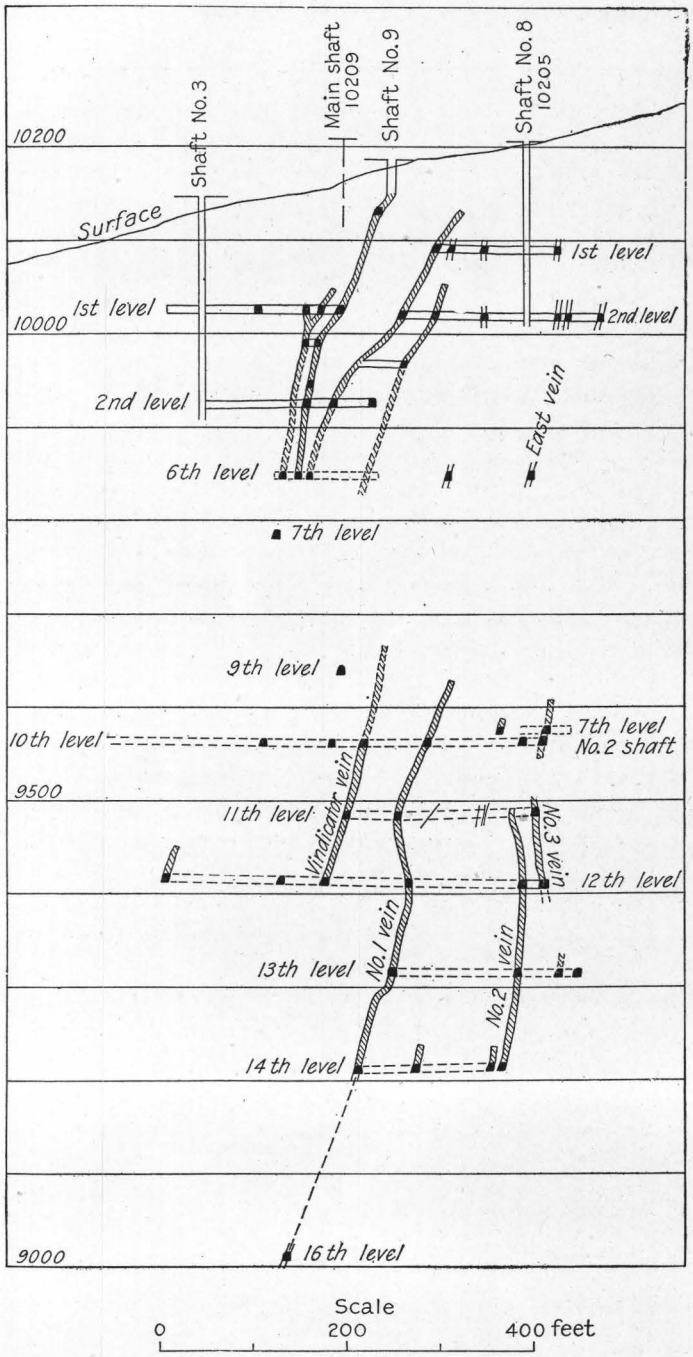


FIG. 52.—Cross section of Vindicator mine along line L-J on plan, showing stoped portions of veins; looking northwest.

DETAILS OF NOS. 1, 2, AND 3 VEINS.

On level 8 No. 1 vein enters, strongly developed, from Lillie ground, with wide stopes, which continue practically unbroken for 400 feet north of the shaft. No. 2 vein begins small, 50 feet southwest of the shaft, and continues with stopes for 300 feet, near the end of which it seems to connect with or cross No. 1 vein.

On level 10 No. 1 vein lies close to the shaft and continues northwest, with large stopes reaching down to the next level. Two hundred feet northwest of the shaft No. 2 vein intersects it. Stopes extend to a point 500 feet from the shaft, where the vein is cut off by a basic dike. The Vindicator spur lies 35 feet southwest of the shaft. No. 2 vein, on the northeast side of the main vein, is worked near the north end of the property, 500 feet north-northwest of the shaft. This shoot, which is not known higher up, continues down to level 14 with a steep north-northwest pitch. On level 10 the stopes show 6 feet of solid latite-phonolite cut by a few tight seams,

with a little fluorite. The ore, however, assays 6 ounces per ton and is shipped as taken out.

On level 11 No. 1 vein is not seen at the station, but appears 80 feet to the northwest. It is stoped for 500 feet up to the basalt dike, where both shoot and vein seem to be cut off. The stopes on No. 2 continue from above, 500 feet north-northwest of the shaft. A new vein called No. 3 here appears, 35 feet to the northwest of No. 2, diverging slightly northward. Excellent stopes have been opened on No. 3 at the northern boundary line, the shoot pitching steeply northward. No. 3 shows first 400 feet northwest of the shaft as an oxidized seam, 2 inches wide, often assaying 7 ounces per ton. The screenings of the drift run 3½ ounces. It then widens and forms a shoot 180 feet long and up to 15 feet wide. The latite-phonolite is fresh, but contains a little pyrite. No well-defined central seams are here visible, but there are irregular cracks, oxidized in places and trending in every direction, horizontal as well as vertical.

On level 12 the shoot on No. 1 vein was very productive and extended from near the shaft up to the basaltic dike. Extremely rich ore was stoped from the Vindicator spur, beginning at a point 100 feet northwest of the shaft and continuing for 200 feet. From a dark-brown oxidized streak 1,500 pounds were here mined which contained $15,000. The stopes on No. 2 vein are small, but those on No. 3 are very extensive, reaching to the northern boundary line of the property, where the values are cut off by the same basic dike which affects the shoot on No. 1 vein.

On level 13 the workings on No. 1 continue as before to the basic dike. The Vindicator spur is small. No. 2 vein carries a large stope up to the basic dike, but No. 3 vein is not known and, it is believed, joins No. 2 above the level.

On level 14 the No. 1 shoot was 400 feet long and very rich. Some of the stopes are 28 feet wide. As on the upper levels, it is cut off by the dike at a point 650 feet northwest of the shaft. The shoot descends below this level, but does not reach level 16, the deepest in the mine. Stopes on No. 2 vein, 500 feet north-northwest of the shaft, also descend to level 14. The vein has not been crosscut as yet on level 16.

Some work was being done in 1904 by lessees on level 7 of Vindicator No. 2 shaft, which is 12 feet above level 10 of No. 1 shaft and 625 feet below the surface. The veins worked here, 250 feet east of the shaft, correspond to No. 2 and No. 3 veins, and are also known as the Wood and Campbell veins. These veins intersect the basic dike, and the values are said to stop against it on its west side, as they do on the east side in the lower levels.

DETAILS OF WALLACE VEIN.

The Wallace vein, together with several spurs near the surface, has been stoped for a horizontal distance of 200 or 300 feet from near the collar of shaft No. 2 down to level 13, the shoot pitching slightly northward. The vein apparently forms the extension of the Sigel vein in the southern part of the property, but probably does not actually continue across. Branching off to the east from Wallace vein are several seams of less importance. On one, called No. 4, some

good ore has been found on level 12. Another, the "Jumbo," is very large and contains much quartz as filling and replacement, but no values are encountered (fig. 51, p. 419).

DETAILS OF SOUTHERN VEINS.

The Christmas or La Bella vein can not be followed far northward from the boundary of the Christmas mine. It has been stoped in the Vindicator practically from the surface down to a depth of 500 feet from No. 6 shaft, though the stopes are not more than 100 feet long; they connect with Christmas workings. The vein has also been opened and stoped on levels 8 and 12. On level 8 the stopes are 50 feet long and 6 feet wide. On level 12, 750 feet below the surface, the rock is very hard and tight and the small stopes are located close to the Christmas line.

The Sigel and New veins have no surface workings, but are opened by a crosscut from No. 6 shaft on level 5, 350 feet below the surface, and continue into Golden Cycle ground. The strike is here N. 60° W. On level 8, in the main shaft, the veins are narrow, but with well-defined walls. The central seam of the New vein, which lies 80 feet southwest of the Sigel, contains 3 ounces per ton in places. On level 12 there are important shoots, the Sigel being stoped for 130 feet from the Golden Cycle line and 160 feet high, while the New vein, which here branches from the Sigel near the boundary line, is stoped for a distance of 100 feet. The veins are here partly oxidized and show a narrow central seam with several tight parallel cracks. Galena and zinc blende, with quartz and calaverite, coat the seams. The stopes are 4 or 5 feet in width. The screenings which constitute ore contain about 3 ounces per ton.

On level 14, 950 feet below the surface, both veins are again opened and the New vein stoped 5 feet wide. It consists of a narrow, partly oxidized seam with tellurides and coated with dolomite.

CHRISTMAS MINE.

Between the Vindicator and the Golden Cycle mines lies the privately owned Christmas claim. Although a small property, with the only vein thus far productive confined to the southwest corner, the mine has a reported production of $330,000. It is opened by a main shaft with eight levels, the lowest 605 feet below the collar, which has an elevation of 10,159 feet. Fig. 53 shows the position of the veins near the shaft, according to surveys of V. G. Hills. The drifting is confined chiefly to the southwest corner of the claim, though there is a crosscut 250 feet long northeast to the Lillie line and a longer crosscut due east to the same line on the 514-foot level. The mine is now worked on a small scale by lessees.

On the surface a narrow northeasterly trending belt of breccia separates an area of latite-phonolite on the southeast from the Vindicator area of syenite on the northwest. As shown underground the breccia contains a large amount of latite-phonolite, and the contacts separating it from this rock are very indistinct. The stations at the 239- and 515-foot levels are in breccia. In the upper level breccia continues northeast through the 250-foot crosscut and is cut by a narrow

dike of latite-phonolite 150 feet from the shaft. At the end of this crosscut is another dike, said to be syenite. The main vein west of the shaft is in latite-phonolite. On the 515-foot level brecciated latite-phonolite appears at the station, but changes to massive rock of the same kind 75 feet northeast, at the first vein. Four hundred feet east of the shaft in the long drift and crosscut the latite-phonolite changes to denser phonolitic rock, and a dike of syenite is met at the Lillie line, possibly the same as that in the crosscut on the 239-foot level. On the west side from the main shaft breccia continues to the La Bella vein.

The principal vein is the La Bella, which is also worked on both adjacent properties. Its strike is N. 45° W. near the surface, but it swings to N. 34° W. on the lowest level. The dip is nearly vertical in the upper levels, but turns 70° SW. in the four lower levels. Two or three lesser veins diverge toward the southeast; one of them, the Talbot, crops near the small Wilkinson shaft and is cut on several lower levels dipping very steeply northeast; a second vein is opened at No. 3 shaft, 400 feet east-southeast of the main shaft, and is also cut on the 514-foot level.

The La Bella vein consists of several closely contiguous branches converging toward the northwest. In the vein the rock is often remarkably fresh, locally with well-preserved augites; in one place a transition to syenite was noted. There are usually several narrow and tight seams and many minor cracks, all coated with carbonates, quartz, and tellurides.

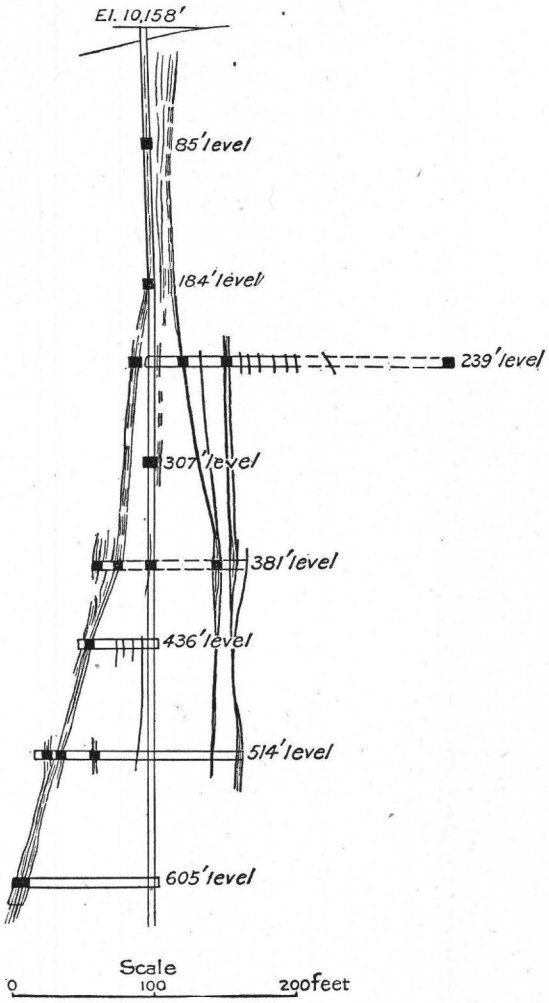


FIG. 53.—Cross section through Christmas shaft, showing Christmas veins; looking northwest. (After V. G. Hills.)

Two shoots have been mined. One, beginning just north of the shaft and up to 10 feet wide on the 239-foot level, continues to the 605-foot level and thence pitches northward into Vindicator ground, 200 feet northwest of the shaft, where it has been mined on level 12, about 150 feet below the deepest Christmas level. A second shoot lies near the Golden Cycle line, which is only 50 feet southeast of

the shaft, and from the lowest levels pitches into that property; on the 514-foot level at the boundary line it is up to 15 or even 20 feet wide. The same shoot has been opened in the Golden Cycle on level 9, 400 feet below the 605-foot Christmas level.

LILLIE MINE.

The Lillie claim adjoins the Vindicator property on the southeast and occupies an area of 7 acres. It was operated by the Lillie Gold Mining Company (Limited), of London, but is now the property of the Vindicator Company. The total production approaches $1,300,000, and the dividends paid amount to about $400,000. The development consists, besides several small shafts, of a principal shaft 1,526 feet deep, with twelve levels turned, as shown in fig. 54. The elevation of the collar is 10,222 feet; level 12 connects with the deepest (1,200-foot) Vindicator level 16 at an elevation of 9,009 feet; the shaft was sunk 300 feet deeper. The workings, while occupying only a small horizontal space, are extensive, and the old stopes on practically every level above 12 connect with the Vindicator drifts, the line being but 175 feet distant from the shaft. To the southeast the drifts extend only 200 feet; but on level 8 an exploratory drift reaches 600 feet from the shaft in this direction. The mine has not been operated for several years. The water is held at the same level as in the Vindicator. There was little opportunity for examination of geological features, which, however, are similar to those in the Vindicator. The prevailing rock is latite-phonolite, while breccia is apt to appear on the northeast side of No. 1 vein.

The Lillie has two main veins, named No. 1 and No. 2. No. 1 is the principal one and really forms the south end of the persistent lode which traverses the Findley, Hull City, Vindicator No. 2, and Vindicator shafts, holding a direction of N. 60° W., and at intervals sending out branch veins which diverge toward the north. The Lillie No. 1 is very nearly vertical, as shown in fig. 54. No. 2 vein branches from it 50 feet south of the shaft and lies on the southwest side; at the Vindicator line it is about 100 feet from No. 1.

The main vein had one very large ore shoot, which at the surface was 200 feet long and at a depth of 550 feet pitched into Vindicator ground, and here continued to a depth of 900 feet, at the same time lengthening its horizontal dimension. Some of the Lillie stopes were up to 20 feet wide. On the branch (No. 2) vein very rich ore occurred at the intersection with No. 1. Beginning 200 feet below the surface, the shoot on No. 2 continued with a length of 200 to 300 feet to a depth of 800 feet and then entered the Vindicator property, in which, however, it did not persist very far. The developments below the 800-foot level are said to have shown very little ore in the Lillie.

GOLDEN CYCLE AND THERESA MINES.

PRODUCTION AND DEVELOPMENT.

The Golden Cycle Mining Company owns a roughly rectangular area of 25 acres adjoining the Vindicator and the Christmas on the southeast side. It is one of the large mines of the district, notable for its output of medium-grade ore. The

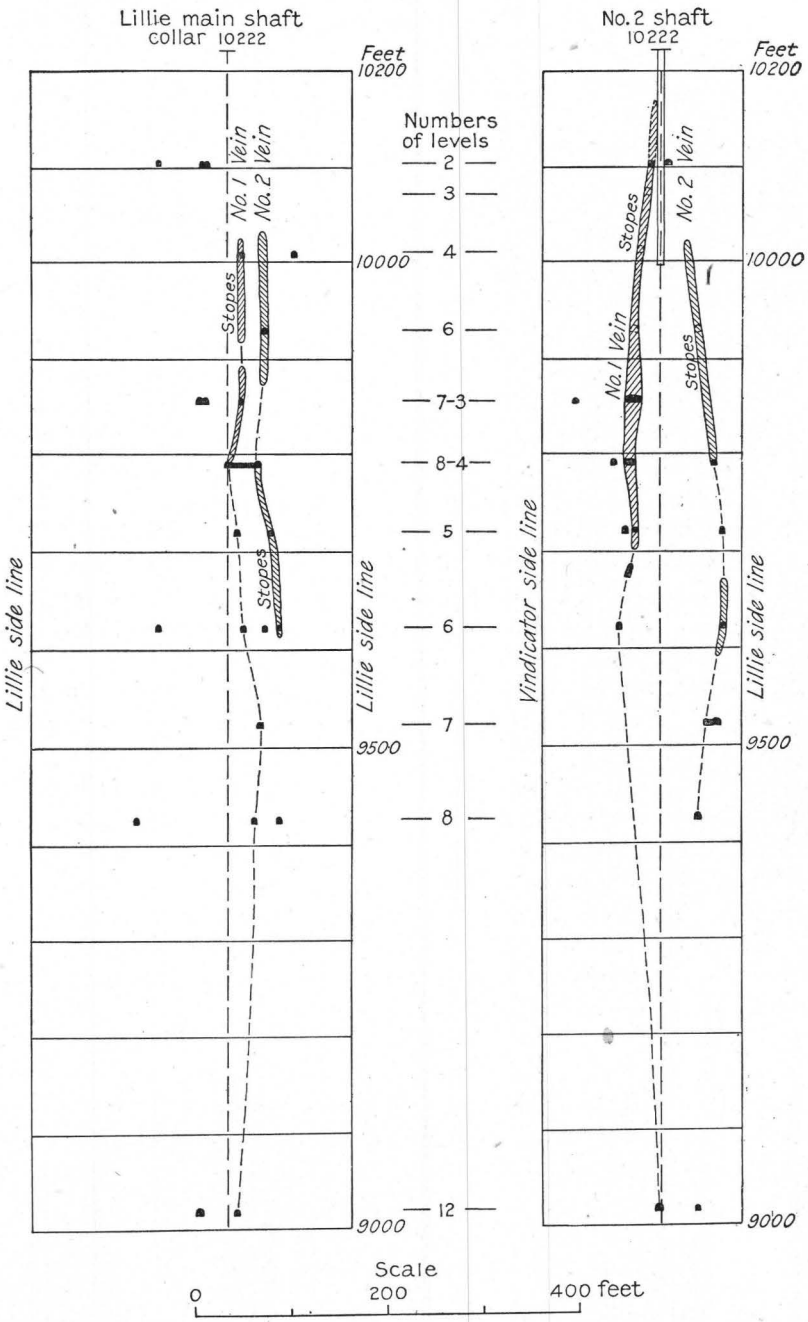


FIG. 54.—Cross sections of the Lillie vein, perpendicular to the plane of shafts 1, 2, and 3, showing stopes on veins.

production, which dates from 1896, amounts to nearly $4,000,000 up to January 1, 1905. Dividends of $350,000 have been paid in the same time.

Production of the Golden Cycle mine from 1902 to 1904, inclusive.

Period.	Amount.	Gross Value.
	Tons.	
July 1, 1902–Dec. 31, 1902	18,751	$408,220
Jan. 1, 1903–Dec. 31, 1903	35,300	831,960
Jan. 1, 1904–Dec. 31, 1904 [a]	22,479	406,194

[a] Mine was closed during May, June, July, and August, 1904.

The main shaft is located on a bluff just north of the town of Goldfield, and the elevation of its collar is 10,066 feet, or 143 feet below the main shaft of the Vindicator. The shaft is 1,030 feet deep; level 3 is 276 feet below the collar, while the subsequent ones are respectively 400, 500, 600, 700, and 1,000 feet below the same datum. There are also two smaller shafts—the Anna, on the Harrison vein, and the La Bella, on the Revenue system. A tunnel with an elevation of 9,897 feet gives access to the upper workings. The total developments amount to several miles.

The Theresa property consists of the claim of the same name, adjoining the Golden Cycle on the east, and was until recently worked in conjunction with the Golden Cycle. It is developed by a shaft situated 200 feet southeast of the main shaft of the Golden Cycle. The bottom level is the same as level 7 of the Golden Cycle, but the workings of level 8 of the latter mine have also been extended into Theresa ground. Four hundred feet north of the Theresa shaft is the Tateman shaft, which explores the upper part of the Revenue system down to an elevation of 9,927 feet. There is also a crosscut 700 feet long on level 5 of the Theresa shaft which opens the whole northern part of the claim up to the boundary underneath the Tateman shaft. The drifts and crosscuts on the Theresa amount to several thousand feet.

The Gold Knob shaft was sunk 600 feet deep in the breccia 850 feet southwest of the Golden Cycle shaft and in the line of extension of the Legal Tender vein. The crosscuts are said to have thus far failed to develop any veins.

The Golden Cycle connects with the Vindicator drainage basin. In June, 1903, level 10 was kept dry by pumping 50 gallons a minute, most of which came from the Legal Tender system, while the Revenue veins are almost dry. The Vindicator was then pumping 210 gallons a minute. Later on, in March, 1904, pumping was discontinued in both mines and water rose to between levels 8 and 9. At the end of 1904 the Golden Cycle, the only mine then pumping, kept the water below level 10 by raising 300 gallons a minute.

The mine is free from gas except a small amount occasionally occurring in the long crosscut southwest on level 9.

GEOLOGICAL FEATURES.

On the surface the shaft is situated in an oblong area of latite-phonolite, separated by a strip of breccia 200 feet wide from the Vindicator area of syenite,

which reaches to the southeast about as far as the Christmas mine. The underground developments do not correspond to the surface relations, but indicate that the southern half, at least, of the area of latite-phonolite forms a flat body underlain by breccia and that in depth it in all probability connects with the Vindicator rock mass. On the tunnel level the rock south and west from the shaft is a breccia, while latite-phonolite extends from the Legal Tender vein close to the shaft up to the Christmas line. On level 3 latite-phonolite begins 30 feet north of the shaft and on levels 4 and 5, 130 feet from the same place. The rock is brecciated in places along the La Bella vein. On level 6 the same contact is found 350 feet north of the shaft in the crosscut which leads direct to the Revenue veins. Brecciated rock is again met in spots in the La Bella and Sigel veins. Finally, on level 8 the contact lies 400 feet north of the shaft at the Middle vein, and the Legal Tender vein is in breccia all along for 270 feet northwest of the shaft. Latite-phonolite extends from the Middle vein up to La Bella, and here, as in other levels, doubtless connects with the Vindicator area. No normal syenite was seen in the mine. The workings on level 10 were not far advanced at the time of the first visit, in June, 1903, and showed only breccia. A crosscut on level 9, 600 feet long, explores the southwestern territory and shows only normal breccia. For the last 100 feet the breccia is fine-grained and crumbling, almost without secondary alteration; it contains much phonolite.

No basic dikes have been found. On level 9 the Harrison vein is in places followed by a narrow phonolite dike. Another dike, which also seems locally irregular and nonpersistent, in places lies closely to the northeast of Legal Tender vein. It was seen on level 3, where it is 35 feet wide and 40 feet from the vein, on level 5, and on level 8, where the northwest end of the Legal Tender vein, 270 feet northwest of the shaft, is in phonolite. It is probably the same dike which lies parallel to the Theresa East vein, a spur of the Legal Tender, on levels 7 and 8, near the Theresa line.

THE VEINS IN GENERAL.

The Golden Cycle mine depends for its ore on three vein systems with a general northwesterly, slightly diverging strike and very steep southwesterly dip. If continuous these systems would intersect at a point near the Gold Knob shaft in Goldfield. The Harrison vein strikes west-northwest and is opened for a distance of 500 feet about 100 feet southwest of the shaft, and has also been cut in a shaft on the Aluminium claim a few hundred feet farther north-northwest. Four hundred feet west of the shaft it has, on upper levels, an important spur called the Anna.

The Legal Tender vein strikes nearly due northwest, and on level 9 lies immediately north of the shaft; its dip is very steep to the southwest. It has been opened for a distance of about 700 feet, beginning in Theresa ground and extending to a point 300 or 400 feet northwest of the shaft; drifts are extended on it on all levels, including 10. A spur near the shaft and another called the Theresa East vein have proved valuable.

The Revenue system is the most complicated. It lies 500 to 800 feet north of the shaft, and the various veins trend north-northwest. Between the Revenue and the Legal Tender on levels 6 and 8, but not above, lies the Carr or Middle vein.

In the Revenue the most southerly is the Revenue vein, known on all upper levels down to 7, while it is less well developed on 8 and 9. It has several spurs. The Sigel vein, opened on level 6 at the Vindicator boundary, lies in the continuation of the Revenue, but the actual connection has not been established. About 100 feet north of the Revenue is the La Bella vein, known on levels 3 to 9, inclusive. A vein carrying small values was cut near the end of the long southwest crosscut on level 9; it occured in the loose, unaltered breccia which there forms the country rock.

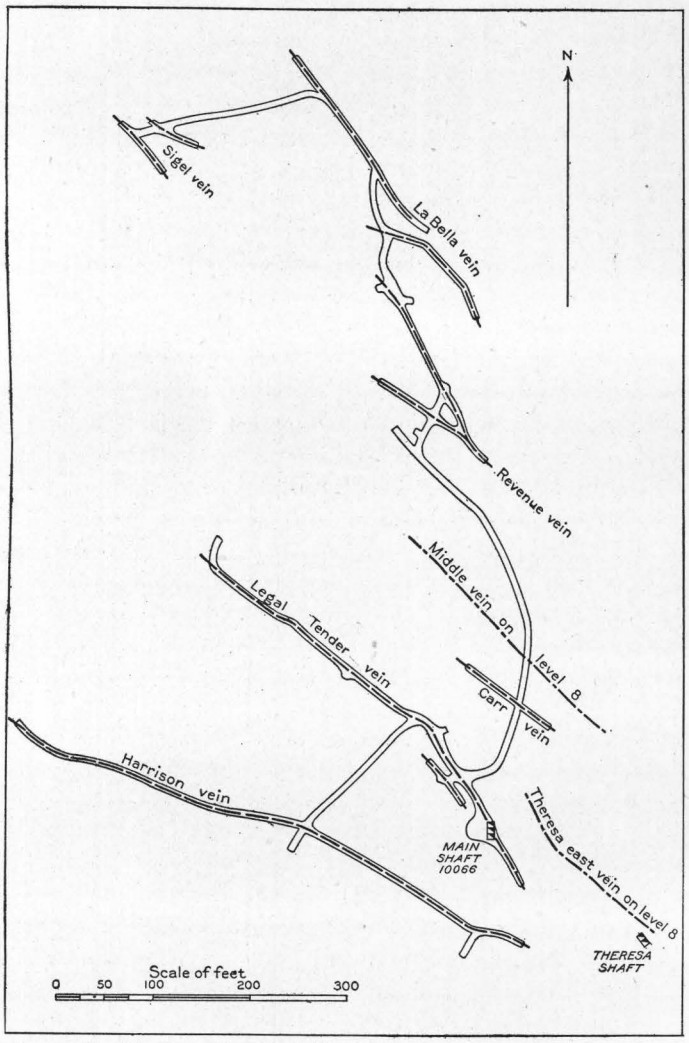


FIG. 55.—Map of level 6, Golden Cycle mine; elevation 9,463 feet.

OXIDATION.

Oxidation has penetrated to the bottom level along most of the seams, and the ores invariably pan free gold. Calaverite is, however, found occasionally, and one vein, the Middle, on level 8, is not oxidized, possibly because not reaching to the surface. The natural water level is not positively known, but is believed to have had a depth of about 800 feet.

VEIN STRUCTURE AND ORE.

The veins as a rule are narrow sheeted zones, in many cases with a pronounced central seam and not quite so tight as in the Vindicator, though the rock is often very fresh within the veins. The seams are coated by quartz, dolomitic carbonates, and a little fluorite; celestite needles also occur. Native gold is the principal ore mineral, with a little unchanged calaverite and occasionally a little pyrite, galena, and zinc blende. A spur vein along the phonolite dike at the Theresa East vein contains much galena and zinc blende, but carries low values in gold. The breccia and latite-phonolite throughout the productive ground contain a little pyrite and dolomite, but the alteration is never pronounced. The alteration is strongest within the veins and, as shown by the crosscut on level 9, is apt to disap-

pear entirely away from the strong vein systems. The ore is sometimes shipped as broken, but often it is found more advantageous to screen it; its grade is low compared with some other mines like the Vindicator, averaging between $20 and $25. On the other hand, the tonnage is considerable.

ORE SHOOTS.

The ore shoots of the Golden Cycle are not more than a few hundred feet long; they are either vertical or pitch steeply northward, as, indeed, seems to be the rule throughout this part of the district. No cross fissures are present and no structural conditions seem to influence the ore shoots, except possibly spurs and branches which sometimes have an enriching effect. On the Harrison vein, with the Anna spur, a good ore shoot, 10 feet wide in places, went to the surface and was also stoped on the tunnel level. On levels 3 and 4 it lengthened to 500 feet and the Anna spur proved very productive. Lower down it decreased in length to 300 feet on level 7. On levels 8 and 9 the vein is of low grade; it here appears as a narrow sheeted zone with a central clay seam from which values of $10 may be obtained.

The most productive vein is the Legal Tender. Its shoot is said to have been poor and short on the highest levels, though it has been stoped on these in Theresa ground. The shoot has a decided northward pitch. On level 3 the shoot is 250 feet long and lies on both sides of the shaft. On level 6 it increases its length to 400 feet. On level 8 the shoot extends 300 feet northwest from the shaft and has been very rich, while the vein breaks up southeast of the pay shoot. Finally, on level 9 the shoot is 400 feet long and values are maintained. In the deepest level the Legal Tender vein shows 7 to 10 feet wide with entirely oxidized seams in fresh pyritic breccia. In stopes between levels 8 and 9 the payable portion is 6 feet wide, without well-defined walls. The rock is a fresh breccia cut by a central seam and many smaller ones, all brown and oxidized. The Theresa East vein first appears on level 7, 35 feet east of the Legal Tender, and much ore was stoped on it between levels 7 and 8. On level 8 it dips 60° SW. and joins the Legal Tender 30 feet above level 9. The ore extracted from a single raise from level 9 to 8 near the Theresa boundary line is said to have yielded $25,000. The vein is 5 feet wide, and shows oxidized seams. Screenings often yield 6 ounces per ton. The Middle vein shows a good ore shoot on level 8, with a very rich central seam, sometimes containing 200 ounces per ton.

An important ore shoot has been mined on the Revenue vein from the surface; it is 200 feet long on the tunnel level and 10 feet wide in places. These large stopes continue through succeeding levels from 3 to 8, inclusive, and show at least one important spur vein.

On the La Bella vein shorter stopes connecting with the Christmas mine were carried to the surface from the tunnel level, while on level 3 the vein was small and the ore body short. On levels 4 and 5 the shoot was much better and up to 150 feet long. Ore continues on this vein down to level 9, the deepest yet opened. The vein here shows a small central seam carrying a little calaverite, but mostly oxidized. Little fluorite is present. The screenings from a width of 3 or 4 feet contain about 2 ounces per ton.

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CHAPTER VII.—MINES OF BATTLE MOUNTAIN (EAST GROUP).

GENERAL INTRODUCTION.

Battle Mountain rises directly north of Victor, in the southern part of the volcanic area. On the northwest it is separated from Raven Hill by Arequa Gulch, and on the southwest from the granite mass of Squaw Mountain by a well-marked saddle. On the south Battle Mountain merges into the granitic slope upon which is built the town of Victor. On the southeast it is separated by Wilson Creek from Big Bull Mountain and on the north is connected by an open saddle with Bull Hill.

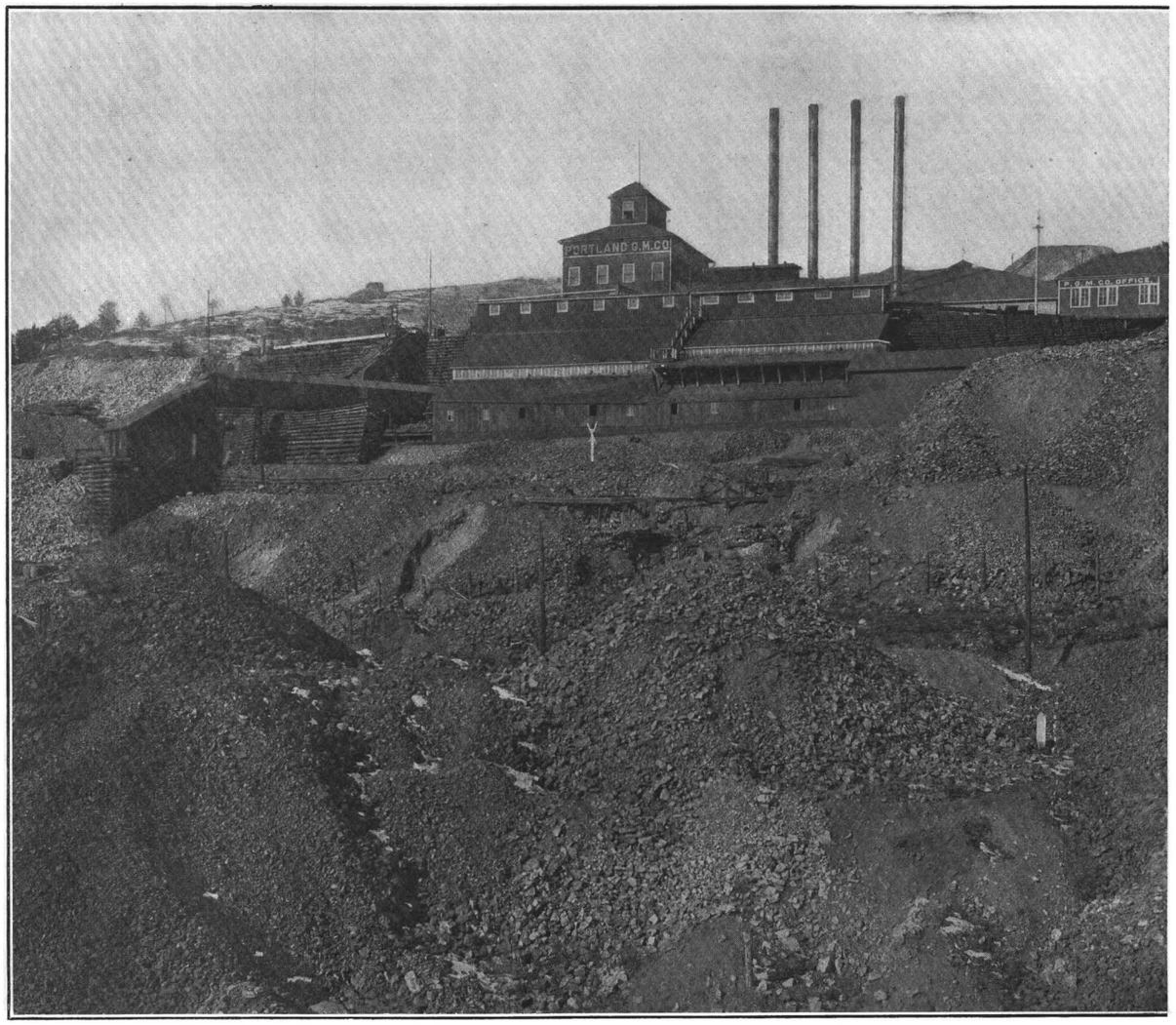
The principal rock of Battle Mountain is a volcanic breccia of mingled phonolitic and granitic detritus. This breccia, which is bounded on the south by the nearly vertical rim of the Pikes Peak granite, is intricately intruded by masses of syenite and latite-phonolite and by phonolite and "basalt" dikes.

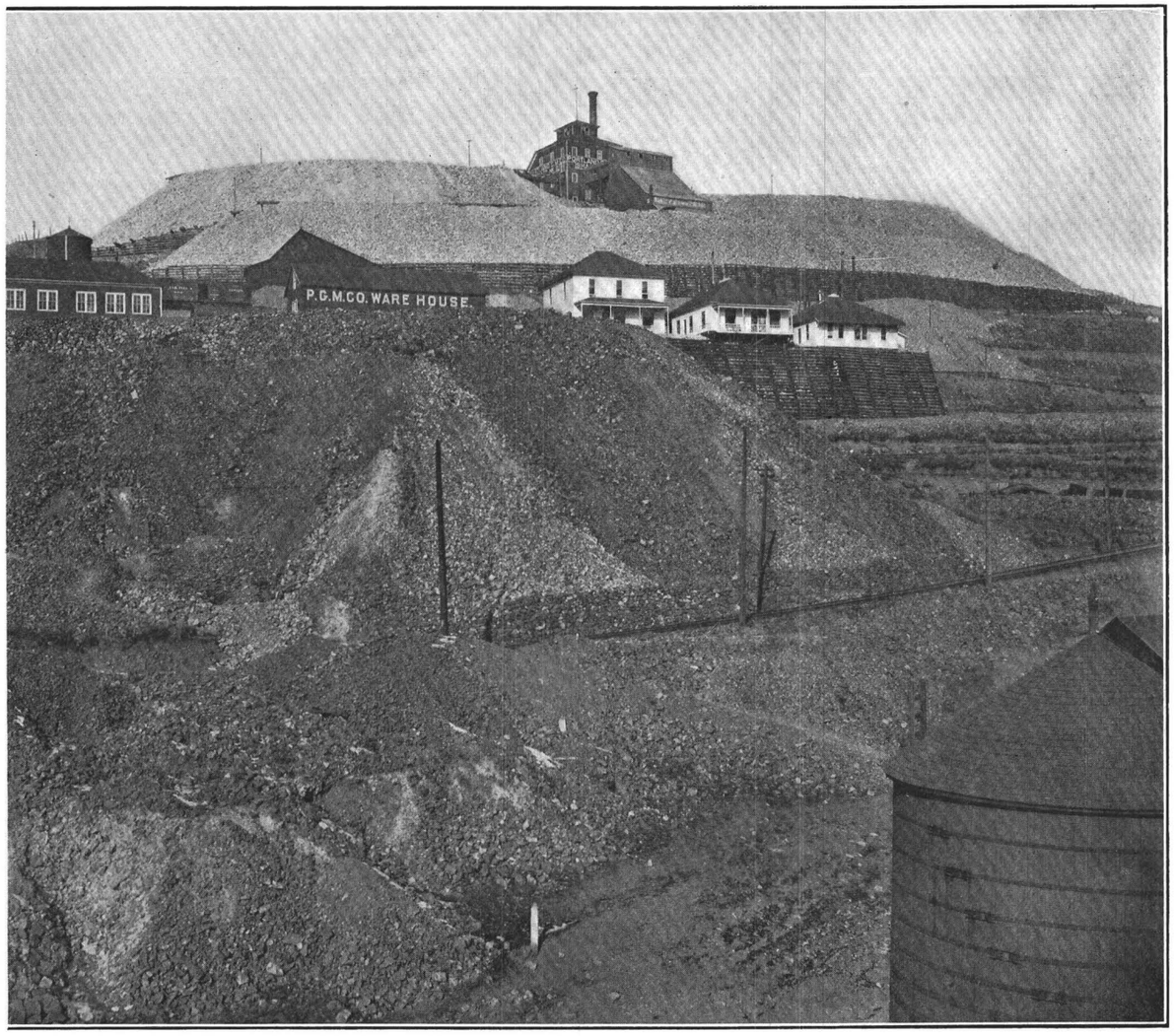
The mines of Battle Mountain are not only numerous, but constitute the most productive group in the entire district. Some of the ore bodies are entirely in breccia, others are entirely in granite, and still others are partly in breccia and partly in granite, or in some cases in phonolite or "basalt" dikes. On the northwest slope of the mountain are the Eclipse and Carbonate Queen mines. On the south slope, nearest Squaw Mountain, are the Ajax, Dead Pine, and Gold Coin mines, the latter in the town of Victor and not strictly on Battle Mountain. East of these mines is another line comprising the Granite, Monument, Dillon, and Mary Cashen mines. East of these again are the Portland, with workings extending under the summit and northern slope of the hill, the Strong, and Stratton's Independence mines.

PORTLAND MINE.

INTRODUCTION.

The Portland mine, the largest in the district, is on Battle Mountain, just north of Victor. The original Portland claim, located by James Doyle early in 1892, was a small triangular fraction on the south slope of the mountain and about 300 feet northwest of Stratton's famous Independence claim. Doyle entered into partnership with James Burns, and soon afterwards John Harman was given a third interest. In a short time the three prospectors discovered ore, but were at once involved in litigation with surrounding claim owners. W. S. Stratton, however, came to their aid, additional claims were acquired, and in 1894 the present company, capitalized at $3,000,000, was organized, with Stratton as its first president. The holdings of the company at that time included the Portland, Anna Lee, Bobtail, Hidden Treasure, Scranton, and Captain claims. Other purchases followed in succeeding years, until at present the Portland Gold Mining Company owns about





THE PORTLAND MINI FROM THE SOUTH.

183 acres in the shape of an irregular strip of territory, nearly a mile long and about one-third of a mile wide, which stretches north and south over the eastern summit of Battle Mountain. South of the Portland property are those of the Stratton's Independence (Limited), and the Strong Gold Mining Company; west of it are the Dillon, Monument, Granite, and Ajax mines; on the north the Blue Bird and Last Dollar mines; and on the east the Modoc and Rigi mines.

At present the mine has three working shafts and the largest and most complete equipment in the district. The Portland Company operates its own mill near Colorado Springs.

PRODUCTION AND DIVIDENDS.

The following table, compiled from the admirable annual reports of the Portland Company, gives the tonnage, gross value, and average value per ton of the ore raised from the mine, also the dividends from April 1, 1894, to the end of the year 1905. In the next to the last column is given the proportion of silver to gold in the ore for those years for which data are obtainable. This proportion is expressed by giving the ounces of silver present with 100 ounces of gold.

Production and dividends of the Portland mine.

Year.	Net tons.	Gross value.	Average value per ton.	Ounces of silver per 100 ounces of gold.	Dividends.
1894	7,826.286	$553,975.75	$40.78	.....	$67,290
1895	31,516.346	1,700,094.89	53,94	.....	479,790
1896	23,598.172	1,116,128.29	47.29	.....	360,000
1897	18,852.224	1,177,642.65	62.46	.....	360,000
1898	27,798.850	1,879,681.96	67.61	.....	570,000
1899	38,548.090	1,951,219.34	50.61	6.87	720,000
1900	60,786.755	2,351,369.26	38.68	4.30	750,000
1901	76,905.550	2,408,413.23	31.31	2.41	720,000
1902	89,664.279	2,334,023.76	26.03	(a)	270,000
1903	90,244.582	2,608,993.59	28.91	(a)	360,000
1904	96,521.385	2,597,993.82	26.91	(a)	720,000
1905	109,232.000	2,422,033.42	b 23.60	(a)	.....
Total	671,394,519	23,101,569.96	.....	.....	5,377, 80

a Output for this year given as ounces of gold.
b Low-grade ore from dumps (8,246 tons at $5.84 per ton) is not included in this average.

UNDERGROUND DEVELOPMENT.

According to the report of Mr. F. M. Kurie, manager, the linear development of the Portland mine, including drifts, crosscuts, shafts, winzes, and raises amounted on January 1, 1905, to 30 miles 3,513 feet.[a] From 3 to 4 miles of new development are completed each year.

The main working shaft is the No. 1, or Burns, 1,120 feet deep, situated on the south slope of Battle Mountain near the south end of the Portland property. The No. 2 shaft, 1,282 feet deep, lies 750 feet about north-northeast from the Burns shaft, and 162 feet higher up on Battle Mountain. The No. 3 shaft, 1,155 feet

a Total development to January 1, 1906, 34 miles 3,466 feet.

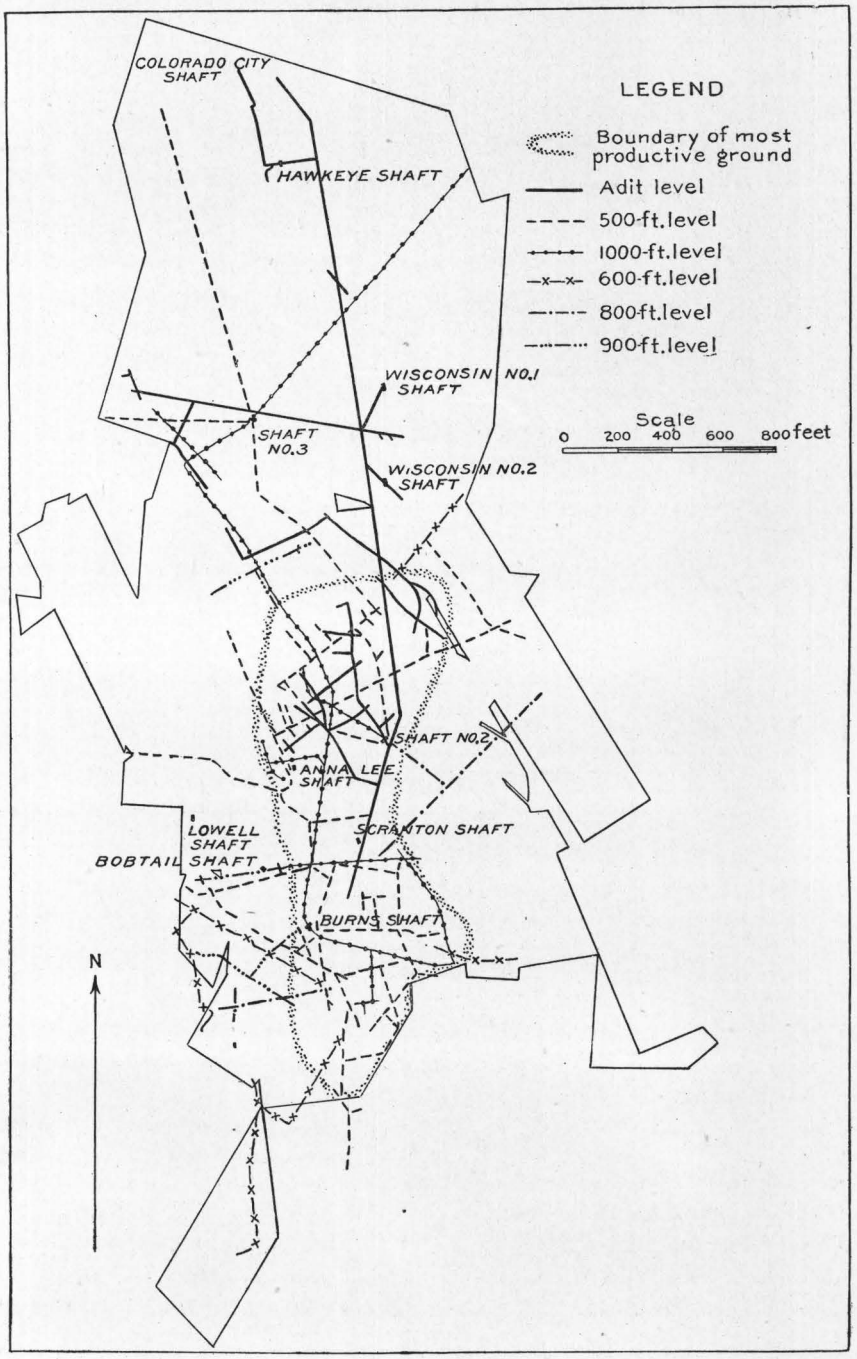


FIG. 56.—Plan of the Portland mine, showing the boundaries of the property and parts of some of the principal levels.

deep, lies 1,900 feet a little west of north from the Burns shaft and 1,300 feet nearly north-northwest from the No. 2 shaft; it is on the north slope of Battle Mountain, just below the summit, and its collar is 250 feet above that of the Burns shaft. An adit over 3,100 feet in length enters Battle Mountain near the collar of the Burns shaft and connects with the No. 2 and No. 3 shafts at about 162 and 250 feet below the surface, respectively. Through this adit timbers are taken in to these shafts and ore run out to the ore house near the Burns shaft.

Besides the shafts mentioned are a number of old openings, such as the Anna Lee, Bobtail, Diamond, Scranton, and Wisconsin shafts, formerly worked as independent mines, but at present serving only for ventilation, and two small shafts, the Colorado City and Hawkeye, near the north end of the property, which have recently been connected with the main Portland workings. Since the time of visit the Lowell shaft, northwest of the Burns shaft, has been sunk to a depth of 170 feet, and stopes have been opened on three levels.

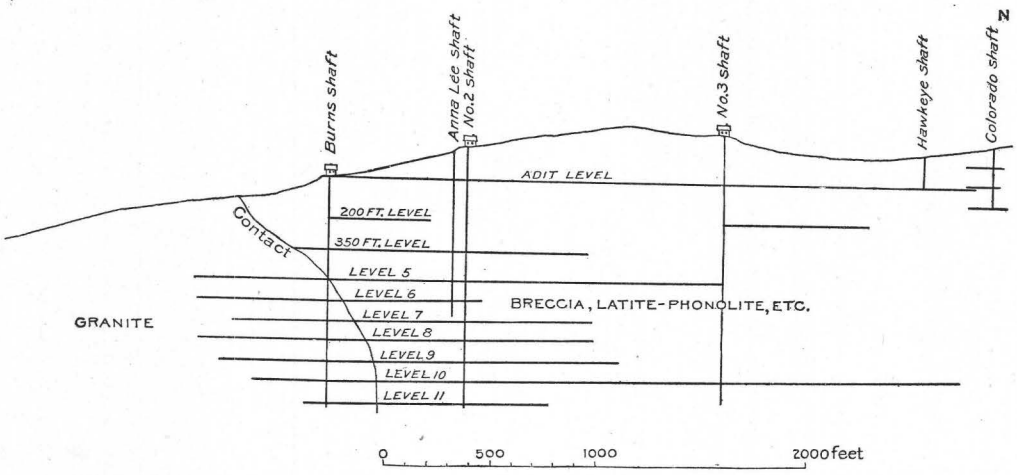


FIG. 57.—Generalized longitudinal projection through the Portland mine; stopes not shown.

The principal levels now worked are designated as follows, the figures referring to the collar of the Burns shaft: The adit level, the 220-foot level, the 350-foot level, the 500-foot level, and thence levels at intervals of approximately 100 feet down to the 1,100-foot level. An idea of the general plan and extent of these levels may be had from figs. 56 and 57.

GEOLOGICAL FEATURES.

The workings of the Portland mine are partly in the breccia and eruptive rocks of the Cripple Creek volcanic neck and partly in the encircling granite through which these volcanic materials were ejected and intruded. (See Pl. V, p. 26.) The granite is of the Pikes Peak type,[a] such as underlies the town of Victor and is exposed on Squaw Mountain. It is petrographically described on pages 43 to 45

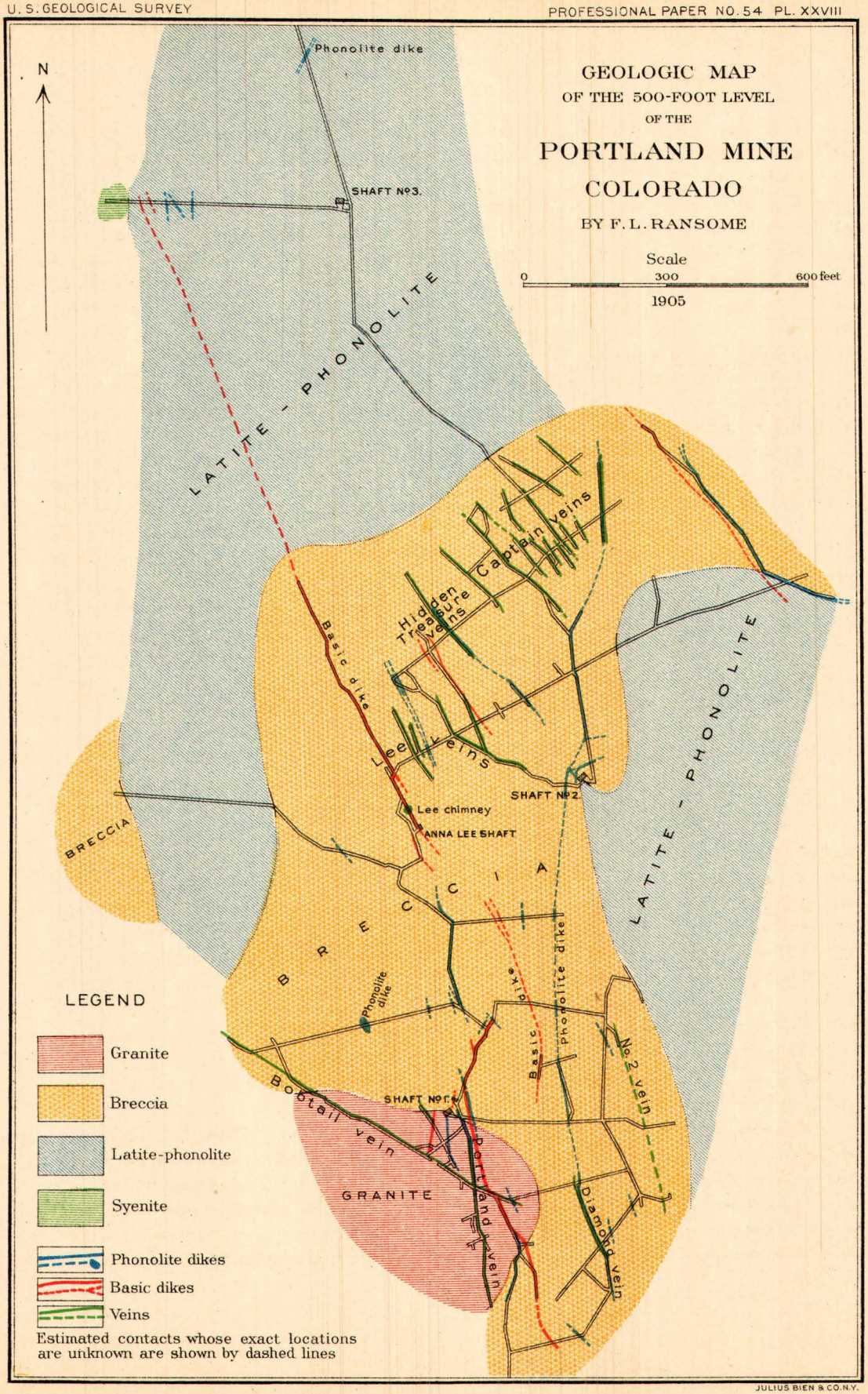
[a] Mathews, E. B., The granites of Pikes Peak, Colorado: Bull. Geol. Soc. America, vol. 6, 1894, p. 472. See also Geology and mining industries of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 22-23.

of this report. It is normally rather coarse grained, with conspicuous porphyritic crystals of pink microcline. A tendency toward gneissic structure is frequently noticeable.

The common breccia of the Portland mine is a hard, rather even-textured gray rock in which the breccia structure is seldom very conspicuous. Recognizable fragments of phonolite or andesite over an inch in diameter are rare, and the breccia in which occur the ore bodies of the Captain and Hidden Treasure veins, near the No. 2 shaft, is so fine grained and homogeneous that its true character might easily escape detection by an eye untrained to its peculiarities or familiar only with the more obvious nature of the breccia prevailing in the Raven Hill mines. Locally, however, blocks of granite, some of them as much as a foot or even 6 feet in diameter, occur within the breccia, particularly in the vicinity of the contact with the granite wall which limits the breccia on the south. This granitic breccia is very well shown on the 500-foot level, in the west crosscut to the Bobtail vein, northwest of the Burns shaft. Although such large fragments of granite are not common in the breccia of the northern part of the mine, yet close inspection of the finer grained phases, such as constitutes the country rock of the Captain veins, usually reveals little bits of pink microcline derived from the comminution of the granite. The microscope shows that together with particles of microcline and quartz of granitic derivation occur splinters of plagioclase and small fragments of the feldspathic groundmass of andesitic and phonolitic rocks. No ferromagnesian minerals have been seen in any of the volcanic breccia of the Portland mine. Secondary pyrite is almost everywhere present, disseminated in varying abundance through the rock and usually accompanied by more or less calcite.

In certain parts of the mine the breccia exhibits banding, which in some cases closely resembles ordinary bedding. Such a structure was noted on the 600-foot level east of the No. 2 vein, in a fine-grained phase of the breccia resembling a tuffaceous sandstone. The bands here are rather indistinct and are due to not very sharply differentiated alteration of slightly coarser layers with the prevailing fine grained material. Similar banding occurs in the northern part of the mine on the 500-foot level in the country rock of some of the Captain veins. The bands here are generally nearly horizontal. They are not persistent, but fade out gradually into the fine-grained homogeneous breccia. The structure is best exhibited, however, south of the Burns shaft on the 220-foot level. Here also the banding occurs in an unusually fine-grained tuffaceous phase of the breccia which grades both horizontally and vertically into coarser material showing no banding. The bands are a foot or two thick and are nearly horizontal. The rock cleaves parallel to the bands and thus heightens the effect of regular stratification. The banded structure, however, is very local and passes by insensible gradations into coarser breccia, in which no bonding is perceptible.

The origin of this banding in the tuff breccia is not clear. There is no evidence of the former existence of any considerable water body in which stratification might have taken place, nor do the constituent particles of the breccia appear waterworn when examined in thin section. It is probable that the structure is a very local phenomenon, incidental to the accumulation of the volcanic ejectamenta, and that it is to be ascribed to the winnowing action of air currents on fragments thrown up



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from the old crater, to the sorting of particles by rolling down slopes, or to slight difference in size of the comminuted fragments thrown out by successive volcanic explosions.

The contact between the granite and breccia is an irregular surface which plunges steeply down under the breccia to the north and east. Its dip is rarely less than 70°, is frequently approximately vertical, and in places forms what would be an overhanging cliff were the breccia removed. Some idea of the irregularity and general steepness of this contact may be had from Pl. V (p. 26). As is there well shown, the granite in the Portland workings forms a bold promontory jutting into the breccia-filled funnel of the Cripple Creek volcano. Along the northern scarp of this promontory, west of the Portland mine, are the workings of the Granite, Dead Pine, and Ajax mines. Along the eastern declivity, south of the Portland, are the workings of Stratton's Independence mine.

The contact is well exposed on all the Portland levels from the 500-foot to the 1,000-foot. As a rule it is sharp and readily determined. The breccia for a few inches from the granite is usually hard, rather fine grained, and, as shown by microscopic study, chiefly of granitic origin. It rests snugly against the rather minutely irregular wall of granite, which is not as a rule noticeably fractured or shattered. Usually there is no evidence of faulting along the contact, and there can be little doubt that the breccia was in the main originally deposited in the position it now occupies relative to the granite. Occasionally there has been some fissuring along planes adjacent and generally parallel to the contact. Such fissure planes, however, do not follow the irregularity of the actual contact and are not connected with any important faulting.

On the 500-foot level a sharp contact between granite and breccia is well exposed in a short drift on the so-called Shaft vein, just west of the Burns shaft. The contact here is less steep than is common on the lower levels, dipping north at about 60°. It may also be well seen about 300 feet southeast of the Burns shaft in a crosscut east from the Portland vein. The contact is here ideally sharp, the breccia resting closely upon an uneven surface of granite. The dip is abnormally low, being only about 15° toward the east. This low dip is undoubtedly local, and if the breccia could be removed the granite at this point would probably be found forming a relatively flat bench or step, with steep scarps above and below. The contours of Pl. XXVIII are strongly indicative of such changes of slope.

On the 600-foot level the contact as exposed a short distance north and east of the Burns shaft is definite and close. It is rather irregular, but nearly vertical on the whole. Near the Diamond vein, however, about 300 feet east of the shaft, the contact is a regular plane dipping about 35° NE. and exhibiting clear evidence of some faulting between the granite and the breccia, but the movement is apparently local and not connected with any great displacement. The moderate dip, here as on the 500-foot level, prevails on the crest of the granite promontory. It is 20° steeper, however, than on the level above, which fact, taken in connection with what is known of the contact below, indicates proximity to the outer edge of the granitic bench already mentioned.

On the 700-foot level the contact between the granite and breccia is exposed in the main drift about 100 feet north of the Burns shaft. It is here sharp and

close, rather irregular, and as seen in the drift nearly vertical. East of the Burns shaft the contact practically coincides with the No. 2 vein.

On the 800-foot level the contact is in part the east wall of the No. 2 vein. It is sharp and irregular in detail. The granite is locally shattered for a foot or two from the contact, which is here nearly vertical. Toward the north the contact soon swings westward, away from the No. 2 vein, and is again well exposed in the main northeast crosscut about 125 feet from the Burns shaft. This contact is remarkably close and definite and shows no evidence of faulting. Its course where cut by the crosscut is nearly north and south, and it dips about 80° E.

On the 900-foot level the contact between the granite and breccia is exposed in at least five places. North of the Burns shaft the granite shows some brecciation near the contact, and the latter is not so sharp and distinct as in other parts of the mine. Just east of the No. 2 vein, which is partly within the granite on this level, the contact is clearly exposed in a short crosscut. The granite is shattered, but not brecciated, for a distance of 2 or 3 feet from the breccia, while the latter contains abundant particles of microcline and some small fragments of granite, those seen being less than 3 inches in diameter. The contact here dips 75° to 80° E. A little farther north a crosscut west of the No. 2 vein, which is here wholly in granite, exposes a close, definite, irregular contact of the latter rock with the breccia. The dip of the contact here is practically vertical.

On the 1,000-foot level the contact is exposed about 100 feet north of the Burns shaft and along the No. 2 vein. In general it is approximately vertical and presents characteristics similar to those observed on the level above. As previously noted, the lodes are not deflected when crossing the contact.

Intimately associated with the volcanic breccia and tuff are bodies of massive latite-phonolite and syenite. The latite-phonolite is usually a light-gray porphyritic rock showing small phenocrysts of feldspar and biotite. Its petrographical character is described on pages 68 to 84 of this report. The rock, when unaltered, is readily distinguished underground from the breccia by its more angular fracture, greater hardness, crystalline texture, and, in one of the masses, by the presence of the black, sparkling scales of biotite, which do not so far as known occur in the volcanic breccia. The latite-phonolite is also far less generally impregnated with pyrite than the breccia. But notwithstanding these differences it is always an exceedingly difficult matter to determine the exact contact between the massive rock and the breccia, owing to the fact that the latite-phonolite is itself shattered or brecciated near the contact and locally mineralized with pyrite. When both are mineralized and altered, sharp distinction is seldom, if ever, possible between brecciated latite-phonolite, on the one hand, and a volcanic breccia containing abundant particles of similar rock on the other. There is nearly always a debatable zone from 10 to 100 feet in width which passes on one side into less shattered massive latite-phonolite and on the other into a breccia containing, besides latite-phonolite, particles of quartz and microcline from the granite and sometimes of phonolite.

The principal occurrence of latite-phonolite is in the northern part of the mine, in the vicinity of the No. 3 shaft, which is practically in this rock nearly down to the 1,000-foot level. It forms a large mass whose shape is only partly determinable

from the present underground development. The southern boundary of this latite-phonolite, on all levels, lies along the northern edge of the great Hidden Treasure-Captain ore zone, and there can be little doubt that the presence of the latite-phonolite has determined the position and particularly the northern limit of this ore zone. The adit level, from a point near the Wisconsin shaft, extends northward for nearly 1,200 feet through this body of latite-phonolite before again entering the breccia. It is noteworthy that the ore of the Colorado City and Hawkeye shafts occurs in the breccia just north of this latite-phonolite, the latter occupying the relatively barren ground between this ore and the Captain-Hidden Treasure ore zone. On the same level a west crosscut past the No. 3 shaft is entirely in this body of latite-phonolite, which is the prevailing rock in the vicinity of the Lost Anna shaft. The same large irregular mass of latite-phonolite is encountered on the lower levels just northwest of the Hidden Treasure and Captain stopes. The 500-foot and 1,000-foot levels, however, are the only ones which explore the latite-phonolite for any considerable distance. The distribution of the latite-phonolite on the 500-foot level, so far as known, is shown in Pl. XXVIII. On that level a crosscut west of the Anna Lee shaft cuts through about 300 feet of latite-phonolite, which, as the surface map (Pl. II, in pocket) shows, is probably an offshoot from the main body to the north. On the same level a crosscut west from the No. 3 shaft, after passing for about 450 feet through latite-phonolite, is continued for about 70 feet in syenite. This is probably the same mass as that mapped on the northern slope of Battle Mountain (Pl. II). The contact between this syenite and the latite-phonolite is indistinct, and the one rock probably grades into the other.

In September, 1903, the drift north from the No. 3 shaft was about 700 feet in length and all in the latite-phonolite. The eastern contact of the massive rock with the breccia has apparently a westerly dip, for while on the adit level the latite-phonolite extends at least 400 feet east of the No. 3 shaft, on the 1,000-foot level the contact lies from 50 to 75 feet west of the shaft, which on this level is in breccia.

The latite-phonolite (biotite trachyte) just considered is the "mica-bearing andesite" of Cross,[a] which he described as occurring on Battle Mountain, but omitted from his geological map on account of the difficulty of determining its exact boundaries.

East of the No. 2 shaft and the No. 2 vein is a part of the Portland property that has as yet had very little underground exploration. The geological map (Pl. II, in pocket) shows that there is exposed at the surface just east of the Burns shaft, stretching northeastward along the slope of Battle Mountain and eastward to Goldfield, an exceedingly irregular area of latite-phonolite. This phonolite is met with underground on the adit level, extending from the portal to a point about 200 feet north of No. 2 shaft. In places, particularly near the shaft, it is fresh and approaches syenite in texture. As in the case of the andesite, its contact with the breccia on the northwest is obscured by shattering and mineralization, so that practically nothing can be made out of the geological relation of the two rocks. Below the adit level the phonolite is known to occur in the old Scranton workings and on the 220-foot Portland level. It formed the general country rock of part of the

[a] Geology and mining industries of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 75-76.

stoped-out Portland vein, but as these old upper levels are for the most part inaccessible, it is not at present practicable to ascertain the form and extent of this eruptive mass. It has not been recognized on the 350-foot level, but on the 500-foot level a long crosscut northeast of No. 2 shaft passes for about 400 feet through a body of altered massive rock which is probably part of the same mass (Pl. XXVIII). Two other levels, the 500-foot and the 600-foot, reach this latite-phonolite. On the 500-foot level a massive rock is exposed on the south side of the station of the No. 2 shaft. It is too much altered for satisfactory determination, but is apparently latite-phonolite. A similar altered rock occurs along the east side of a little drift 450 feet northeast of the Burns shaft (Pl. XXVIII) and is probably part of the same mass. On the 600-foot level what seems to be the southern continuation of the same body of rock is encountered in the north face of a short drift about 500 feet east of the Burns shaft, and apparently also in a crosscut about 200 feet east of the No. 2 vein. The rock on this level is in part unaltered and is clearly a latite phonolite. (See p. —.) It might have been expected that the same rock would have been cut in the long northeast (Last Dollar) crosscut on the 800-foot level. But this shows nothing but breccia, and it is probable that the latite-phonolite of this part of the mine occurs in masses of very irregular shape.

All the large rock masses of the Portland mine are cut by numerous dikes. These exhibit considerable diversity of trend, but the greater number have courses ranging from north to N. 35° W. In other words, dikes and lodes are generally parallel or coincide. The general arrangement of the dikes is illustrated for one of the most important and representative levels in Pl. XXVIII.

The most abundant dikes are those of phonolite. They range in width from a few inches to 30 or 40 feet, the greater number, however, being from 2 to 5 feet. The phonolite is invariably altered, and presents the usual appearance characteristic of this rock when occurring as dikes within the mineralized portion of the district. It is usually a pale-green aphanitic rock with a well-marked platy parting parallel to the dike walls. While many of the phonolite dikes are very irregular, changing in width, dip, and strike from point to point, some maintain a fairly uniform width and trend for over 1,500 feet. One of the most persistent is a nearly north-south dike which coincides with the No. 9 Captain vein on the north, passes just west of No. 2 shaft, and continues into Stratton's Independence mine about 600 feet southeast of the Burns shaft. It is not certain that this is really a single continuous dike, but it has been cut and drifted on at so many points (Pl. V, p. 26) as to render such continuity probable. As examples of shorter and more irregular dikes may be cited some occurring near the No. 2 shaft on the 500-foot level and the dike accompanying the Portland vein.

Besides the phonolite dikes, there are a number of "basalt" dikes. These are usually nearly vertical and have the same general strike as the phonolite dikes. They are rarely over 6 feet in width, and fairly regular. When followed by drifts, they are frequently found to pinch and disappear, but a short crosscut to one side or the other w ll usually reveal a second dike, which when followed soon attains the average width of the first and continues on the same general course. These dikes are invariably decomposed, so that their original petrographic character can

be but imperfectly discovered. Some of them, as the dike exposed on the 500-foot level east of the Captain veins (Pl. XXVIII) were olivine-feldspar basalts, possibly nepheline bearing, in which the olivine has been altered to serpentine and carbonates and the groundmass is full of calcite. Others, such as the Anna Lee dike, which passes through the Anna Lee shaft (Pl. XXVIII) and is probably one of the dikes cut in the crosscut west of the No. 3 shaft, contained phenocrysts of olivine and augite lying in a groundmass rich in augite and magnetite. This groundmass, though obscured by calcite, apparently never contained plagioclase, and the rock is probably to be classed as a limburgite. The basaltic dike shown on the 500-foot level (Pl. XXVIII) just east of the Burns shaft is also probably a limburgite. It contains a little biotite and some kernels of unaltered olivine. The groundmass shows abundant calcite and a clear isotropic mineral which is probably analcite.

As a rule the basic dikes as encountered underground are of a dull dark-greenish color, so softened by decomposition as to be readily picked down and rapidly disintegrating on exposure to the air. The harder, fresher phases are nearly black and commonly reveal a regular platy jointing parallel to their walls. These fine parallel cracks are frequently filled with white calcite and the structure thereby accentuated (Pl. XVI, *B*, p. 166).

The basic dikes are all later than the phonolite dikes, which they frequently cut. Whether the feldspathic basalts are earlier or later than the limburgites is not known, though it is probable that both belong to the same general period of eruption.

LODE SYSTEMS.

The Portland mine contains more productive lodes and presents greater variety in the character of its ore bodies than any other mine in the district. By far the greater number of the lodes have courses lying between north and N. 35° W. In general the more nearly north-south strikes prevail in the southern part of the mine, near the Burns shaft, while the more westerly strikes are characteristic of that part of the mine lying just north of the No. 2 shaft. The only notable exception to the foregoing general statements is that furnished by the Bobtail vein, which strikes about N. 60° W. A number of the lodes are practically vertical; others have a westerly and some an easterly dip. The dips as a whole are high—rarely under 70°. The Bobtail, however, has a southwesterly dip of a little less than 65°. The ground which has hitherto proved most productive in the Portland mine lies in two broad vertical zones which cross the general strike of the lodes nearly at right angles. One of these northeast-southwest zones crosses the lode systems at the Burns shaft, and contains the productive portions of the Portland, Bobtail, Diamond No. 2, Rose, and Scranton lodes. The width of this zone is not susceptible of accurate measurement, but one boundary may be considered as passing about 300 feet northwest of the Burns shaft. The other boundary probably lies between 1,100 and 1,200 feet southeast of the Burns shaft and includes the productive ground north of the No. 1 shaft of Stratton's Independence mine, as well as that of the Strong, Dillon, and Monument mines. Such lodes as pass from granite into breccia, or vice versa, cross the contact between these rocks without noticeable deflection.

The second zone lies northwest of a line passing through the Portland No. 2 shaft and the old Anna Lee shaft. Its width is approximately 600 feet and it includes the productive portions of the Lee, Hidden Treasure, and Captain veins.

Inspection of the map (Pl. II, in pocket) shows that the existence of these two main zones, separated by a comparatively barren zone from 150 to 200 feet in width, is a prominent feature of the Portland mine. It is very doubtful, however, whether these same zones are persistent and can be recognized in the properties adjoining the Portland on the west and east. A long west crosscut and a long northwest drift on the Anna Lee basaltic dike, both on the 500-foot level, have failed to find any southwest continuation of the remarkable zone in which occur the Captain and Hidden Treasure ore bodies. In view of this fact the term zone is perhaps somewhat misleading. The relation of the ore bodies to the mass of the country rock might be expressed by saying that the ore bodies are not distributed generally through the latter, but are clustered together in huge, nearly vertical cores. These rock cores, within which the lodes are productive, are separated from the surrounding relatively barren country rock by rather indefinite boundaries. Their horizontal sections are irregular, but are generally elongated in a northeast-southwest direction, so that in a limited area they have the appearance of zones.

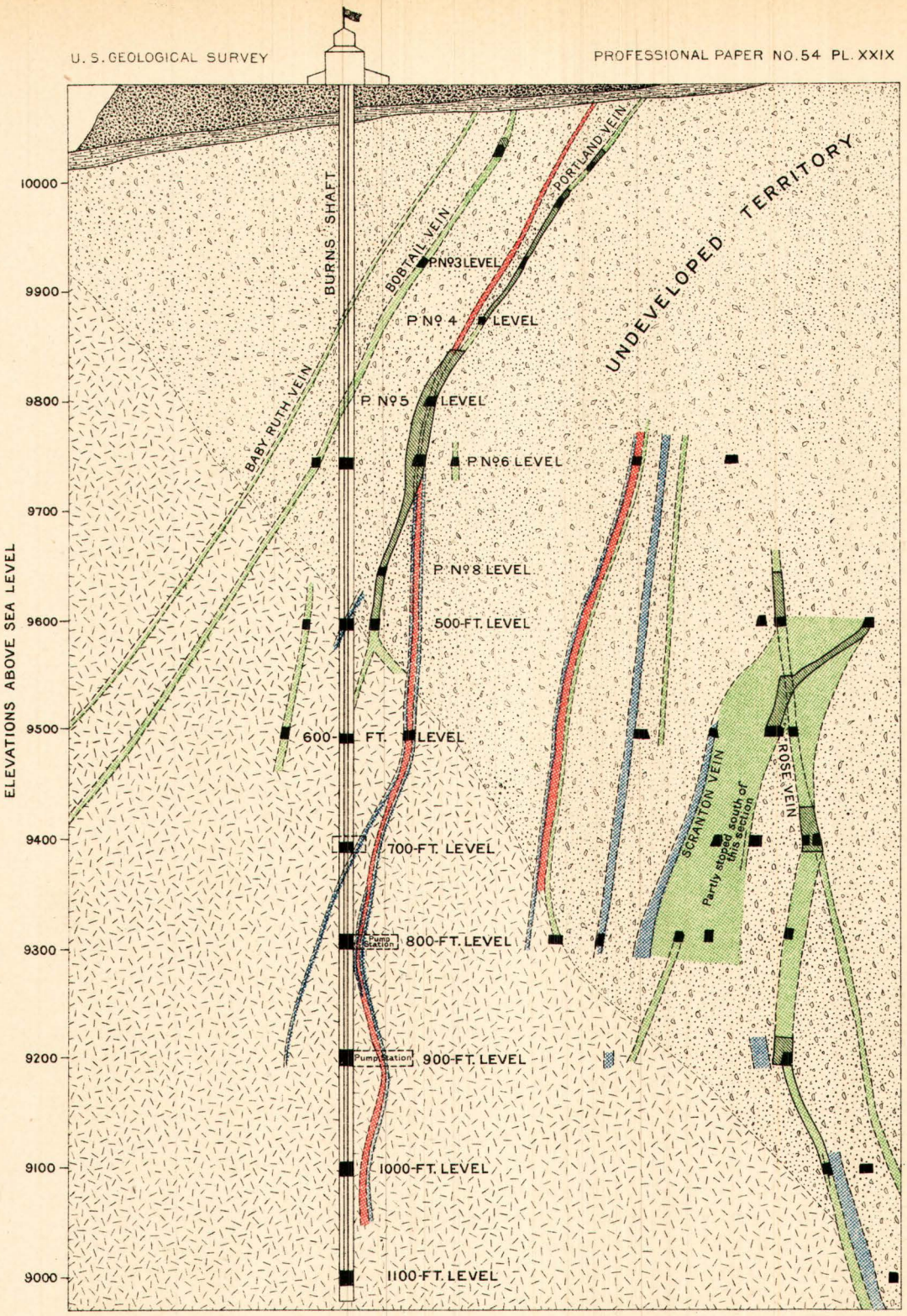
None of the productive lodes of either of the Portland zones has yet been traced into the other zone. The No. 2 and Diamond veins, so productive in the southern zone, are not recognized in the northern zone, nor are the numerous and rich lodes collectively designated the Captain system known south of the No. 2 shaft.

The original Portland vein, sometimes erroneously supposed to be the same as Stratton's Independence vein, has been developed in the southern part of the mine, and lies just east of the Burns shaft. Its course on the whole is nearly north and south, but it is distinctly curved, striking in its northern part a little east of north and in its southern part about S. 25° E. It dips at an average angle of 70° to 75° W. The Portland vein is not distinct on the 600-foot and lower levels.

The Bobtail vein strikes about N. 60° W. and dips about 65° SW. This lode and the Portland vein cross without any observable displacement of one lode by the other. The Bobtail as a rule is a regular, well-defined lode, which outcrops at the old Bobtail shaft and crosses the Portland vein on the surface near the portal of the adit level. Southeast of its intersection with the Portland vein the Bobtail is not very well defined until the 600-foot level is reached. Below this the Portland vein in turn dies out or becomes unrecognizable.

The Diamond veins comprise two or more rather short, generally parallel fissure zones lying 225 feet east of the Portland vein. These lodes strike about N. 10° W. and dip steeply to the west. The Diamond veins have not been identified with certainty on the 500-foot and higher levels.

The most easterly lode of the southern ore zone is the important No. 2 vein, which strikes from N. 20° to 25° W. and is clearly the northern continuation of the Independence vein of Stratton's Independence mine. Unlike the other lodes of this zone, the No. 2 vein dips easterly at an angle of 70° to 75°. It is indistinct and of no importance above the 500-foot level, but is well marked on the 600-foot and lower levels. The so-called Scranton and Rose veins of the 700-foot and 800-foot levels appear to be merely northern continuations of the fissure zone of the



VERTICAL SECTION THROUGH THE BURNS SHAFT, PORTLAND MINE, SHOWING BRECCIA CONTACT, VEINS, AND DIKES

AFTER V. G. HILLS

Scale

0 100 200 300 feet

1905

Basalt dikes | Phonolite dikes | Veins | Stopes | Granite | Breccia | Dump

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No. 2 vein. (See Pl. XXVIII, p. 434.) The relation of the lodes of the southern zone in the Portland mine to those of Stratton's Independence mine is discussed in the description of the latter mine on page 452.

The northern ore zone of the Portland mine comprises a large number of approximately parallel, nearly vertical fissure zones, which are often so closely spaced and so connected by branching fissures as to render their identification extremely difficult unless continuity is demonstrated by continuous drifts or stopes. Names were originally given to the more prominent fissure zones as they were encountered on various levels, but it was found upon further development that these lodes are often accompanied by adjacent nearly parallel lodes, which, though they may be of no importance on one level, may contain valuable ore bodies on another. Such additional lodes were distinguished by prefixing numbers to the name of the original. Thus, for example, there are the No. 3 Hidden Treasure, the No. 4 Lee, and the No. 9 Captain veins. The general strike of the lodes of the northern ore zone, as may be seen from Pl. XXVIII, is regular and seldom varies more than a few degrees from N. 35° W. The dip, as nearly as can be determined in lodes so close together and often distinct only for short distances, is on the whole about vertical.

The most southwesterly lodes of this zone are the four Lee veins, numbered from southwest to northeast and lying just east of the old Anna Lee shaft. These are rather short lodes of not very regular strike. Nos. 1, 2, and 3 have the prevalent strike of N. 30° to 35° W. The No. 4 Lee, however, strikes N. 65° W. and dips about 75° NE. This, the most easterly of the four Lee veins, has great vertical persistency and is recognized on all the levels from the adit down to the 1,000-foot level. It is more nearly vertical than most of the lodes of the northern ore zone.

North of the Lee veins are the No. 1, No. 2, No. 3, and No. 4 Hidden Treasure veins. These constitute a zone of generally nearly parallel fissures, ranging on different levels from a single narrow fissure to a total width of about 100 feet on the 900-foot level, where four individual zones of fissuring are recognized. The general strike of the Hidden Treasure veins is about N. 30° W. They thus join the more westerly No. 4 Lee vein at their southern ends. Inspection of Pl. XXVIII shows that the Hidden Treasure fissure zones align with the No. 2 vein of the southern ore zone, but so far as known there is no connection of the lodes across the intervening barren ground. While the No. 2 vein dips, as we have seen, to the northeast, the Hidden Treasure veins are, on the whole, approximately vertical. The Hidden Treasure veins are of but little value above the 500-foot level. On that level the No. 1 Hidden Treasure, and on the 600-foot level the No. 2 Hidden Treasure also, attain economic importance, which they maintain down to the 800-foot level, where the No. 3 Hidden Treasure becomes the prominent lode of the system and so continues to the bottom of the mine.

Immediately northeast of the Hidden Treasure veins is an extensive series of parallel fissure zones known as the Captain system. The general strike of these fissures is N. 35° W. and they are, on the whole, nearly vertical. They constitute a broad sheeted zone from 400 to 500 feet in width, which is not sharply distinguished from the Hidden Treasure veins. Both sets of lodes belong, in fact, to one great zone of parallel fissuring. Within the Captain system are distinguished nine principal lodes, numbered from southwest to northeast. But these lodes are not

equally distinct on different levels and there is often much minor fissuring of the country rock between them. It is therefore by no means certain that the same number is always applied to the same lode on different levels. For example, the No. 4 Captain vein on one level may correspond to what is termed the "No. 5" Captain vein on another. The designations of these lodes are frequently changed as development throws new light on their relations. The easternmost productive lode of the series, the No. 9 Captain vein, presents an exception to the general strike and dip of the other lodes of the Captain system and is associated with a phonolite dike. This lode strikes a little east of north and dips west at about 80°. It probably should not strictly be included within the Captain system.

The Captain veins, while economically of great importance, as will be later shown, are not persistent. They have rarely been followed horizontally for more than 300 feet. First attaining importance between the 220-foot and the 350-foot level, the known lodes of the system become indistinct and of comparatively little value below the 600-foot level, though some ore occurs in them above the 700-foot level.

North of the great ore zone in which occur the Lee, Hidden Treasure, and Captain veins is an extensive territory now being exploited from the No. 3 shaft. Thus far no ore bodies of importance have been discovered in this part of the Portland workings proper, though ore was formerly shipped from the old workings of the Colorado City and Hawkeye shafts nearer the surface. About 225 feet southwest of the No. 3 shaft, however, is the Lost Anna vein, striking northwest and southeast and dipping steeply to the northeast. This lode, which lies in the general line of the Captain veins, is known on the adit and 1,000-foot levels. While apparently not of much importance on the upper level, it promises well below the 1,000-foot level.

CHARACTER OF ORE.

Probably no one mine in the Cripple Creek district has during its history produced more varied types of ore than the Portland. All the unoxidized ores, however, are alike in owing their value to the presence of a telluride of gold, which seems to be almost invariably calaverite, though the occurrence of sylvanite has been reported by Rickard.[a] This telluride is rarely found in well-formed crystals and is frequently present in particles so minute as to be invisible to the naked eye.

The chief contrast as regards texture and general mineralogical association of the ores is to be found between those occurring in granite, on the one hand, and those found in breccia or phonolite, on the other.

The ores in the granite are of distinctly metasomatic origin. The alteration of the country rock is always more or less closely related to fissuring, though the fissures are in some cases microscopic. The change from altered to unaltered rock, while never sharp, may take place within a distance of a few inches. The most striking characteristic of the altered rock is a porous texture and a loss of more or less of the reddish tint of the unaltered granite. Closer examination shows that while the original porphyritic aggregates of pink microcline may remain, the rest of the rock, consisting originally of microcline, oligoclase, quartz, and biotite, may

[a] Rickard, T. A., The Cripple Creek gold field: Inst. Min. and Met., London, vol. 8, 1899.

be completely recrystallized as a porous, vuggy aggregate of valencianite (secondary orthoclase), quartz, fluorite, occasionally a little calcite, pyrite, calaverite (rarely visible), and sometimes a little sphalerite and galena. Ore of this type was formerly of much greater importance in the Portland mine than now, and was stoped in large quantities from the Diamond veins.

The ore at present most typical of the mine is that occurring in breccia, particularly in the Captain stopes. This consists of fine-grained gray breccia, containing much finely disseminated pyrite and considerable scattered carbonate, which appears to be in most cases dolomite rather than calcite. The calaverite occurs in very narrow fissures or joints in this breccia, associated with crystalline films of dolomite, with sometimes a little quartz and fluorite. In most places the ore shows very little calaverite to the naked eye; but in some of the richer stopes the rock, when split open along these joints, reveals an abundance of thin-bladed crystals of silvery calaverite that are occasionally 2 inches in length and frequently form branching or stellate groups. These crystals are often accompanied by a little molybdenite. The value of the ore appears to lie wholly within the narrow joints which are seldom individually large enough or persistent enough to be dignified even with the name of veinlet. The fine pyrite impregnating the breccia is not known to be auriferous, though samples of pyritized breccia often contain $2 to $3 per ton in gold. The ore of the Hidden Treasure veins has crystallized in larger and more open fissures than the Captain ore and gangue minerals are consequently more conspicuous. The calaverite occurs with dolomite (often in well-developed rhombohedrons), fluorite, and quartz.

The Lost Anna and Lee veins are characterized by more open fissuring and more abundant vein matter than most of the productive Cripple Creek veins. They contain abundant pyrite, and in some places galena and sphalerite, associated with dolomite, quartz, and fluorite. Calaverite occurs usually in the porous or vuggy portions of the vein, and in the Lost Anna vein is sometimes associated with roscoelite.

The ore of the Anna Lee chimney was soft and oxidized down to the bottom of the worked-out ore shoot.

PAY SHOOTS AND LODE STRUCTURE.

With the exception of the so-called Anna Lee chimney, all of the ore of the Portland mine occurs in the form of lodes; that is, in nearly vertical deposits of essentially tabular form. The general plan and distribution of these lodes has been already described. Some account will now be given of the shape and structure of the ore bodies themselves.

Three important types of ore bodies have been recognized: (1) Deposits along fissure zones in breccia, (2) deposits along fissure zones in granite, and (3) mineralized phonolite dikes. These three classes are not always distinct, for, as will presently be shown, deposits of the third class are not infrequently combined with deposits belonging in the first or second class.

In the first class belong the first eight Captain, the three Hidden Treasure, and the four Lee veins of the northern ore zone and a portion of the No. 2 vein in the southern zone. These lodes are sheeted zones of varying width, definiteness,

and persistency. An excellent example of the more persistent and well-defined mineralized zones of sheeting is the No. 3 Hidden Treasure vein, as developed on the lower levels of the mine. Just above the 1,000-foot level this lode has a pay shoot about 500 feet in length, with an average width of about 12 feet. In the wider parts of the lode the fissuring is rather irregular. There are generally two or more nearly parallel and approximately vertical fissures, the outer ones being 6 to 10 feet apart. Between these the breccia is traversed by cracks running in all directions. The best ore occurs in the main vertical fissures, which are mere cracks in the rock, usually less than an inch in width, with a lining or vuggy filling of fluorite. There are no definite walls to the lode, the rock outside of the main vertical fissures being also irregularly jointed and carrying gold for varying distances from the main fissure zone. Where the stoping width of the lode, which is in some cases 15 feet, narrows to 10 feet or less the sheeting of the rock is more regular and more conspicuous. Such parts of the lode frequently exhibit in the neighborhood of 20 rather regularly spaced narrow parallel fissures with nearly vertical dips. Those sections of the lode in which such regular sheeting occurs are usually of higher grade than the wider and less regularly fractured portions.

The other lodes in the breccia are all generally similar in structure to the Hidden Treasure lode. Some, such as the Lee veins, are narrower and often more sharply differentiated by their narrow-spaced vertical fissuring from the country rock. Definite vein walls, however, do not occur. Occasionally, as in the No. 1 Lee vein just above the 800-foot level, the sheeted structure passes into a less regular form of reticulating fractures suggestive of what are commonly known as stringer lodes. Other lodes, such as those composing the Captain group, are even less distinctly differentiated from the country rock than the Hidden Treasure lode. While vertical sheeting can sometimes be recognized in the medial portions of the Captain veins, the existence of the lode is often marked merely by the irregular fracturing and jointing of the breccia. Such fracturing frequently involves all of the rock intervening between the indistinct medial planes of two or more of the Captain veins, and the fractured rock constitutes practically a single large ore body which is stoped as a whole. Such is the great stope 120 feet wide, on the Nos. 3, 4, 5, and 6 Captain veins above the 350-foot level. In these large stopes it is often difficult or impossible to recognize any linear system of fissures such as might properly be called a lode. Practically all the minute fractures in the breccia contain telluride of gold, often invisible, but sometimes occurring in thin sheets of flat radial aggregates of sylvanite or calaverite along fissures a small fraction of an inch in width, and revealed by splitting the breccia along these veinlets. Such lodes pass gradually and indefinitely into the country rock, the limits of the ore body being determinable by assays alone.

The lodes in the breccia are not all equally persistent, nor is persistency always commensurate with the size and importance of ore bodies. The largest ore body, about 500 feet in length, is found in the No. 3 Hidden Treasure vein. This lode, however, is not certainly known above the 600-foot level, whereas the smaller No. 4 vein has been stoped almost continuously from the surface to the 1,000-foot level.

In the Captain group of lodes the largest ore body is something less than 300 feet in length, and most of those discovered are shorter than this. These lodes

first attained importance between the 220- and 350-foot levels, and have been very productive near the 350-foot level. Below the 600-foot level, while the Captain fissuring continues, the ore is of low grade, and on the 1,000-foot level such indistinct fissuring as persists is associated with but little more value than is found in the breccia country rock, most of which in this part of the mine affords assays up to $3 in gold per ton. The No. 1 Hidden Treasure vein, while recognized on the 350-foot level, first becomes important between this level and the 500-foot, and has been stoped down to the 900-foot. The No. 2 Hidden Treasure has been productive from the 600-foot to the 800-foot level, while the No. 3 Hidden Treasure, first stoped above the 700-foot level, has maintained its importance to the bottom of the mine.

Owing to the uncertainty attaching to the identification of individual members of these closely spaced Hidden Treasure and Captain groups on different levels, the foregoing statement as to the vertical distribution of the various pay shoots may be modified in the course of future underground development. But enough is known to bring out the essential fact that the pay shoots in the various bodies do not as a rule possess great vertical persistency and may occur at all depths thus far explored. There are pay shoots known in depth which do not reach the surface and there are pay shoots known at the surface which do not extend to great depth.

In the southern ore zone the No. 2 vein and its branches are the only lodes which are of much importance within the breccia. This lode is not definitely recognized on the 350-foot level, though a lode stoped above that level and called the Diamond vein is probably really the No. 2 vein, the Diamond vein proper apparently never having been recognized in the breccia above the 600-foot level. Between the 500- and 800-foot levels the ore bodies of the No. 2 vein have been stoped to a width of 40 and occasionally of 60 feet, up to the Stratton's Independence line. The width of this ore is subject to sudden changes, a narrow sheeted zone of pay ore 4 to 5 feet wide expanding within a few feet to a width of 50 feet and again as abruptly contracting. The wider ore bodies occur near the 600- and 700-foot levels, the pay shoots being generally narrower on the lower levels. Toward the north the lode appears to split, the Rose and Scranton stopes on the 700-foot level being probably on branches of the main zone of fissuring, known as the No. 2 vein.

Lodes formed by mineralization along fissure zones in granite are well exemplified by the Diamond vein and by portions of the No. 2 vein. In the granite the fissures which served as channels for ore deposition are less conspicuous than in the breccia. In the latter rock the valuable constituents of the ore are practically confined to the fissures themselves. Not so in the granite. Here metasomatism has been more active and ore minerals, among which fluorite and pyrite are usually most conspicuous, occur distributed through the mass of the rock, in many instances for 20 or 30 feet from the main fissure zone. As a result of this action, the ore bodies are usually of very irregular shape. As a rule there is little or no waste mixed with the ore, whereas in the breccia the rock between the joints or fissures is invariably worthless. At varying distances from the main fissure zone which was the determinative factor in the formation of the ore body the ore changes to unmineralized granite. In some cases the change is abrupt, in some gradual, but only under exceptional circumstances is there a distinct wall separating country rock and ore.

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The great Diamond ore body, which about the year 1896 furnished the bulk of the ore from the Portland mine, had a maximum width of fully 50 feet and a length of about 100 feet. This ore body extended from a point just above the 600-foot level nearly to the 1,000-foot level. Above the 600-foot level the ore ended abruptly at the contact of the granite with the overlying breccia. Between the 600- and 700-foot levels the ore body was divided by a huge horse of granite, on the east side of which the bulk of the ore lay. The collapse of this horse, after the removal of the ore, formed a great chamber now well seen from the 700-foot level.

The body was largest between the 700- and 800-foot levels, and averaged over $100 of gold per ton as shot down in the stope, while several carloads of ore mined in 1899 just above the 600-foot level carried over 30 ounces of gold per ton. On the 900-foot level the ore was usually less than 10 feet in width and had fallen in value to an average of about $25 per ton. Below this level the ore barely paid for extraction, and just above the 1,000-foot level ended rather abruptly, in many cases apparently at inconspicuous, nearly horizontal joint seams in the granite. On the 1,000-foot level the Diamond vein is represented by two sheeted zones in the granite, both accompanying phonolite dikes. These zones have a maximum width of about 4 feet and are approximately 50 feet apart. These fissures are accompanied by pyrite disseminated through the sheeted granite, but contain no ore. The phonolite dikes visible on the 1,000-foot level are said to have occurred irregularly in the ore body above, but the ore itself was always in the granite, never in the phonolite.

The best example in the mine of an ore body formed by the mineralization of a phonolite dike is the original Portland vein. It is essentially a sheeted zone which was most productive where it coincided with the dike. At the adit level the general country rock is latite-phonolite and the lode is apparently in the same rock down to the 220-foot level. On the 350-foot level the Portland dike and vein are in breccia. In the present condition of the old stopes no satisfactory study of the lode is practicable. The ore body seems to have been irregular in width and usually to have had well-defined walls—those of the phonolite dike. The lode was stoped almost from the surface nearly down to the 500-foot level. On this level the lode has left the phonolite dike and is in granite. The granite adjacent to the rather indistinct fissure zone is metasomatically altered and has the porous texture characteristic of granitic ore. It is not, however, of sufficient value to pay for extraction.

The Bobtail vein, one of the most regular and persistent lodes in the mine, was studied only on the 500-foot and lower levels, where it is mainly within the granite, southwest of the Burns shaft. It was there seen to be of an entirely different type from any of the lodes just described. As a rule the lode shows considerable oxidation even down to the 900-foot level and its character is thereby somewhat obscured. It strikes nearly northwest and southeast and dips southwest. The Bobtail and Portland veins cross without any apparent faulting and most of the Bobtail ore occurs on the west side of the Portland vein and within a distance of 100 feet from the intersection. Smaller bodies, however, occur in other parts of the lode, as near the contact of the granite with the breccia, at about the 500-foot level. The rather irregular fissuring of the Bobtail lode follows what at first glance appears to be a narrow, irregular dike of some darker rock than the granite. Closer examination of the so-called Bobtail dike suggests, however, that it is a breccia containing fragments

of granite. This is confirmed by the microscope, which shows the material to consist chiefly of finely comminuted microcline and quartz, evidently derived from the granite, with usually a little secondary quartz, fluorite, and pyrite. No volcanic fragments were detected in this material. The Bobtail vein is therefore a fissure zone which follows not a dike, but an older fissure filled with brecciated material. This original fissure probably dates from the volcanic period, but whether it was filled, like the great crater, with particles which had previously been blown into the air, or by the trituration of the wall rock by movement along the fissure, could not be determined. The breccia of the fissure apparently passes without break into the breccia filling the throat of the old Cripple Creek volcano.

Another deposit, unique in the Portland mine, and indeed in the district, is the Anna Lee chimney or stock. No work has been done on this deposit for years and little can be added to the descriptions given by Penrose[a] and later by V. G. Hills.[b]

Mr. Hills says:

This ore chimney occupies the pipe or neck of an extinct mineral spring. It follows one of the main basalt dikes and extends downward, as far as yet followed, some 1,130 feet. It has several remarkable features. It is nearly circular in plan and varying from 15 to 30 feet in diameter, and extends nearly vertically, but with a sort of a corkscrew form, into the earth. The ore filling this pipe consists of well-rounded pebbles cemented together with material which is composed, for the most part, of the same rock pulverized. This ore contains from 9 to 15 per cent of lime and 7 per cent iron, thus differing from any other ore body in the district. It is also a remarkable feature that the gold values contained in the pebbles and in the cementing material are about the same. The values are distributed with remarkable evenness through the mass, thus forming a notable exception to the rule of gold deposits.

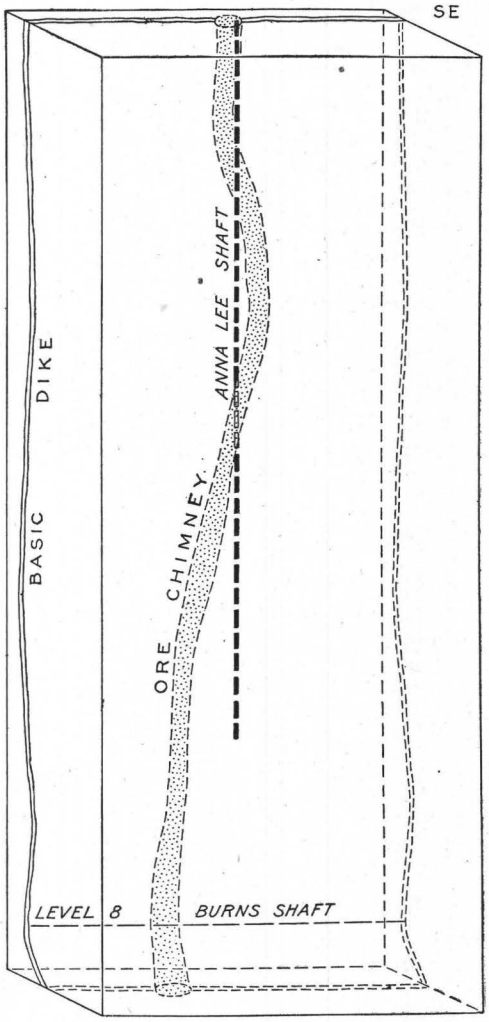

FIG. 58.—Stereogram of Anna Lee ore chimney. (After V. G. Hills.)

Mr. Hills gives a stereogram of the Anna Lee ore shoot, which is reproduced in fig. 58.

[a] Mining geology of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895. pp. 205–207.
[b] Eighth Ann. Rept. Portland Gold Mining Company, 1902.

This remarkable ore body was mined down to a point above the present 900-foot level of the Portland mine, where the ore ceased. The old stope is at present accessible only on the 800-foot level. Here the ore body was roughly circular in plan and about 25 feet in diameter. The basalt dike has an average width on this level of 4 to 5 feet, but at the chimney expands to the east in an irregular swell and attains a local width of 15 to 20 feet. It is in this short swell and in the immediately adjacent breccia that the ore occurred. Just at this point the No. 1 Lee vein comes into the dike from the east, the ore body occurring at the junction of dike and lode. The less decomposed portions of the basalt, petrographically described on page 93, contain no ore, but much of the rock is traversed by numerous reticulated cracks along which decomposition and oxidation has proceeded, causing the rock to superficially resemble a breccia. This material is in part ore. The bulk of the ore on this level, however, seems to have occurred in the breccia alongside the dike at the junction with the No. 1 Lee vein. This breccia contains abundant particles of microcline from the granite, is impregnated with pyrite, and is rather soft. It shows much oxidation, which penetrates the mass of the breccia very irregularly, with usually a sharp line between oxidized and unoxidized material. Nothing was seen on this level of the rounded pebbles referred to by Mr. Hills. The relation of the No. 1 Lee vein to the ore body on the 800-foot level strongly suggests that the vertical chimney-like character of the deposit may be due to the intersection of the basalt dike with the No. 1 Lee vein, but on the 500-foot level the lode known as the No. 1 Lee does not reach the dike at the Anna Lee chimney. It is probable, however, as Penrose suggests,[a] that better exposures would reveal on all levels the connection of the ore body with one or more fissures intersecting the dike.

VALUE OF THE ORE.

The average value of the Portland ore from 1894 to 1904 is shown in the table on page 171. It ranges from a maximum of $70.78 a ton in 1894 to $26.03 a ton in 1902. Some of the best ore in the past came from the Diamond stopes in the granite. Large bodies of this ore near the 700-foot level were practically free from waste and averaged $100 to $150 a ton as shot down in the stopes. On the 900-foot level the tenor of the ore fell to about $25 a ton, and near the 1,000-foot level, where stoping was in progress at the time of visit, the ore shoot was barely paying $15 to $20 a ton.

On the Hidden Treasure No. 3 stope, above the 1,000-foot level, about one-fourth of the rock broken is left in the stopes as waste. About 35 per cent of the material hoisted is screenings, with an average value of about $50 a ton. The remaining 65 per cent of coarse material is sorted to ore having an average tenor of about $20 a ton.

While some very rich ore is sometimes found in the Captain stopes, these bodies are notable rather for their size than for unusual richness, and the ore as mined is probably not very different in tenor from the general average of the mine.

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[a] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 207.

UNDERGROUND WATER.

According to Mr. V. G. Hills,[a] from whose reports most of the following facts in regard to the underground water of the Portland mine are taken, the first water was reached at a depth of 630 feet in the Burns shaft, or 9,452 feet above sea. This was 117 feet lower than the first water of Stratton's Independence mine. The discharge did not exceed 300 gallons a minute until a depth of 704 feet was reached, when it rapidly increased to 700 gallons a minute. In 1896, 1897, and during the first half of 1898 no record of discharge was kept. In the summer of 1899 the Portland was pumping an average quantity of 1,180 gallons a minute from a depth of 792 feet, or an elevation of 9,290 feet above sea. At this time the Elkton mine, three-fourths of a mile to the northwest, was dry at 9,243 feet elevation, or 47 feet lower than the pumping level of the Portland. In January, 1903, the Portland water, which had been allowed to rise above the 1,100 foot level, remained stationary at an elevation of 9,005 feet, or at a depth of 1,084 feet. It then stood 13 feet higher than the water in the Elkton mine. In August, 1903, the water in the Portland had receded to a point 86 feet below the 1,000-foot level and was falling at the rate of 2 or 3 inches a week. At this time Stratton's Independence, the Strong, Gold Coin, and St. Patrick mines were all pumping and keeping their water levels below that of the Portland. The difference amounted to 562 feet in Stratton's Independence, 133 feet in the Strong, 240 feet in the Gold Coin, and 90 feet in the St. Patrick. That the Portland water should recede so slowly under these circumstances is a remarkable illustration of the comparative impenetrability of the granite to underground water, even when, as in the case of the Portland and Stratton's Independence mines, adjoining mines are on the same zones of fissuring.

The influence of the El Paso tunnel on the water level in the Portland mine we have been unable to learn.

STRATTON'S INDEPENDENCE MINE.

INTRODUCTION.

Stratton's Independence mine lies immediately south of the Portland mine, a short distance northeast of Victor. It is one of the oldest, and probably the most famous, of the Cripple Creek mines. It is owned by the Stratton's Independence (Limited), a London company with an authorized capitalization of £1,100,000. The property comprises 14 claims and forms a compact group covering 110 acres. Over 400 men were employed prior to the strike of 1903, and the average amount of crude ore hoisted daily in 1902 and the first half of 1903 was about 630 tons, of which about 40 per cent was shipped after sorting. Since the time of visit the company has ceased direct operations and the mine is now worked by lessees.

The mine has an interesting history. In 1891 Winfield Scott Stratton, who, though a carpenter by trade, was also a keen and well-informed prospector, was searching for cryolite on the west side of Pikes Peak. Hearing of Womack's discovery in Poverty Gulch, Stratton turned his attention to Cripple Creek, and in

[a] Ninth Ann. Rept. Portland Gold Mining Company, 1903, pp. 86-89.

June examined and sampled the indistinct outcrop of the lode now known as the Independence. His samples were assayed in Colorado Springs, and, though the results were not encouraging, Stratton, impelled by a happy inspiration, rode up to Cripple Creek and on the 4th of July, 1891, staked out the Washington and Independence claims. He began work on the Washington, the southern of the two claims, and gave a bond and lease on the Independence, which he at that time regarded as the less promising property. Fortunately for him the bond was never taken up and he thus retained the claim which, with near-by claims subsequently acquired, yielded him during the next few years a profit of over $2,000,000. The Washington claim, lying within the granite, produced considerable ore near the surface, but was soon surpassed by the Independence, lying partly within the breccia. In September, 1894, the Independence shaft was 70 feet deep, and during the preceding month shipped 800 tons of ore, of which the lowest carload contained 3½ ounces of gold per ton. This ore was hoisted by a horse whim, and the mine was already regarded as the richest in the camp. Machinery was soon installed, and when Penrose made his examination in the latter part of 1894 the shaft was 200 feet in depth. In January, 1895, a depth of 300 feet had been reached and a flow of 25 gallons of water a minute encountered. In March the daily output had risen to about 90 tons of ore, carrying from 8 to 15 ounces of gold. It was then the most profitable mine in the district, though the Portland was shipping a slightly greater tonnage. Development proceeded steadily, and in 1897 the main shaft was 900 feet in depth. Negotiations for the sale of the mine were begun about this time, and in 1899 the property, after a comprehensive examination and report by T. A. Rickard, was purchased by the Venture Corporation (Limited), of London. In his report Mr. Rickard stated that the mine up to the end of 1898 had produced 41,694 tons of ore, of a gross value of $3,837,359, affording its owner a profit of $2,402,164. The stopes aggregated 370,570 cubic feet, no less than 35 per cent of the entire output having come from development work in levels, winzes, and raises. The ore reserves were estimated by him at 70,000 tons, of a gross value of $6,712,000 and of an average gold content of 4¾ ounces per ton. He further expressed his opinion that fully $8,000,000 would be extracted from the ground already developed. Mr. Stratton was paid by the issue to him of 1,000,000 shares at £1 each, from the sale of which by the Venture Corporation he is reported to have realized about $10,000,000. On May 1, 1899, the property passed into the hands of its present owners.

New hoisting machinery was soon installed and a very active attack made on the ore reserves by the new company. Under the advice of Mr. John Hays Hammond the shaft was sunk to 1,430 feet and extensive exploratory work done on the lower levels, without, however, revealing any ore bodies comparable to those known above level 9. Although the mine has continued to produce heavily up to the date of writing and has supplied ore of a gross value considerably in excess of Mr. Rickard's estimate, later developments have not been satisfactory to the company, and the mine has received some notoriety from a suit entered against the Stratton estate to recover a portion of the purchase price on the ground of alleged misrepresentation at the time of sale.

The mine was shut down for about two months in 1903, owing to a general strike in the Cripple Creek district. The company resumed operations for a time, without, however, attaining the large ore tonnage shipped before the strike, though the grade of ore shipped was reported as somewhat higher. At present the mine is worked by lessees.

PRODUCTION AND DIVIDENDS.

The following table exhibits the production of the mine and the dividends paid, the figures being taken chiefly from the original prospectus and annual reports of the present company. As appears from this table, which probably does not include all that came from the property under Stratton's ownership, the mine has produced 723,095 ounces of gold, including some silver, worth nearly $14,000,000. The average sales value of the unrefined gold, computed from all available data, has been $19.24 per ounce. With silver at 50 cents per ounce, this value would indicate the presence of approximately 7 ounces of silver to every 100 ounces of gold, or about the relative proportion of the two metals found in calaverite.

During the fiscal year 1903–4 Stratton's Independence produced 43,758 tons of ore, with a gross value of $21.695 per ton. As the total cost of production amounted to $24.29 per ton, the mine was operated at a loss.

Under the leasing system in force during the year 1904–5 the total quantity of ore shipped by the lessees was a little less than 50,000 tons, with a gross value of $1,978,800. The company received approximately $509,250 in royalties and cleared a net profit for the year of $457,093. Since the opening of the mine to lessees additional dividends amounting in all to $606,250, have been declared to date (November, 1905), bringing the total dividends paid by the present company up to $4,627,730.

Production and dividends of Stratton's Independence mine.

Year.	Tons of ore (2,000 pounds to the ton).	Ounces of gold (unrefined).[a]	Average ounces per ton.	Gross value.[b]	Dividends.[b]
1891–1893	2,000	5,000	2.50	$100,000	.....
1894	5,159	26,827	5.20	523,859	.....
1895	9,007	61,968	6.88	1,208,109	.....
1896	7,125	39,544	5.55	794,130	.....
1897	10,024	40,946	4.08	751,685	.....
1898	8,379	24,987	2.98	459,576	.....
1899	[d] 48,048	[c] 91,421	[d] 3.75	3,472,189	$970,005
1900		150,296			1,778,345
1901	[d] 57,534	120,060	[d] 2.32	2,573,373	788,130
1902	[d] 96,173	102,588	[d] 1.22	2,274,108	121,250
1903	[d] 86,257	[e] 59,458	[d] 1.06	1,761,379	363,750
	329,706	723,095	.....	13,918,408	4,021,480

[a] The mine records give output as ounces of gold, taking no separate account of silver present. The average sales value of this unrefined gold is $19.24 per ounce.

[b] In calculation, the pound sterling is taken as equivalent to $4.85.

[c] May to December.

[d] For fiscal year from July 1 to June 30.

[e] Output curtailed by general miners' strike.

UNDERGROUND DEVELOPMENT.

The principal shaft is the Independence, situated about 500 feet north of the south end of the Independence claim. This is a vertical shaft about 1,430 feet in depth. The No. 2 shaft, near the north end of the property, 600 feet in depth and extending only to level 5, is now in disuse. The levels above 9 are 100 feet apart. Between level 9 and the 1,400-foot level is an intermediate level at 1,150 feet, and short sublevels, not directly connecting with the main shaft, at 960 and 1,150 feet below the collar of the shaft.

All of the ore, with the exception of a little above level 2 and the ore bodies of the old Washington mine, lies north of the shaft, the productive workings thus being between the shaft and the Portland property. South of the shaft are a few long exploratory drifts and crosscuts, which on level 7 extend southward for 1,200 feet. The workings north of the shaft are exceedingly intricate. The drifts follow a number of intersecting lodes ranging in strike from north to northwest and of various dips from 20° to vertical. The plans of the different levels when assembled on a single sheet form a maze of almost hopeless complexity, in which all but the drifts on a few of the most important and persistent lodes are obscured by the tangle of crossing lines. The levels above the sixth are generally more complicated in plan than the lower levels.

LODE SYSTEMS.

The most prominent lodes of the Independence mine are the Independence, Emerson, Bobtail, Grant, No. 6, and Flat veins. Their general relation to the lodes of the Portland mine is partly shown in Pl. V (p. 26). The Bobtail, Diamond, and No. 2 veins of the Portland, converging from the north, and the Emerson, Bobtail, West Bobtail, Independence, West Independence, and other veins of Stratton's Independence, converging from the south, come together in a plexus of fissures near the boundary between the two mines. It is thus impossible to correlate with certainty the veins of one mine with those of the other. On some levels the stopes on the Independence vein are continuous with those on the No. 2 vein in the Portland. On level 3, however, the Independence veins (Pl. V) are apparently continued by the Diamond vein. The Grant and East veins of the Independence undoubtedly coalesce with the No. 2 zone of sheeting in the Portland. The Emerson and Bobtail veins of the Independence come together near the Portland line, and it is an open question which should be regarded as the continuation of the Portland Bobtail. All of the veins are connected by branching fissures near the line between the two mines, and any of these fissures may carry ore. Consequently, stopes begun on one vein sometimes come up on what had been regarded as an entirely distinct vein on the level above. The truth of the matter probably is that none of the veins preserve distinct individuality across the region of complex fissuring in which they come together.

The rocks of the Independence mine, particularly above level 5, are cut by a complex network of fissures, few of which possess any features sufficiently characteristic to serve for their identification from level to level. This has led to some

confusion of nomenclature, owing partly to the fact that when ore leaves one fissure zone and follows a branch or intersecting lode the original name of the lode is frequently retained in spite of the significant change in strike and dip. So far as observed, the intersections of the different fissure zones in the Independence mine are not associated with any perceptible faulting.

An idea of the relation of the lodes in a horizontal plane may be had from fig. 59, which is a plan of level 4. The No. 6, East, and No. 1 veins, however, have no development on this level. The Independence lode has a general course of N. 15° W., but it is far from straight. Near the Independence shaft it strikes nearly north and south. Farther north, however, after entering the breccia, it gradually assumes a nearly northwest course and then curves gently eastward until, near the Portland line, it again runs north and south. This curve may be seen on all the levels except the first. The northern part of this level follows a fissure with southwest dip, which, while known locally as the Independence, is probably not that lode, but a different one, formerly called the Black Diamond vein. The general dip of the Independence lode is easterly, at angles ranging from 70° to vertical.

The Emerson lode, which lies for the most part northeast of the Independence, strikes N. 58° W., and dips southwest at angles ranging from about 50° near level 1 to about 68° near level 5. The relation between the Independence and Emerson lodes is not clear on level 1. The Emerson turns north as it comes into the Portland and has not been identified in that mine. The Independence or No. 2 lode is also very indistinct on the 350-foot Portland level (which is about 12 feet below level 1 of the Independence), though there is a fissure with southwest dip known as the Diamond vein which may be the same as the fissure called the Independence in the northern part of level 1 of the Independence mine. It is by no means clear, however, that the Diamond lode of the 350-foot Portland level is the same as the nearly vertical Diamond lode which proved so productive in that mine below level 5.

On levels 2 and 3 the Independence, Emerson, and Bobtail lodes all meet close to the Portland line, near the No. 2 shaft of the Independence mine. On level 4 the Emerson and Independence cross about 75 feet south of the No. 2 shaft. On level 5 the crossing occurs still farther south, but the indistinct portion of the Emerson west of the Independence is here in the granite and contains practically no ore. On the levels below the fifth the Emerson lode is unknown.

The Bobtail lode lies southwest of the Emerson and strikes in general northwest. The two lodes thus gradually come together and both may be represented in part by the Bobtail in the Portland. Some of the fissuring known as the Emerson in the Independence mine seems, however, to turn northward in the Portland and may join with what are there known as the Diamond and No. 2 veins. Cross and branch fissures are so numerous in this vicinity and individual fissures so often nonpersistent and indistinct that definite correlation is in most cases impossible. The Bobtail, like the Emerson, dips southwest, and at about the same angle. Its general relations to the Independence and Emerson are well shown in Pl. V (p. 26). Like the Emerson, also, the Bobtail is of no importance below level 5, though obscure traces of the lode may be detected in the granite on some of the lower levels.

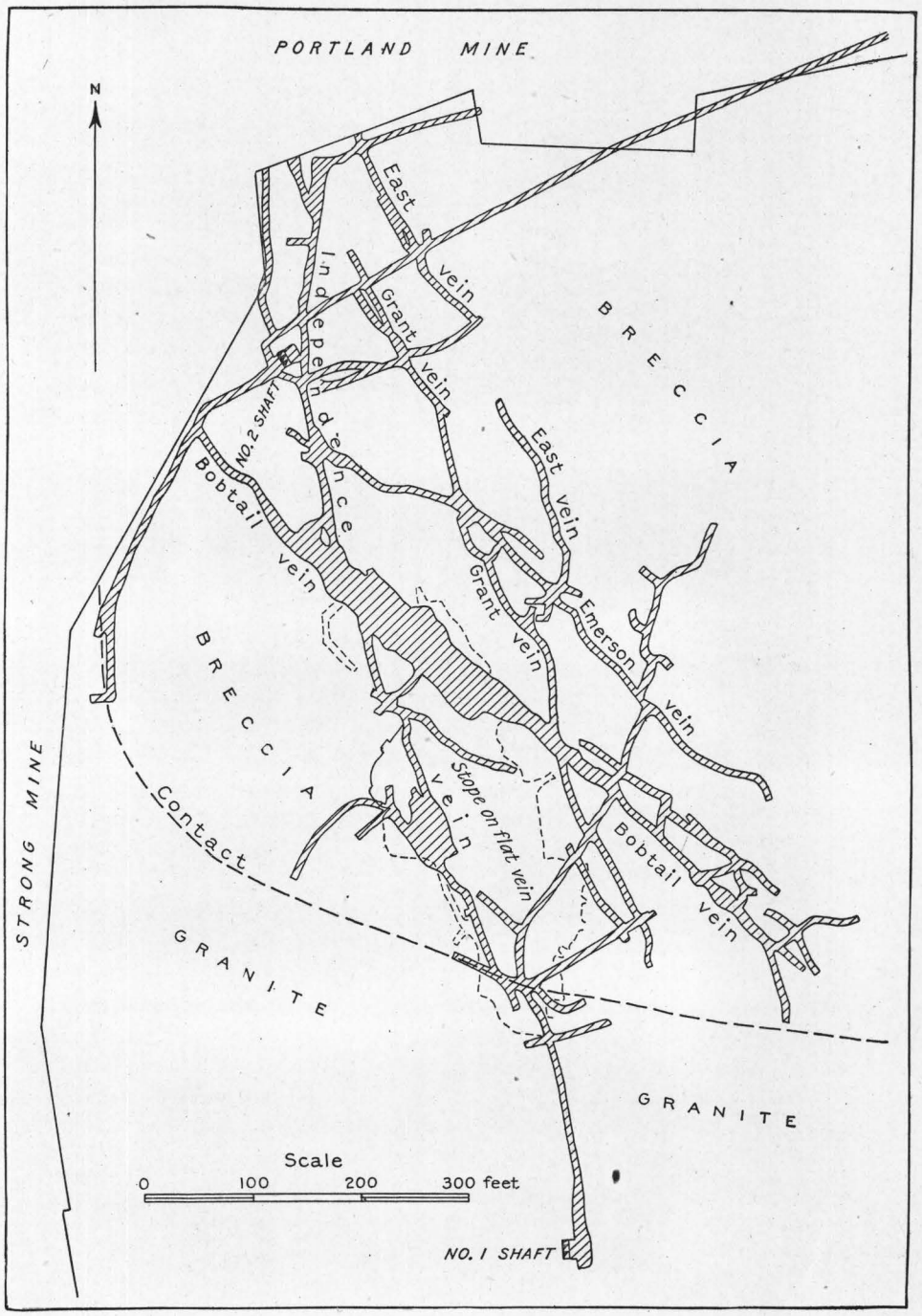

FIG. 59.—Map of level 4, Stratton's Independence mine, showing vein system.

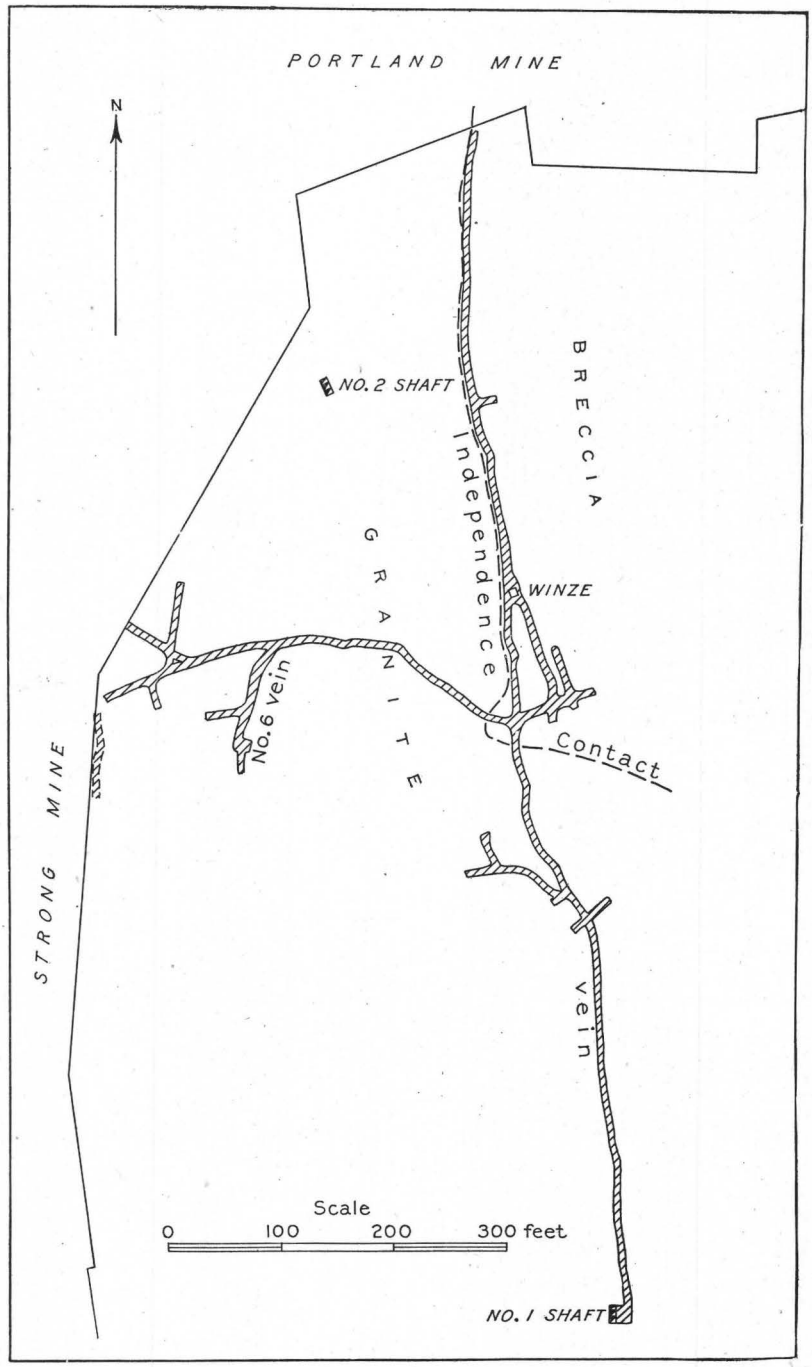

FIG. 60.—Map of level 8, Stratton's Independence mine showing vein system.

The Grant lode lies east of the Independence and strikes about N. 23° W. It dips westerly at angles ranging from 55° to 70°. The Grant crosses the Bobtail and Emerson, and joins the Independence in the north end of the mine. It is not known on the levels below the fifth. The No. 6 lode lies west of the Independence lode and has been developed from level 5 to level 9. It strikes nearly north and south and is about vertical.

In addition to the lodes hitherto mentioned there are a number of minor lodes, often of no great persistence. Some of these are parallel to the more important sheeted zones; others are plainly branch lodes. They add greatly to the complexity of the fissure systems and to the difficulty in following and identifying the principal lodes. The West Independence lode runs generally parallel with the Independence lode on levels 1, 2, and 3. The East Independence is a branch lode known only below level 8, and has by some been confused with the Emerson. The Bobtail has at least two branch lodes above level 3, one known as the West Bobtail and one as the East Bobtail. Northeast of the Emerson lode and crossing or joining it at various points are a number of less persistent sheeted zones known on different levels as the East Emerson, London, East London, Drury, East Drury, and East lodes.

The Flat vein of the Independence mine lies between levels 2 and 4, dipping in general about 18° W. It is best seen on level 3, which cuts it about 200 feet north of the shaft and immediately north of the granite-breccia contact. It consists essentially of two nearly parallel zones of sheeting about 8 feet apart which differ from the usual sheeted zones in the breccia and granite only in their unusually low angle of dip. The Flat vein is not very persistent and has not been identified with certainty on levels 2 and 4. It has been exploited for a distance of 400 feet in a northwest-southeast direction, and 100 to 125 feet in a northeast-southwest direction. It is crossed without any apparent faulting by the Independence lode and by a number of minor sheeted zones running generally parallel with the Independence. A similar but much less important flat vein, known as the East Flat vein, occurs on level 4 near the Emerson lode, the two intersecting without visible displacement.

One very significant fact apparent from a study of the various levels of the Independence mine is the much greater abundance and more open or dispersive character of the fissuring in the upper levels as compared with the lower. While to a certain extent this change seems to be progressive from level to level, yet the most marked difference is between the fifth and upper levels, on the one hand, and the sixth and lower levels on the other (figs. 59 and 60). As will appear when the geological features of the mine are considered, this general fact may be expressed in different terms by stating that the breccia is locally much more extensively fissured than the granite. The diminution of the fissuring in depth is fairly well exhibited by a comparison of the drifts on the different levels. For while to some extent the fewer drifts on the lower levels merely signify a less advanced stage of mining development, yet they are nevertheless fairly expressive of an actual contrast in the relative abundance and prominence of the fissures in the upper and lower parts of the mine.

GEOLOGICAL FEATURES.

Like so many of the large mines near Victor, Stratton's Independence is partly in granite and partly in breccia. In general petrographical character these rocks are identical with those described in the Portland mine, though, as the Independence workings do not extend so far into the breccia, certain facies of this rock, such as those in the vicinity of the Captain lodes, do not occur in the more southerly mine. While in the Portland mine the contact between the granite and breccia is generally convex toward the northeast, in the Independence it is concave (Pl. V, p. 26). In the Portland the granite projects into the breccia as a steep promontory; in the Independence the breccia lies in the curved embayment on the east side of this jutting point of granite. The benched form of the contact surface, already described in the Portland, is also well exhibited in the northern part of the Independence embayment. (See fig. 61, p. 458.) The Independence shaft is sunk in the granite, the collar being very close to the granite-breccia contact as exposed at the surface. The drifts running north from the shaft at successively lower levels cut the contact at increasing distances from the shaft (fig. 62), the successive increments of distance being such as to show that this portion of the contact has a general dip of at least 60° N. or NE. Farther north, however, the dip becomes considerably less than this above level 5 and considerably more below it. There is thus in the northwestern part of the mine, adjoining the Strong and Portland mines, a notable bench-like flattening of the granitic surface against which the breccia rests (Pl. V, p. 26; fig. 62, p. 459). As a consequence of this, the productive northern portions of the levels above the fifth are chiefly in breccia, while below level 5, the workings are chiefly in granite. This fact may be exhibited with greater clearness by noting the relation of the Independence lode to the country rocks on different levels. On levels 1, 2, and 3 the lode, in granite near the shaft, soon passes into breccia and continues in this rock past the Portland line. On level 4, the Independence lode passes into breccia about 250 feet north of the shaft, and thence northward remains wholly in this rock. The granite, however, on this level appears again in the Strong drift, about 325 feet west of the Independence vein (Pl. V, p. 26), showing that the dip of the contact is bringing the latter nearer the vein. On level 5 the lode enters the breccia about 300 feet north of the shaft; but about 675 feet north of the shaft, near the crossing of the Emerson lode, the granite reappears and continues to form the west wall of the Independence lode into the Portland ground. Below level 5, there is practically no breccia west of the Independence lode, the latter being either wholly in granite or following in a general way the steep granite-breccia contact (fig. 62). This statement, however, requires some qualification with reference to the 1,400-foot level. The granite-breccia contact near the north end of this level is indistinct, and the narrow fissure, supposed to be the Independence vein, apparently enters a granitic phase of the breccia about 100 feet south of the Portland line. Whether or not this is merely a level irregularity in the contact could not be determined.

The granite-breccia contact is hardly so well exposed in the Independence workings as in the Portland. In general it is fairly distinct on the upper levels, the granite as a rule not showing much brecciation in its vicinity. In detail it is

exceedingly irregular, diversified with minor salients and reentrants. The breccia near the contact is sometimes, as on the 1,400-foot level, so full of granite fragments, some of them of large size, that it is difficult to determine in a small exposure whether the rock seen is breccia or massive granite.

Both granite and breccia are cut by phonolite in the form of dikes, sills, and irregular masses. In general the Independence lode, as known in the granite, follows a phonolite (strictly latite-phonolite) dike, but the dike, as pointed out by Penrose,[a] is much more irregular in its course than the lode and the two are not

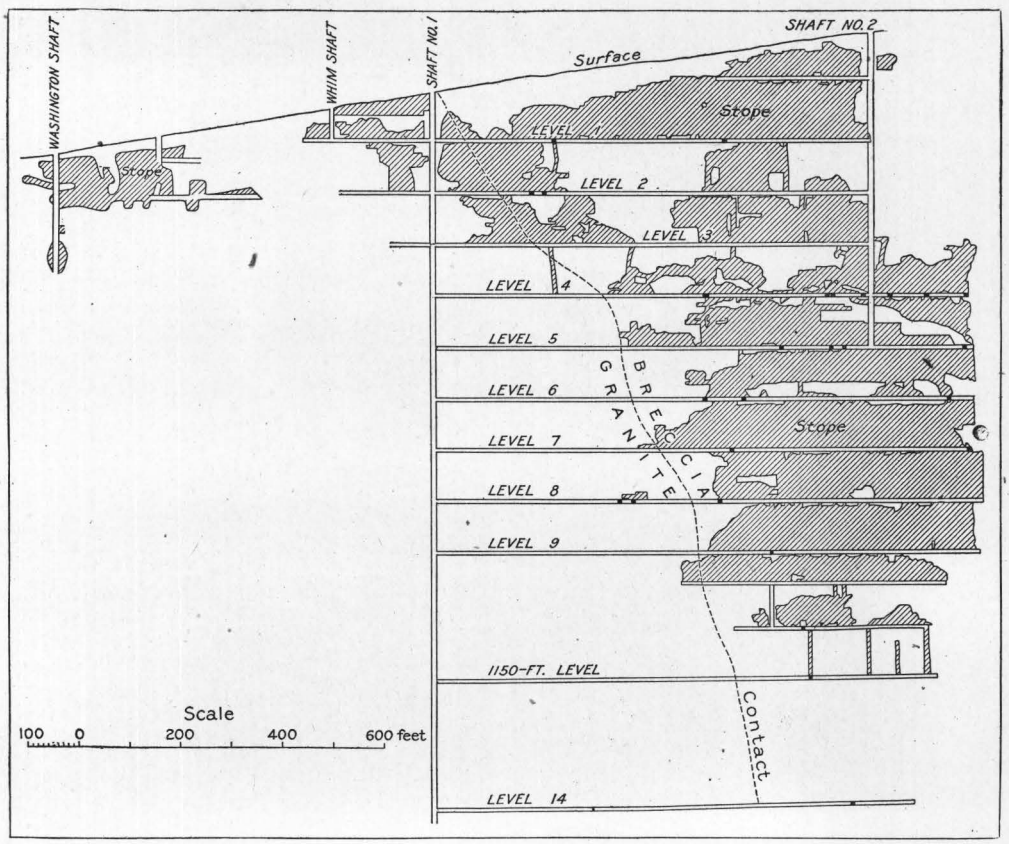

FIG. 61.—General north-south section through Stratton's Independence mine, showing stopes in Independence vein.

always together. The extensive developments in the breccia since Penrose's visit show that in that rock the relation between dike and lode is less close than in the granite. The dike becomes more irregular as it enters the breccia, branches, and frequently sends off intrusions along the contact between the breccia and the granite. While several of the lodes in the breccia follow phonolite dikes for varying distances, it can not be said that any single lode and dike are continuously associated throughout their known horizontal and vertical extent. For example, the West Independence lode on level 2, is generally associated with a phonolite dike. On

[a] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 201, pl. 14.

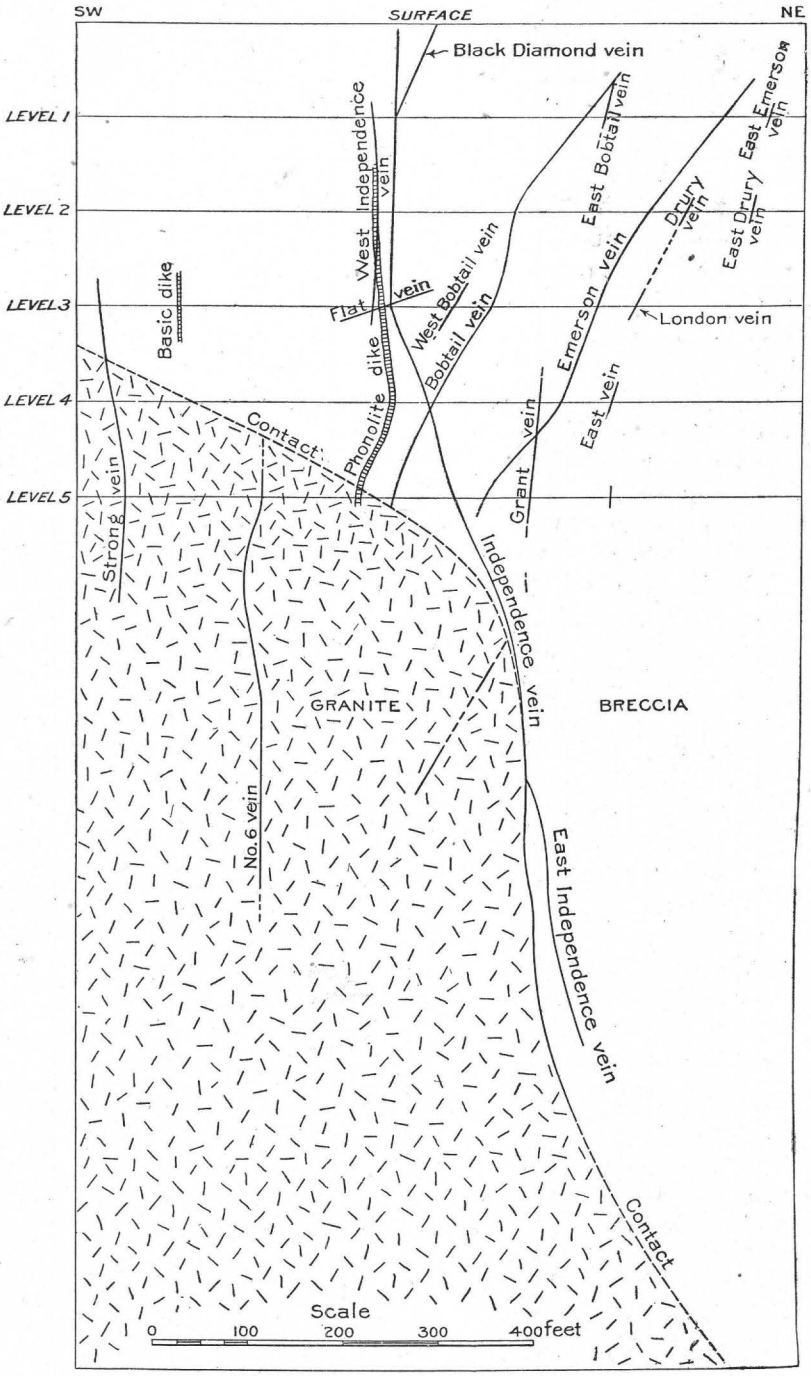

FIG. 62.—Section through Stratton's Independence mine, showing the relation of the veins to the granite-breccia ontact.

level 3 what appears to be the same dike lies between the Independence and the West Independence lodes in the southern part of the mine, but turns southeastward across the Independence lode, crosses the Flat vein in the large stope just above level 3, known as the Little Bull Pen, and meets the granite-breccia contact about 150 feet east of the Independence lode. Here it apparently joins with an irregular dike-like intrusion which follows the contact and may be seen in the main Independence and Bobtail drifts where they pass from breccia into granite. On level 4, the same Independence dike is crossed by the Independence lode about 75 feet south of the Independence-Bobtail intersection and is cut by the Bobtail northwest of that intersection. Thus on this level it exhibits no significant connection with either lode, though it contained a comparatively short ore shoot which branched in a southeast direction from the main Independence pay shoot. On level 5, a phonolite dike, apparently the same Independence dike, lies in the granite west of the Independence lode in the northern part of the mine and crosses to the west side of the No. 6 lode near the Portland line. The No. 1, Bobtail, and East Bobtail lodes accompany phonolite dikes for part of their courses on this level, the dike along the Bobtail fissure zone connecting with an irregular phonolite intrusion at the granite-breccia contact. On level 6, the Independence phonolite dike is followed by the main drift north to the breccia, in which, as usual, it becomes irregular. A little phonolite, possibly a part of this dike, occurs along the Independence lode near the Portland line. On level 7, the Independence phonolite dike has been followed northward from the shaft for a distance of 450 feet, to the breccia, and south of the shaft for about 1,050 feet. At the south end of the mine the dike terminates abruptly against a close cross fissure. There is no evidence of movement along this fissure subsequent to the phonolitic intrusion. The original dike fissure apparently ended at this point. On level 8, the Independence dike is cut near the shaft and followed northward for 350 feet in the main drift. Here it apparently branches, one branch turning northwestward and the other continuing north and probably connecting with some phonolite exposed at the south face of the East Independence lode, at the granite-breccia contact. On level 9, the dike runs generally north from the shaft for about 300 feet and then turns northwest, away from the Independence lode. On the 1,150-foot level the Independence dike accompanies the Independence lode for a distance of 700 feet north of the shaft to the granite-breccia contact. Beyond this point it was not seen. On the 1,400-foot level it runs north for 300 feet from the shaft, and then divides, one branch turning northwestward, as on levels 8 and 9, and the other continuing north to the contact. A west crosscut on this level exposes other phonolite dikes in the granite which have no apparent connection with lodes. A long southeast drift or crosscut on the same level, approximately along the granite-breccia contact, shows some very irregular dikes of phonolite and a number of sill-like intrusions of the same rock, dipping gently eastward and cutting both granite and breccia near the contact.

The main phonolite and "basalt" dikes of the Strong mine are exposed in several drifts near the Independence-Strong line in the extreme western portions of several of the Independence levels, but as these dikes are fully described in connection with the Strong mine they need not be further considered at this place. With the exception of the Strong dike and some small decomposed basic dikes in the western

part of the mine that are probably part of the same dike zone known in the Strong mine, "basalt" dikes are absent in the Independence mine.

The northeastern part of the Independence property, particularly the ground under the northern part of tract A of the Wilson Creek placer location and under the northern half of the Wonderland claim, has not been thoroughly explored. Such long crosscuts, however, as have been run out into the breccia in this territory, on the third, fourth, and 1,400-foot levels have not been particularly encouraging. On level 4 (Pl. V, p. 26) a long northeasterly crosscut which crosses and recrosses the Portland line cuts the same latite-phonolite noted in the Portland mine east of the No. 2 lode. The contact between this rock and the breccia which is locally banded, is not entirely definite, though it can in some places be determined within the range of a foot in distance. The massive rock is not particularly shattered near the contact and its contrast in texture and composition with the breccia a foot or so away is suggestive of intrusion into the latter.

PAY SHOOTS AND LODE STRUCTURE.

By far the greater part of the ore from Stratton's Independence mine has come from that part of the breccia filling the granitic embayment and lying above the bench-like flattening of the contact above level 5. Good ore occurs in the granite in the Independence lode above level 3 in the old Washington workings near the surface, and in the No. 6 vein, but the amount of ore hitherto extracted from this rock is small indeed compared with the great tonnage obtained from the breccia. Between the fifth and 1,050-foot levels a large amount of ore has been mined from the part of the Independence lode that follows the general course of the granite-breccia contact.

The ore bodies occur as pay shoots in lodes, such irregular ore masses in granite as occur in the Ajax and Elkton (Thompson) mines having here no exemplification. These pay shoots in some cases attain considerable width, the stopes along the Bobtail on level 4 being in places 50 or 60 feet wide. Such wide ore bodies are usually associated with a corresponding widening of the zone of generally parallel sheeting constituting the lode, or with the convergence or intersection of two or more definite lodes.

The main pay shoot of the Independence lode begins at the surface, about 250 feet south of the granite-breccia contact, and extends northward practically to the Portland line. Its southern limit pitches north at an angle with the horizon which may be generalized at about 52°, a somewhat lower angle than that of the granite-breccia contact. Below level 3 the ore rarely extends from the breccia into the granite, and then only for short distances. On levels 1, 2, and 3 the ore in the granite occurred in a sheeted zone apparently of the usual type found in this rock, though the details of the occurrence of this ore could not be studied in 1904. Below level 3 the Independence lode between the shaft and the granite-breccia contact is usually a rather indistinct, narrow zone of fissuring in the granite or in the Independence phonolite dike, and contains practically no ore. At the contact the lode usually becomes rather irregular, apparently splitting into several branching fissures, and the ore generally begins abruptly as the breccia is entered and continues almost continuously to the Portland line. The ore occurs in a

mineralized sheeted zone in breccia, granite, however, forming a portion of the foot wall from level 5 down. Owing to the northerly dip of the contact, the portion of this great pay shoot lying in the Independence ground becomes shorter on successive lower levels. Below the 950-foot level, moreover, the ore becomes narrower, and on the 1,150-foot level all that is known of the Independence lode is a single narrow fissure containing a little fluorite and pyrite, but no workable ore. On the 1,400-foot level the lode is even less distinct, and it is doubtful whether it can be recognized with any certainty. In general, the Independence lode exhibits the same structural characteristics as its northern continuation, the No. 2 vein of the Portland, which has already been described. It will be unnecessary, therefore, to do more than note a few special features. On level 7 the pay shoot extends for a short distance into the granite, south of the contact, as a mineralized sheeted zone about 4 feet wide, consisting of three principal parallel fissures. These little fissures are partly filled with fluorite, quartz, pyrite, and calaverite.

On level 6 the first ore in the Independence lode, as one goes north, occurs in an irregular expansion of the Independence phonolite dike at the granite-breccia contact. Thence northward it occurs partly in breccia and partly in phonolite, close to the granite. Where the phonolite is sufficiently mineralized to constitute ore, the rock has a porous texture, being full of little cavities containing nests of pyrite, fluorite, and calaverite. The same minerals occur also in the narrow crevices of the sheeted zone and in less regular minute cracks traversing the rock. Where the lode passes through breccia containing granitic fragments, the latter usually show the same porous texture and the same character of mineralization as occur along the Diamond lode in the Portland and in the granitic ore bodies of the Ajax and Elkton mines. On level 5 the Independence pay shoot attains its greatest width at the crossing of the Emerson lode. On level 4 are several local expansions of the ore to unusual width. The first of these is just north of the contact, where the main lode is crossed at small angles by some fissures running approximately northwest and southeast, or parallel with the Bobtail lode. The ore here, which is under the Flat vein, attains a width of about 40 feet. This ore is all in breccia, the value, as usual, being concentrated in the actual fissures. Another wide body of ore occurs at the crossing of the Bobtail, which on this level comprises a large number of parallel fissures forming a sheeted zone about 50 feet in width. A smaller though important widening of the ore occurs at the crossing of the Emerson, and, finally, at the Portland line, the convergence of the Independence, Grant, and East lodes determines a large ore body which has been worked in the great Independence stope on the No. 2 vein in the Portland. On level 3 a body of ore fully 50 feet in width was stoped in the breccia just north of the contact, at the intersection of the Independence lode with the Flat vein and with the northwest-southeast fissures already noted.

The Emerson and Bobtail are essentially sheeted zones in breccia, and their pay shoots are generally rather narrow. At points of intersection with other fissures, however, or where other sheeted zones of generally parallel strike but slightly different dips approach so near as to constitute locally a single fissure zone, the ore bodies may expand to unusual dimensions. This is particularly striking along the Bobtail lode on level 4, where several fissures of nearly parallel strike,

which are distinct on level 3, join to form a single ore body, which for a length of over 200 feet has a width of 40 or 50 feet. The Emerson pay shoot attains its maximum length (about 600 feet) on level 5. A short distance below this level the lode, if it persists, enters the granite, and within this rock, so far as known, it carries no ore. On the northwest the pay shoot ends near the Portland line. On the southeast the pay shoot, as seen on level 5, continues for about 150 feet southeast of the crossing of the Drury lode. The Emerson sheeted zone, however, continues in the breccia beyond this point, but has not been followed to the granite-breccia contact.

The Bobtail pay shoot reaches its greatest length (about 1,000 feet) just above level 2. This diminishes to about 450 feet on level 5. A short distance below this level the Bobtail, like the Emerson, meets the granite-breccia contact and the economic importance of the lode vanishes. On the northwest the pay shoot reaches the Portland line only near level 2. On the southeast the ore extends up to the granite-breccia contact on level 3, but on all other levels ends well within the breccia, though this fissure zone apparently continues to the contact and probably into the granite.

The Grant, Drury, East, and London lodes are usually narrow sheeted zones in the breccia and are not known below level 5. They contain several important pay shoots, which, however, are not so persistent in depth and length as those of the Independence, Emerson, and Bobtail. The occurrence of their ore bodies could not be well studied at the time of visit, but they appear to be of the usual structural type—narrow zones of close sheeting, with the value chiefly in the form of calaverite in the fissures.

With the exception of the upper 300 feet of the Independence lode and the contested portion of the Strong lode, the only important lode known in the granite of the Independence mine is the No. 6 lode. This has shown a fairly continuous body of ore from the granite-breccia contact above level 5 (fig. 62, p. 459) to level 6 and isolated ore bodies between levels 6 and 9. The lode is a narrow sheeted zone in granite, in some places following a phonolite dike. The granite between the fissures is altered to a porous mass consisting chiefly of secondary feldspar, with nests of pyrite and calaverite partly filling the irregular cavities. The best ore occurs in a rather soft decomposed streak, usually from 3 to 8 inches in width, and is worth about $50 per ton.

One of the most interesting ore bodies in the mine was that stoped from the Flat vein above and below level 3. This stope has a length from southeast to northwest of about 400 feet, and an extreme width of about 200 feet. The ore had an average thickness of 6 or 7 feet and dipped northwesterly at about 18°. It lay generally in the breccia, being bounded on the southwest by the granite, and passing somewhat irregularly into barren breccia in other directions. The ore occurred in a sheeted zone, which in some portions of the stope is divided into two zones by a slab of country rock. These zones of sheeting are not merely coextensive with the ore, but persist beyond the margin of the ore body into the granite and into the breccia. The Flat vein is crossed by the Independence lode and phonolite dike, and by a number of other fissures of general northwest strike. The ore was continuous with that of the Independence lode and extended for varying distances

above and below the Flat vein into some of the other nearly vertical fissures. Still other fissures contain ore only at their intersection with the Flat vein. The flat ore body may be regarded as a special case of the local expansion or coalescence of ore bodies at the intersections of lodes. The mine affords several examples of such ore bodies at the intersections of nearly vertical fissure zones. The intersections of such lodes with the Flat vein appear to have supplied unusual facilities for ore deposition, some of the richest ore having been stoped from this body. The value, as usual, was in the small fissures of the sheeted zones, the calaverite being accompanied by fluorite and partly oxidized.

VALUE AND CHARACTER OF THE ORE.

The average value of the ore produced by Stratton's Independence mine has varied from a maximum of $132 a ton in 1895 to $20 in 1903. During March, 1904, 4,650 tons of ore were shipped, which averaged about $30 a ton. Some of the ore formerly stoped from the Flat vein is said to have been wonderfully rich, though no actual figures for the value of carload lots have been obtained. A small sample bag of ore stolen from this vein and afterwards recovered was found to contain $80 in gold.

There were comparatively few places where the actual occurrence of ore could be well studied in the Independence mine at the time of visit. The richest ore, on the whole, occurred in the Flat vein as calaverite associated with fluorite in very narrow fractures in the breccia, and probably to some extent in the porous metasomatically altered granitic fragments traversed by these fissures. This ore was partly oxidized.

The ore of the Independence vein is of the same general character as that in the No. 2 vein of the Portland. Owing to the abundance of granitic fragments in the breccia along the course of this vein, the ore partakes somewhat of the character of ore found in the massive granite. The granitic fragments alongside and between the fissures are altered to spongy aggregates consisting chiefly of secondary orthoclase or valencianite, with fluorite and considerable pyrite in small crystals. Calaverite and perhaps sylvanite occur in the fissures of the sheeted zone, usually with quartz and fluorite, and in the metasomatically altered granitic breccia as particles usually too small to be detected with the naked eye.

The ore of the No. 6 vein is similar in mineralogical character to the Diamond ore in the Portland mine, though the metasomatic alteration has been much less extensive in the Independence mine.

Some very rich ore, consisting of little irregular stringers of nearly solid calaverite in dark sheeted breccia, has come from the Emerson vein near level 4. The calaverite is intimately associated with pyrite, molybdenite, and a little quartz and fluorite. Pyrite is also finely disseminated through the breccia near the vein, but so far as known is not auriferous.

In many places ore occurs in phonolite dikes, nearly always as calaverite in very narrow fissures associated with fluorite and quartz as gangue.

Galena is rarely visible in the Independence ore, but is said to have occurred in considerable abundance in the Bobtail vein above level 2. It also occurs sparingly in the Emerson vein just above level 7.

UNDERGROUND WATER.

The first water encountered in the Independence mine was 275 feet below the collar of the shaft, or 9,569 feet above sea level. In January, 1895, the shaft, then 300 feet deep, could be kept free of water by raising about 25 gallons a minute. At the time of sale in 1899 the mine, then 900 feet deep, made about 350 gallons of water a minute. In January, according to Mr. V. G. Hills,[a] the quantity of water pumped was 300 gallons a minute. This, however, was being considerably augmented by development work on the 1,400-foot level, and in July of the same year the flow had increased to 450 gallons. The bulk of this water issues from fissures in the granite in the northern part of the level. The level at which the water would stand if pumping were abandoned is estimated by Hills at 8,940 feet above sea level, or about 913 feet below the collar of the shaft. On April 17, the quantity of water raised by the pumps had increased to 560 gallons a minute, the increase being due to additional development work on the 1,400-foot level.

[a] Fourth Ann. Rept. Portland Gold Mining Company, 1903, p. 91.

CHAPTER VIII.—MINES OF BATTLE MOUNTAIN (WEST GROUP) AND OUTLYING PROSPECTS.

STRONG MINE.

INTRODUCTION.

The Strong mine, situated on the southern slope of Battle Mountain, near the northern limits of the town of Victor, is owned by the Strong Gold Mining Company, of Colorado Springs, incorporated in 1892 with a capital of $500,000. It lies between Stratton's Independence mine on the east and the Dillon mine on the west. On the north it joins the Portland property. The Strong workings were originally confined to the Strong claim, running about N. 6° W. By compromise with the Portland company, however, 250 feet from the north end of the Strong claim were exchanged for a triangular area extending southward from the Portland property between the Strong claim and the Maggie claim of Stratton's Independence mine and tapering to a point about 600 feet south of the northeast corner of the original Strong claim.

PRODUCTION.

Statistics of the gross production of the Strong mine are not obtainable, but for a comparatively small mine it has been a remarkably regular and profitable producer. The dividends paid are as follows:

Dividends paid by Strong mine.

1892–1896	$555,000	1901	$300,000
1897	145,000	1902	375,000
1898	300,000	1903	200,000
1899	300,000		
1900	300,000		2,475,000

UNDERGROUND DEVELOPMENT.

Access to the Strong workings is through the vertical Strong shaft, 904 feet in depth and situated about 340 feet from the south end of the claim. There are nine levels, approximately 100 feet apart. These are of generally linear plan and run nearly north and south. The principal development has been north of the shaft. The northern portions of levels 2, 3, 4, and 5 were not accessible at the time of visit, being partly caved in and partly bulkheaded.

LODE SYSTEMS.

There is but one important lode in the Strong mine—a nearly north-south zone of sheeting, which usually dips to the east at angles ranging from 80° to 90°. The general dip is about 84°. As will presently be shown, this lode is closely related to two nearly north-south dikes, one of phonolite and one of basalt.

GEOLOGICAL FEATURES.

The general country rock of the mine is the conspicuously porphyritic Pikes Peak granite prevalent in this part of the district. Here, as elsewhere, this granite often exhibits a distinct gneissoidal structure. The northern portions of levels 1, 2, and 3, and perhaps also of levels 4 and 5, extend into the breccia, the contact between the granite and the breccia being irregular, but distinct. On level 1 the breccia is first seen in the main drift about 425 feet north of the shaft. The contact, which is followed for about 500 feet by the drift, runs in a general north-northwest direction for about 300 feet and then turns nearly due north toward the Burns shaft of the Portland mine. On level 3 the contact crosses the main drift about 600 feet north of the shaft, and has been drifted on for about 500 feet northward from this point. Its general course is similar to that on level 1, and its dip, as shown by the relative positions of these two levels, is easterly, ranging from 65° on the south to 85° on the north. The breccia seen in the Strong mine presents no unusual character and is similar to that already described in the southwestern part of the Portland mine.

There are two important phonolite dikes in the Strong mine. The larger and better known of these, while somewhat irregular in trend, has in the main a north-south course. It has been identified on all of the levels and extends through the Strong claim, entering near the middle of the south end line and passing out near the northeast corner. It thus cuts both granite and breccia. Its general dip is that of the Strong lode, the two being sometimes coincident for several hundred feet. When not coincident the phonolite dike usually lies a few feet east of the lode, though in one place, on level 6, it lies immediately west of the ore. The average width of the dike is about 7 feet. It is composed of the altered greenish-gray aphanitic phonolite, with platy parting parallel with the walls, that constitutes the common dike facies in the Cripple Creek mines.

The second phonolite dike, known as the "cross dike," derives its name from the fact that its course crosses that of the first dike. It is apparently more irregular and less persistent than the main dike, its course, as observed on different levels, varying from west-northwest to north-northwest. The dip is in general to the southwest. On level 1 the cross dike is exposed in breccia in the right-hand branch of the main north drift, about 800 feet north of the shaft. Its course as exposed for a length of 70 feet is far from straight, but seems to be in general about west-northwest. It was not noted in the left-hand branch of the drift and may not cross the granite-breccia contact (Pl. V, p. 26). On level 3 the dike is in granite and intersects the main phonolite dike 575 feet north of the shaft. There is no evidence at the crossing that one dike is older than the other, and they were probably intruded simultaneously. The dip of this portion of the cross dike, as indicated by its relative positions on levels 1 and 3, is southwest at an angle of about 40°. On level 4 the dike could not be seen, but on level 5 it is encountered about 600 feet north of the shaft and followed for some distance by the main drift. Its course here is roughly north-northwest. It is not altogether certain that this is the same cross dike known on the upper levels. If it is, it indicates not only a pronounced

change in the strike of the dike, but a local reversal of dip between levels 3 and 5 from 40° SW. to about 80° SE. Such irregularity, however, is in full accord with the observed behavior of other phonolite dikes in the granite, as may be seen, for example, in the Gold Coin mine.

Below level 5 the cross dike, while retaining its north-northwest strike, resumes its southwesterly dip. It is apparently not exposed on levels 6 and 7, but is well shown on level 8, 470 feet north of the shaft, and on level 9, 450 feet north of the shaft. Its dip in the lower part of the mine thus appears to be about 75° SW.

In addition to the phonolite dikes there is in the Strong mine a basic dike which is important from its relations to the ore bodies. This dike has the same general course as the main phonolite dike, lying sometimes on one side and sometimes on the other side of the latter. The "basalt" dike cuts the phonolite dike and is therefore younger. It is probably not perfectly continuous, but pinches out locally to appear again in another parallel fissure a few feet to the east or west. The width of the dike varies from a fraction of an inch up to 3 feet. The usual width is about 18 inches. The rock is generally rather soft and decomposed, exhibiting the fine platy parting and calcitic veining parallel with the walls which is characteristic of the basic dikes in this district. The only trace of the dike seen on level 1, is a little streak of decomposed "basalt" lying between the ore and the main phonolite dike, about 100 feet south of the shaft. On level 3, however, the "basalt" dike is well developed, lying from 25 to 40 feet east of the shaft. It has been drifted on here for about 200 feet, but is not exposed in the northern part of the level. On level 5 the dike lies 40 feet east of the shaft and is here coincident with the Strong lode. The ore leaves the dike, however, about 125 feet north of the shaft, the dike lying in the east wall. About 250 feet north of the shaft the dike is offset about 15 feet at a cross fissure. While this cross fissure may possibly be a fault, of later age than the dike, close examination rather indicates that this offset of the north-south fissure existed before the intrusion of the basalt. The general relations of the "basalt" dike to the phonolite dikes and to the Strong lode on level 5 are shown in Pl. V (p. 26). On level 6 the "basalt" is first seen about 250 feet north of the shaft and is thence followed northward by the main drift. About 450 feet north of the shaft the main phonolite dike appears, and from here to the north end of the level both dikes run together, the "basalt" cutting across from one side to the other of the phonolite. A similar relation between the two dikes exists also on level 7. On level 8 the dike is drifted on about 50 feet east of the shaft, and appears again in the northern part of the level, where it accompanies the phonolite dike. On level 9 also the basic dike lies 40 or 50 feet east of the shaft, but about 100 feet north of the shaft it turns nearly north-northwest, running about 100 feet southwest of and nearly parallel with the phonolite cross dike. This is probably an offshoot from the main dike along some branch fissure; in which case further development on and below level 9 will discover another "basalt"-filled fissure more nearly in the general north-south line of the dike as known on the upper levels.

FORM AND STRUCTURE OF THE ORE BODIES.

All of the Strong ore occurs in the form of lodes or veins and most of it within two pay shoots in the main Strong lode. One of these pay shoots near the shaft is known as the south shoot and is separated from the north shoot on all levels by a greater or less interval of barren ground.

The south pay shoot has been stoped almost from the surface to level 9. It attains its maximum length (about 550 feet) on level 3. On all levels above the eighth this ore body extends both north and south of the shaft, lying chiefly, however, on the north side. Practically no ore has been found south of the shaft on levels 8 and 9. As no stope maps are kept, the shape of this pay shoot can only be surmised from what is visible in the drifts. It appears to be on the whole nearly vertical, tapering irregularly almost to a point on level 9. It is essentially a mineralized sheeted zone in granite. On level 1, however, the main phonolite dike forms the east wall of the lode. On level 5 the lode and the basic dike are coincident for nearly 300 feet. The ore, however, occurs entirely within the granite, alongside the dike, the latter being waste. On levels 6, 7, and 8 neither phonolite nor "basalt" occurs with the ore.

As no work was being done on the south pay shoot at the time of visit the mode of occurrence of this ore could not be satisfactorily studied. The pay shoot is said to have been rather narrow, but richer on the whole than the north shoot. There were no definite walls to the ore, which passed through low-grade ore into the granitic country rock. The lode appears to have been intermediate in character between those like the Dorothy of the Gold Coin mine, where the value is practically confined to the actual fissures, and those like the Diamond of the Portland mine, where the metasomatically altered granite between the fissures is also ore.

The north pay shoot apparently first becomes of importance near level 4, though a small chimney-like body of ore is said to have extended from the south end of the pay shoot up to level 2. On levels 5 and 6 the north pay shoot is respectively 200 and 400 feet long and is typically developed. The main phonolite dike, about 7 feet wide, is here closely followed by the basic dike. The latter lies usually on the west side of the phonolite, sometimes in contact, but frequently separated by a few feet of granite. At one place on level 6 the "basalt" cuts across to the east side of the phonolite, follows the east contact for about 125 feet, and then again crosses the phonolite to the west side. The ore closely follows the "basalt," which, however, is itself of no value. The phonolite dike also appears to have influenced in some way the ore deposition, for it is noticeable that the ore very rarely accompanies the basic dike when it diverges for any considerable distance from the phonolite. The ore occurs almost wholly in the granite. Where the two dikes are in contact, side by side, the "basalt" constitutes a definite wall, limiting on one side ore which on the other sides grades indefinitely into the granite. Where the two dikes are not in contact, the intervening slab of granite is usually mineralized and constitutes ore. Such ore has two definite walls—the phonolite dike on the one side and the basic dike on the other. The latter dike at such places thus has ore on both sides. The cases where the phonolite is sufficiently mineralized to be ore

are usually at those points where the "basalt" cuts across the phonolite. On level 9, at the time of visit, the north ore shoot had been found and had been drifted on for about 200 feet. Stoping had not begun, however, on this level.

The mineralization of the granite in the north pay shoot is not related to such distinct parallel sheeting as is observable in the south pay shoot. The ore-depositing solutions apparently worked outward from the narrow channels furnished by the platy partings and contact planes of the dikes and took advantage of such small irregular cracks and joints as existed in the granite. The granitic ore is usually rather spongy in texture, closely resembling that from the Diamond lode in the Portland mine or from the large southwest stope in the Ajax mine. Contrary to the practice in most of the mines in the district, very little assaying is done in the Strong mine, the ore usually being readily distinguished from the country granite by its color and greater porosity.

CHARACTER OF ORE.

The ore of the Strong mine is almost entirely metasomatically altered granite. Rounded residual kernels of the original pink microcline of the granite remain, but the quartz and biotite have been completely changed to a porous aggregate of adularia, quartz, fluorite, pyrite, and calaverite. The adularia is easily distinguishable under the microscope from the original microcline by its greater clearness and frequent sharply automorphic outline. The secondary feldspar is often optically continuous with an older individual of microcline, the two being separated by a sharp sinuous line. The tiny crystals of adularia are rarely optically homogeneous, but appear to be built up of wedge-like or sector-shaped portions that extinguish at slightly different angles, and produce an optical effect similar to that often observed in thin sections of vein quartz and illustrated in the quartz of this same ore. The quartz in the Strong ore occurs in allotriomorphic grains crystallized with the secondary feldspar and as a crystalline film lining the little irregular vugs of the porous altered granite. Fluorite is not very abundant in the ore; it occurs usually as little implanted crystals in the vugs or in minute fissures in the original microcline. Pyrite occurs abundantly disseminated in minute crystals through the secondary minerals of the ore, and these crystals are sometimes gathered into little nests or bunches. Calayerite seems to closely accompany the pyrite and occurs in such minute particles that it can rarely be detected or distinguished from the pyrite even with a hand lens. No oxidized ore is now worked in the Strong mine.

UNDERGROUND WATER.

According to an estimate made by Mr. V. G. Hills,[a] in July, 1903, the water level in the Strong mine, were pumping discontinued, would stand at 8,984 feet above sea level, or 771.99 feet below the collar of the shaft. At that time, however, it was kept down by pumping to 8,872 feet, or 883.99 feet below the collar. The water was held at this point and level 9 kept open by pumping about 500 gallons a minute. In April, 1904, this amount had decreased to 330 gallons. The greater part of this water comes from the northern part of level 9. No data exist

[a] Ninth Ann. Rept. Portland Gold Mining Company, 1903, p. 87.

for determining the original water level of the mine. The height to which the water rises when pumping is stopped has slowly decreased since the shaft was sunk to its present depth.

GRANITE MINE.

INTRODUCTION.

The Granite mine, owned by the Granite Gold Mining Company, of Denver, capital $1,000,000, is situated on the northern edge of Victor, between the Portland and Monument mines on the east and the Ajax, Dead Pine, and Gold Coin mines on the west. The workings are embraced within the generally north-south Granite claim. The mine is operated under the leasing system.

PRODUCTION.

The Granite mine is credited with a gross production of $400,000 prior to January 1, 1900. We have been unable to secure any later statistics.

UNDERGROUND DEVELOPMENT.

The main shaft, 1,000 feet in depth, is situated on the eastern edge of the claim, 250 feet from the northeast corner. The first level below the collar of the shaft is the so-called level 5, 445 feet below the surface. Level 6 is 150 feet below level 5. Then follow levels 7, 8, and 9, 100 feet apart, and finally level 10, 80 feet below level 9. The workings lie mainly south of the shaft, comprising on most levels a main north-south drift, reached by a westerly crosscut from the shaft, and various spur and parallel drifts with their connecting crosscuts. Level 6 is the most extensive, connecting on the west with the Dead Pine mine and on the east with the Portland mine. A drift on this level also passes under the Monument shaft. About 380 feet from the south end of the claim is the South shaft, about 200 feet deep, connecting with three short levels. These were not visited.

LODE SYSTEMS.

In the Granite, as in the Monument and Dillon mines, two prevalent systems of fissures are recognizable, one set striking nearly north, while the other set strikes nearly northwest. The most prominent of the nearly north-south fissure zones is the Granite lode, striking N. 8° E. This lode varies in dip on the different levels, but on the whole is nearly vertical. West of the Granite, at a distance near the middle of the claim of about 100 feet, is the West lode, striking in general due north and also approximately vertical. About 50 feet east of the Granite is the East lode, striking N. 5° E. This fissure zone has been drifted only on level 9, but, like the others, seems to be about vertical. On level 10 a fourth fissure zone, striking north, has been followed between the Granite and West lodes.

The most prominent northwest fissure zone is the Bobtail—clearly the same lode as the Bobtail of the Portland mine. It dips about 60° SW. On level 5 the Bobtail crosses at the shaft. On level 6 it lies about 90 feet and on level 7 about 130 feet southwest of the shaft. On levels 8, 9, and 10 the Bobtail is supposed by those

working the mine to cross the main drift close to the granite-breccia contact, about 150 feet southwest of the shaft. No work, however, has been done on the supposed Bobtail on these levels, and it is probable that the Bobtail lode, elsewhere unusually regular and persistent, instead of turning practically vertical, maintains its characteristic southwest dip and passes into the granite, as in the Portland mine. If so, it may be represented on level 10 by a strong fissure, dipping southwest, which is cut in the main drift 250 feet south of the shaft crosscut.

Southwest of the Bobtail is the Cross lode, striking northwest, and cut by the main drift on level 5 about 300 feet south of the shaft. If the fissure zones known on the different levels as the Cross vein are really all portions of the same lode, that lode exhibits rather notable changes in dip. Between levels 5 and 6 it is vertical. Between levels 6 and 7 it dips about 75° NE., while between levels 9 and 10 the dip is about 65° SW. As there are no continuous stopes on the Cross lode below level 6 it is not improbable that different fissures, having generally a common northwest strike, have been erroneously identified as the Cross lode. It frequently occurs in this part of the district that a narrow sheeted zone in granite, after being followed for a few hundred feet, becomes very indistinct, while a neighboring fissure zone of approximately parallel strike becomes correspondingly more regular and conspicuous. On level 5 the Cross vein apparently has no continuation northwest of the Granite lode. On level 6, however, a small northwest fissure zone runs off from the west side of the Granite lode about 40 feet north of the point where the Cross lode comes in on the east side. It is not clear whether the Cross lode follows the Granite lode for 40 feet before resuming its northwest course or whether the two northwest sheeted zones are really distinct. It is not likely that the offset of 40 feet is due to faulting of the Cross by the Granite lode, for the latter zone of sheeting does not perceptibly fault the granite-breccia contact just north of this point. On level 7 the Cross lode is known only on the east side of the Granite lode, and on level 8 it does not appear to have been recognized. On levels 9 and 10 the Cross lode is fairly distinct and extends across both the Granite and the West lodes. These facts lend additional support to the view that the Cross vein, so called, above level 7 is not identical with the Cross lode of levels 9 and 10.

There is still a third northwest sheeted zone which has been followed on level 6 in a drift north of the shaft and 40 feet northeast of the Bobtail. It dips 70° SW.

GEOLOGICAL FEATURES.

While the Granite mine is chiefly in the familiar porphyritic granite exposed about Victor, the north end of the mine, including the entire shaft, is in breccia. The granite-breccia contact is cut in the main drift at distances ranging from 120 to 225 feet south from the shaft. The rocks for several feet on each side of the contact are usually rather decomposed and show considerable oxidation, even on level 10. The general strike of the contact seems to vary from northwest to west, but, as there are no drifts on it, this point can not be accurately determined. The general dip is northerly, at about 80°. The contact surface, however, is evidently very irregular, and there may be local southerly dips between levels 6 and 7 and between levels 9 and 10.

West of the shaft, along the western edge of the claim, a mass of latite-phonolite is exposed in the crosscut and drift connecting with the Dead Pine mine. This is undoubtedly the same intrusion as that in the northeastern part of the Dead Pine, noted on page 485. Its form is unknown, as its contact with the breccia is exposed at only one point, on level 6, and is there greatly obscured by alteration and pyritic mineralization.

The granite is cut by several very irregular dikes and sills of phonolite—often mere bunches which can not be followed for any great distance, though if completely explored they would probably be found to connect with small dikes below. At the south end of level 10, about 900 feet south of the shaft, is a generally east-west dike which is probably continuous with the east-west dikes of the Dillon and Dead Pine mines. This dike varies in width from 10 to 30 feet, and is here apparently nearly vertical. On its north side it connects with a thick sill-like mass, apparently of no great horizontal extent. This sill dips gently south. It lies in the general line of the Granite lode and contains an ore body which will presently be described. On the same level, about 450 feet south of the shaft, in the vicinity of the Cross lode, is another mass of phonolite, lying along the eastern side of the Granite lode. This is about 40 feet wide and is apparently a north-south dike. It may continue southward and join the sill just described, but the intervening ground is unexplored. Toward the north it seems to contract in width and is probably represented by a dike about 7 feet wide, which crosses the main drift with a northwesterly course about 100 feet south of the shaft. On the levels above the tenth a few irregular bunches of phonolite have been discovered in following the lodes, but no regular or persistent dike is known.

The same basic dike known in the Monument and Dillon mines (pp. 475, 476) continues through the Granite with a general course of N. 20° W. It passes on all levels about 150 feet southwest of the shaft and meets the Bobtail lode, the line of junction pitching southeast. On level 6 dike and lode run together for about 50 feet before they diverge and the dike resumes its usual more northerly course. Where the "basalt" and the Bobtail are together the dike has the usual dip of the lode, about 60° to the southwest. This is either a remarkable coincidence or else the Bobtail fissure existed prior to the basic intrusion. The lowest dip exhibited by the dike elsewhere on this level is 70°, also to the west. On the whole, however, it is practically vertical, as shown by its relative positions on successive levels. The dike suffers no apparent deflection in passing from the granite into the breccia.

CHARACTER OF ORE.

The ore of the Granite mine is in part metasomatically altered granite similar to that described in the Ajax and Portland mines. The best ore being mined at the time of visit, however, occurred in phonolite, as little stringers rarely over half an inch in width, consisting of quartz, fluorite, rather abundant pyrite and sphalerite, with calaverite and a little molybdenite. A vuggy structure is common, many of the little projecting crystals of quartz, fluorite, pyrite, and calaverite being coated with chalcedony. The phonolite in the vicinity of the veinlets contains

nests of fluorite and abundant finely disseminated pyrite. The gold, however, is apparently limited to the veinlets.

The microscope shows that the molybdenite occurs as a coating or envelope about crystals of pyrite. The principal alteration of the phonolite in the vein walls consists in the complete change of the pyroxene or amphibole to aggregates of pyrite, apatite, and an obscure yellowish-brown material resembling limonite. The feldspathic constituents of the phonolite are partly sericitized.

FORM AND STRUCTURE OF THE ORE BODIES.

Nearly all of the ore thus far discovered lies south of the granite-breccia contact. A little ore, it is true, has been stoped from the Bobtail for a distance of 150 feet southeast of the point where the lode meets the basalt dike, but it was of low grade. The lode lying northeast of the Bobtail, on the same level, is a well-defined sheeted zone carrying much fluorite and pyrite but no ore. Within the granite the ore occurs as lodes along sheeted zones, particularly where these cut or follow phonolite dikes and as irregular bunches at the intersections of fissures.

The principal pay shoot is on the Granite lode. Although not continuously stoped, this pay shoot may be considered as extending from a point about 100 feet above level 5 down to level 9. Below level 9 the ore apparently left the Granite sheeted zone and followed a branch or intersecting lode, with a westerly dip of about 60°. On level 10 the same lode lies between the Granite and West lodes. Owing to its relatively flat westerly dip, it joins the Granite lode between levels 9 and 10.

The main Granite pay shoot reaches its greatest development between levels 6 and 7, with a maximum length of about 350 feet. Above level 7 the general pitch of the pay shoot is northerly, while below this level it is southerly. Seen in longitudinal section the ore body is rudely crescentic in outline, with the horns of the crescent turned south. Above level 8 the ore is said to have terminated northward at the granite-breccia contact.

While the Granite lode is generally a narrow sheeted zone of the usual type, at certain points the ore has been stoped to widths of 30 or 40 feet. On level 6 the widest ore occurred close to the contact of the granite with the breccia, where some additional fissures join the Granite lode from the north-northwest. On level 7 the largest body was at the intersection of the Granite and Cross lodes, the ore narrowing from a maximum width of 40 feet at the Cross lode to a few inches near the contact. In all cases unusual width of ore in the Granite lode is associated with the intersection or junction of the main lode with minor fissures. Bodies of good ore frequently occur where the sheeted zone cuts through a mass of phonolite, as on level 9, about 400 feet south of the shaft.

At the time of visit most of the ore was coming from the southern part of level 10, where a north-south sheeted zone which may prove to be the continuation of either the Granite or the East lode traverses the irregular sill-like offshoot from the east-west phonolite dike. This ore is from 8 to 9 feet in width. The lode consists of two small, approximately parallel vuggy veinlets of quartz, about 8 feet apart. Between these the phonolite is rather irregularly fractured and seamed with minute stringers of quartz and fluorite. The value of the ore lies in these

major and minor veinlets, which carry sylvanite or calaverite, associated with pyrite and a little sphalerite. The tellurides are not always visible. They occur most abundantly in the two main fissures. More or less pyrite occurs disseminated through the rock of the lode and as small stringers and bunches. It is said to contain no gold. This ore body was of comparatively recent discovery at the time of visit, and had been stoped for a length of only 25 or 30 feet.

The west lode on levels 6 and 7 is a barren sheeted zone in granite. On level 8, however, a good body of ore has been stoped from this lode for a length of about 150 feet. The best ore occurred in the northern part of the pay shoot, where some phonolite occurs in the line of fissuring. At the north end of the shoot several minor fissures intersect the main lode and are accompanied by a local widening of the ore. Similar ore bunches occur on levels 9 and 10, where the West and Cross lodes intersect.

The Cross vein contained a body of ore lying chiefly on the southeast side of the junction of this lode with the granite lode and extending from level 6 to a point about 40 feet above level 5. The maximum length of this pay shoot was about 150 feet. A small body of ore has also been stoped on level 10 from the Cross lode for a short distance on each side of its intersection with the West lode.

UNDERGROUND WATER.

While the original water level in the Granite was probably, as in the Portland, at about 9,452 feet above sea, or 688 feet below the collar of the shaft, the mine has been drained by the deeper workings in the vicinity and is now dry.

MONUMENT MINE.

INTRODUCTION.

The Monument mine, owned by the Monument Gold Mining Company, of Colorado Springs, capital, $300,000, adjoins the Dillon on the north. It, too, is a small mine, the underground workings being confined to the narrow and very irregular area in the Monument claim that is not covered by older locations. It is almost completely inclosed by the Granite claim on the west, the Portland property on the north and east, and the Dillon claim on the south. The company was incorporated in 1898 and has operated the mine under the leasing system.

UNDERGROUND DEVELOPMENT.

Access to the mine is through a vertical shaft about 550 feet in depth. There are six levels at various distances apart.

LODE SYSTEMS.

As in the Dillon, there are a number of narrow sheeted zones of no great width or persistency. The Monument lode lies west of the shaft and runs nearly due north and south. It dips about 80° E. About 150 feet north of the shaft it is joined on the east side by the Kurtz vein, which strikes northwest and dips about

70° SW. Neither lode has been followed for more than a few feet north of the junction. About 200 feet south-southwest from the shaft, near the northwest corner of the Dillon claim, is the Par Value vein, which strikes N. 8° W. and intersects the Stonehouse lode. In general there are in the mine two intersecting sets of fissure zones, one striking a few degrees west of north, represented by the Monument and Par Value lodes, and one striking nearly northwest, represented by the Kurtz and Stonehouse lodes. The Kurtz lode has not been identified below the 285-foot level.

GEOLOGICAL FEATURES.

The general country rock of the Monument is the same granite that occurs in the Dillon and Strong mines. The same "basalt" dike noted in the Dillon (p. 477) passes through the Monument workings west of the shaft, running nearly parallel with the Monument lode. No phonolite dikes were noted in the workings, but the dike which occurs in the Dillon east of the shaft (p. 477) may, perhaps, be cut in the eastern part of the 309-foot Monument level. No attempt was made to determine this point at the time of visit.

FORM AND STRUCTURE OF THE ORE BODIES.

The ore of the Monument occurs as short pay shoots in bodies which are structurally narrow mineralized sheeted zones in the granite. The sheeted zone of the Monument vein is from 3 to 4 feet wide, but has produced very little ore. The Kurtz lode, however, which is similar in structure, contains good ore above the 285-foot level and has been stoped for a length of 125 feet on the 207-foot level. It is noteworthy that very little ore has been found at the junction of the Kurtz and Monument lodes, the ore on the Kurtz usually beginning a few feet away from the Monument. The Kurtz pay shoot is the longest known in the mine. On the 475-foot level a narrow pay shoot has been stoped for about 100 feet on a sheeted zone which lies 70 feet west of the shaft between the Monument and Par Value lodes and strikes N. 17° W. This zone of fissuring is apparently not known on the level above. Near the south end of this same level another pay shoot occurs in the Par Value lode, extending north and south for 20 to 25 feet from the intersection of this lode by the Stonehouse.

CHARACTER OF ORE.

There was no opportunity at the time of visit for studying typical exposures of the ore. Although no good specimens were seen, the original ore probably consists of sylvanite or calaverite deposited in the crevices of the fissure zones. It is usually more or less oxidized.

DILLON MINE.

INTRODUCTION.

The Dillon is a small mine situated near the northeastern limit of the town of Victor. The Dillon claim lies immediately west of the Strong and east of the Granite claim. It is cut into by some of the older claims of the Portland company, par-

ticularly by the Black Diamond, which divides it into north and south portions. The underground workings are all in the irregular fractional part of the claim lying north of the Black Diamond. The mine is worked by lessees.

UNDERGROUND DEVELOPMENT.

The Dillon workings comprise a vertical shaft about 800 feet in depth, with eight short levels. The main drifts, as a rule, run a little west of north and east of south. The longest drift is about 450 feet, on level 8, which has been run southward into the Black Diamond claim.

LODE SYSTEMS.

There is no dominant or persistent lode known in the Dillon mine, unless a phonolite dike east of the shaft, which carries bunches of ore, may be so called. The chief characteristic of the mine is a number of short, nearly vertical sheeted zones in granite, ranging in strike from north to northeast and carrying bunches of ore at their intersections or junctions. In this respect the mine resembles the Abe Lincoln. (See p. 277.) There are at least four of these sheeted zones exposed in the northwestern part of level 3. The westernmost, known as the Stonehouse vein, strikes northwest, seems rather more persistent than the others, and is known in the Monument mine.

GEOLOGICAL FEATURES.

The general country rock of the Dillon is the familiar porphyritic granite of this vicinity, cut by dikes of phonolite and basalt. One phonolite dike striking about N. 15° W., and with variable but, on the whole, nearly vertical dip, lies about 75 feet east of the shaft. The width of this dike varies from 6 to 8 feet. There is also an east-west dike with northerly dip, lying south of the shaft and well exposed on level 7. This is very probably the same phonolite dike known in the southern parts of the Granite and Dead Pine mines. (See pp. 472 and 485.)

The Dillon shaft was sunk on a basalt dike which strikes N. 20° W. The dike, on the whole, is about vertical, though on some of the levels it lies as much as 10 feet on one side or the other of the shaft. It is usually from 2 to 3 feet in width and is soft and decomposed.

FORM AND STRUCTURE OF THE ORE BODIES.

The ore of the Dillon occurs in irregular bunches in and alongside the phonolite dike east of the shaft and in the short sheeted zones in the granite of the northwestern part of the mine. The ore occurs chiefly in bunches at the intersections of these lodes, and has been found mainly above level 3. The ore associated with the phonolite dike does not apparently follow any very distinct sheeted zone, but occurs at points where local irregular fracturing has provided spaces in the phonolite or adjacent granite for the deposition of tellurides.

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AJAX MINE.

INTRODUCTION.

The Ajax mine is on the south slope of Battle Mountain, just north of and overlooking the town of Victor. It is owned by the Ajax Gold Mining Company, of Denver, capitalized at $1,500,000, and embraces the Apex, Monarch, Mammoth, Pearl, Champion, June Blizzard, Victor Consolidated, Victor Consolidated No. 2, Hallett & Hamburg, Necessity, Orpha Nell, Jolly Tar, Lucky Dick, and Gee Mima claims. Operations were begun in 1895 and have been continued steadily to date. Like the Portland, it is situated on the contact between the granite and the volcanic breccia and has extensive workings in both rocks (Pl. V, p. 26). On the northeast the Ajax ground adjoins the Portland and on the east and southeast the Dead Pine property. The mine is well equipped and employs about 140 men. Statistics of production and dividends are not obtainable.

UNDERGROUND DEVELOPMENT.

The main Ajax shaft, 1,228 feet in depth, is situated near the southern edge of the property. The collar is in breccia, but the shaft enters the granite between levels 1 and 2 and continues in that rock to the bottom. Connected with this shaft are eleven main levels, which, with the exception of levels 4 and 5, are about 100 feet apart. Level 1 is about 125 feet below the collar of the shaft, and level 5 is about 75 feet below level 4. In April, 1904, the drifts and crosscuts on all levels had a total length of 36,143 feet, and the stopes a total volume of 2,020,669 cubic feet. The more important workings fall into two main groups—a very irregular maze of drifts and stopes in the granite, mostly southwest of the shaft, and a series of linear drifts and stopes along two principal fissure zones in the breccia north of the shaft. The latter workings pass under the western part of Battle Mountain and connect on level 5 with the Battle Mountain tunnel opening into Arequa Gulch, between Eclipse and the Economic mill. Level 1 also connects with a long adit called the Ithaca tunnel, which has its portal about 500 feet southwest of the Ajax shaft, in the gulch between Squaw and Battle mountains.

LODE SYSTEMS.

The dominant fissure zones in the Ajax mine strike about N. 30° W., running generally parallel with a number of phonolite dikes. Fissures and dikes dip southwest, as a rule, at angles near 70°. The principal lode is the Apex, which should outcrop along a line connecting the McKay shaft, near the northwest corner of the Dead Pine claim, with the Victor Consolidated shaft, near the north end of the claim of the same name. The Apex lode accompanies a phonolite dike and dips southwest at an average angle of 72°.

About 400 feet northeast of the Apex vein is a second zone of nearly northwest-southeast fissures which have produced some ore and are supposed to represent the northwesterly continuation of what is known as the Bobtail vein in the Granite

and Portland mines. (See Pl. V, p. 26.) The fissures of this second zone, which may conveniently be distinguished as the northeast fissure zone, dip generally to the southwest, but in one or two cases exhibit northeasterly dips. Between these two main fissure zones occur some hitherto less important lodes ranging in strike from north-south to northwest-southeast. These intermediate lodes have not been followed for long distances nor shown to contain large ore bodies.

Lying immediately southwest of the main shaft is a third group of fissures, also striking about N. 30° W., forming a zone from 300 to 400 feet in width. These fissures dip generally to the southwest at angles ranging from 60° to 80°. They occur for the most part in granite, just south of the granite-breccia contact, and are not persistent, rarely maintaining distinct character for more than 250 feet in length. These fissures may collectively be designated the southwest zone.

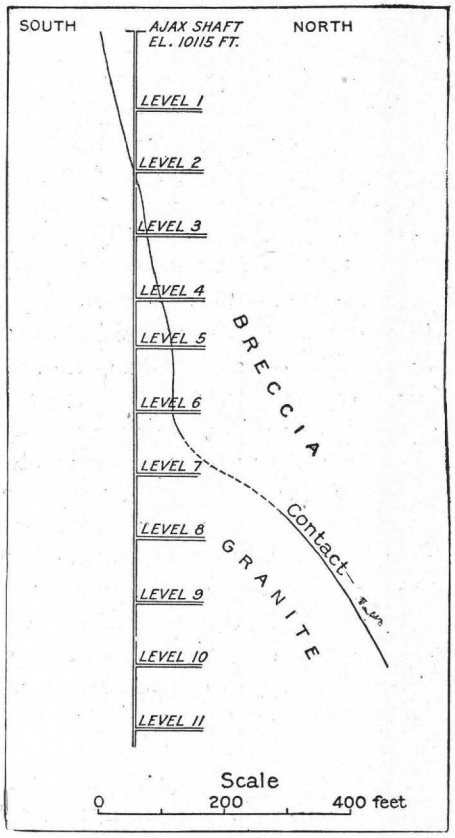

FIG. 63.—North-south section through the Ajax shaft, showing the dip of the granite-breccia contact.

GEOLOGICAL FEATURES.

With the exception that latite-phonolite has not, so far as known, been encountered in the Ajax workings, the rocks of the mine are similar to those in the Portland.

The main contact between the granite and the volcanic breccia of Battle Mountain is well exposed on nearly all the levels and has in many places been drifted on for considerable distances. It is prevailingly steep, dipping north or northeast at angles ranging usually from 45° to 85°. The average dip is probably between 70° and 75°. Near the shaft, particularly in the upper levels, the contact runs nearly east and west. But, as is shown on Pls. II (in pocket) and V (p. 26), the Ajax shaft is situated in an embayment in the granite between the Portland promontory (see p. 27) on the east and the northward turn of the contact, which carries it through the saddle between Squaw and Battle mountains, on the west. This northerly turn is noticeable on all of the Ajax workings that have followed the contact far enough to the west and is particularly conspicuous on the lower levels. A north-south section through the Ajax shaft showing the steep dip of the contact is given in fig. 63. The apparent flatter dip below level 6 is partly real and partly due to the obliquity of this part of the contact to the plane of the section.

The character of the contact between the granite and breccia, when examined in detail, is found to be similar to that described in the Portland. The breccia, containing abundant fine granitic detritus, fits snugly against a wall of granite, which is far too irregular to afford any ground for considering it a fault plane. As in the Portland, blocks of granite from 2 to 3 feet in diameter are sometimes found in the breccia at a distance of 100 feet or more from the granite in place. The contact is usually sharp and definite, though, on account of the granite fragments in the breccia, it is not always conspicuous. The granite close to the breccia is seldom brecciated, though sometimes considerably jointed and occasionally shattered.

A basaltic dike, usually from 2 to 4 feet wide, with steep westerly dip, runs nearly north and south through the Ajax workings, and is conspicuous on all the levels. Above level 3 this dike is practically at the shaft, while on level 10 it passes about 100 feet west. It has undergone the usual decomposition and exhibits the platy parting parallel to the walls that characterizes the basaltic dikes of the district. It cuts squarely across the contact between the granite and the breccia without being deflected from its course. While it may practically be considered a single dike, like others of its type in the district, it sometimes pinches and is succeeded by a second dike lying a few feet to one side or the other of the first, and increasing in width as the latter decreases. No ore occurs in the Ajax basaltic dike.

Many phonolite dikes are encountered in the Ajax, cutting both the granite and the breccia. In petrographical character, alteration, and structure they are in every way similar to the phonolite dikes of the Portland and other mines in the vicinity. They are often exceedingly variable in form, now narrowing or pinching out entirely and now branching, widening into irregular masses, or connecting with nearly horizontal sheets or sills. Such phonolite dikes as cross the granite-breccia contact frequently send off irregular apophyses or branches between the granite and the breccia. Most of the dikes, like the lodes, have general northwesterly strikes, but some with northeasterly strikes occur in the granite. A few only of the phonolite dikes require special mention on account of their relation to the ore bodies. One of these is the Apex dike, which accompanies the Apex lode and continues in a southeasterly direction into the Dead Pine mine, where it is known as the Montana dike. This dike, as seen in the Ajax, usually varies in width from 4 to 15 feet, and like others of its class is branching and irregular. It forms the hanging wall of the productive part of the Apex lode, but in the Ajax mine is not accompanied by any important ore bodies along that part of its course which lies in the granite. In the Dead Pine and Gold Coin mines, however, it becomes economically important.

In the granite southwest of the main shaft are some phonolite dikes of general northeasterly trend which are related to the large ore bodies of this part of the mine. One of these, running almost due southwest from the shaft and dipping about 60° NW., is well exposed on level 7, where it is in part mineralized and has been stoped in places to a width of 6 or 7 feet. Another smaller dike lying northwest of the last and nearly parallel in strike, but with steeper dip, is shown on level 6 passing longitudinally through the great southwest stope in the granite. Possibly there are still other dikes comprised in this northeast-southwest zone, but the irregularity of the phonolite intrusions and the height of the untimbered stopes preclude the detailed tracing out of every dike that may be present.

On level 4, about 50 feet east of the Ajax shaft, is a north-south phonolite dike which forms practically the eastern boundary of a large ore body in granite. The same dike also forms the eastern boundary of another ore body lying under the one just referred to, or on level 5.

FORM AND STRUCTURE OF THE ORE BODIES.

The greater part of the ore of the Ajax mine is in the granite, occurring, as a metasomatically altered and mineralized form of that rock, in large very irregular bodies between levels 3 and 8. One of these bodies, on level 4, lies about 100 feet northeast of the shaft and has been stoped from north to south for a length of about 60 feet. Its width is about 30 feet. The ore lies mainly on the west side of a north-south phonolite dike and is practically bounded on the north by the granite-breccia contact. The altered, mineralized granite which constitutes the ore was irregularly fissured prior to mineralization, the dominant fissures running generally parallel with the phonolite dike. The ore body ends abruptly on the south, not against any discoverable fissure, but by a rather rapid change from mineralized to unaltered granite. A few irregular fissures continue southward from the ore body into this granite. This large ore body has been stoped upward for 50 feet or more, but does not appear at all on the level above. Neither does this ore body continue below level 4, though another similar body does occur on that level nearly under the stope just described. The two masses of ore are separated by barren granite.

On level 5 the main ore body occurs a little farther west, the shaft penetrating its western part. The same phonolite dike noted above here also limits the ore on the east, while on all other sides the ore passes irregularly through mineralized granite into unaltered country rock. This ore body continues with a southwesterly pitch down to a point about half-way between levels 5 and 6, where the ore ends near the east side of the basic dike. A short distance west of this dike, however, a third ore body was found which on level 6 is rudely elliptical in plan, with its major diameter lying north-northeast and south-southwest. The length of this ore body on this level is about 150 feet, and its width about 25 feet. It pitches southwest and has been stoped to level 7, where it has a length of about 100 feet and a maximum width of about 50 feet. Below level 7 the large irregular mass of ore divides into smaller bodies, which though of variable width are so closely related to distinct zones of fissuring as to be practically lodes. These lodes will presently be referred to again.

The great ore bodies in the granite thus occur in a northeast-southwest zone passing through the Ajax shaft. Their aggregate length is about 400 feet and their vertical range about the same. They pitch generally to the southwest, so that the highest bodies occur northeast of the shaft and the lowest bodies southwest of it. Below level 8 they are succeeded by narrower deposits of distinctly lode type.

The occurrence of these large bodies of ore is clearly related to the intersection of the two northeast-southwest phonolite dikes by the numerous northwest-southeast fissures, which has been referred to as the southwest zone, and it is probable that this relation is a genetic one and was largely effective in determining points of ore deposition within the granite.

The lodes in granite, constituting the southwest zone, may be regarded as relatively narrow lateral and downward extensions of the main ore bodies along the northwest-southeast fissure zones. These lodes are best developed on level 7, where at least three well-marked fissure zones, striking N. 38° W., contain ore to a maximum distance of about 150 feet northwest from the axis of the main ore body. They are rather irregular sheeted zones, usually exhibiting two principal parallel fissures 3 or 4 feet apart connected by numerous irregular fractures. The general dip is about 70° SW. The ore is usually about 4 feet wide and similar in character to much of that found in the large, irregular ore bodies just described. The lodes do not have definite walls, the ore passing more or less gradually into the granitic country rock. At their northwest ends the pay shoots grade into slightly mineralized granite containing little veinlets of pyrite. The fissuring in this direction becomes less regular and pronounced, and it is doubtful whether at a distance of 250 feet from the northeast-southwest phonolite dikes any of the lodes are sufficiently distinct to be recognized in crosscutting. On the southeast side of the large ore body these lodes are usually recognizable as rather irregular fissure zones, containing little stringers of pyrite. They are unimportant on this side of the main ore mass and do not contain ore for distances of more than a few feet from the latter. Thus practically all the ore in these lodes lies between two divergent vertical planes passing through the Ajax shaft, one of these planes striking southwest and the other west-southwest.

On levels 9 and 10, below the bottom of the large southwest ore body, some of these lodes have been drifted on, and two of them, probably the two easterly lodes known on level 7 as the B and C veins, have proved productive. Their value on level 11 is yet to be determined.

Those productive lodes of the Ajax that occur in breccia have no obvious relation to the granite-breccia contact, and none of the important breccia ore bodies are found in its immediate proximity. No ore is encountered in the Apex lode until a point is reached about 450 feet north of the Ajax shaft. Here an ore shoot begins which continues northwestward to the Triumph shaft. The maximum length of this pay shoot is 500 feet. Its vertical range is about the same, the ore ending just above level 4, though the Apex phonolite dike, accompanied by some fissuring, is known on lower levels.

The Apex vein is a sheeted zone in breccia, with an average width of 2 or 3 feet. Locally, however, as near an intermediate level about 125 feet below level 1, the ore has been stoped to a width of 56 feet. It strikes N. 30° W. and dips 72° SW. The Apex phonolite dike, here about 5 feet wide, usually forms the hanging wall of the lode, though in places breccia intervenes between the ore and the dike. In its wider parts the lode consists of a number of fissures with considerable barren country rock between them. The dominant fissures have the general strike and dip of the lode, but others are much less regular. Some, particularly where the ore is widest, branch off to the northeast from the main fissures and as they pass into the foot wall dip at decreasing angles until they are nearly horizontal.

Although the breccia in the vicinity of the lode is generally impregnated with pyrite, the ore value is nearly all if not completely in the small fissures, many of

them only a fraction of an inch in width, which collectively compose the pay shoot. The value of the ore thus lies chiefly in the screenings.

The various smaller lodes in the breccia, such as those of the northeast zone, present no structural features of sufficient interest to merit detailed description.

CHARACTER OF ORE.

The general types of ore are found in the Ajax mine, one consisting of metasomatically altered granite and the other of sheeted and veined breccia or phonolite.

The granitic ore has been the more important and is of the same general character as that found in the Portland, Strong, and Independence mines. Viewed at a little distance in the stope walls the ore does not appear very different from the unaltered granite and exhibits the usual conspicuous porphyritic structure due to the development of phenocrystic aggregates of pink microcline. Closer examination, however, shows that in the ore all the other principal constituents of the granite—namely, the quartz, mica, and oligoclase—have been altered to a porous aggregate of adularia, quartz, fluorite, and an obscure green mineral that is probably roscoelite, as the presence of vanadium is shown by chemical analysis. Pyrite occurs in all the secondary minerals and probably calaverite also, though this mineral is very difficult to distinguish from the pyrite, as it rarely occurs in large crystals. It is said to be sometimes visible in the ore, though none has been identified with certainty in the specimens collected. The biotite of the granite is the first mineral to undergo alteration and is transformed to aggregates of quartz, fluorite roscoelite, pyrite, and calaverite. The apatite and zircon of the rock appear to be unaffected by the metamorphism. The granitic ore is frequently traversed by veinlets filled with pyrite, which so far as known is not auriferous. Analyses of the comparatively unaltered granite and of a partly altered specimen constituting ore are given below. The two specimens were taken about 1 foot apart.

Chemical analyses of granite and ore from Ajax mine.

	I.	II.		I.	II.
SiO_2	66.20	59.58	SO_3	None.	None.
Al_2O_3	14.33	16.00	Cl	Trace.	(?)
Fe_2O_3	2.09	.30	F	(?)	[a] .69
FeO	1.93	.65	FeS_2	[b] .12	[c] 4.78
MgO	.89	.03	MnO	.13	Trace.
CaO	1.39	2.03	BaO	.18	.11
Na_2O	2.58	.98	SrO	Trace.	.01
K_2O	7.31	11.93	Li_2O	Trace.	Trace.
H_2O-	.48	.32	V_2O_3	.....	.39
H_2O+	.83	.81	MoO_3	.....	.01
TiO_2	.65	.75		99.74	99.95
ZrO_2	.02	(?)			
CO_2	.36	.26	Less O for F	.....	.29
P_2O_5	.25	.32		99.74	99.66

[a] 1.42 CaF_2. [b] 0.067 S. [c] 2.55 S.

The specimen of ore analyzed does not represent an extremely altered form of the granite, though the biotite is entirely gone. Gold is not estimated, inasmuch as even "2-ounce ore" would contain only 0.006 per cent of the precious metal. The occurrence of molybdenum in the ore is noteworthy, the mineral molybdenite being apparently almost invariably associated with the telluride ores. The bearing of these analyses upon the general subject of the metasomatic changes connected with ore deposition has been fully discussed on pages 193 to 195.

The ore of the breccia commonly occurs in minute veinlets, often showing comb structure, and consisting of quartz and fluorite, with pyrite and calaverite. Some of the veins contain abundant pyrite, but the abundance of this mineral seems to bear no discoverable relation to the richness of the ore.

The breccia in nearly all parts of the mine, often hundreds of feet from any known ore, is abundantly impregnated with pyrite in crystals up to a quarter of an inch in diameter. Whereas in the Portland mine the development of pyrite in the breccia is usually accompanied by the formation of dolomite, in the Ajax country rock the pyrite is associated chiefly with sericite. While it can not be said that there has been no carbonization of the breccia in the Ajax mine, yet none of the thin sections examined contain noticeable quantities of carbonates.

Oxidized ores are not a prominent feature in the Ajax mine. Even on the 125-foot level the oxidation is only partial and on the 400-foot level it is scarcely noticeable.

DEAD PINE MINE.

INTRODUCTION.

The Dead Pine mine, owned by the Ophir Mining and Milling Company, is situated on the south slope of Battle Mountain, between the Ajax and Gold Coin mines. The workings are confined to the Dead Pine claim, which runs about N. 6° E., following the general course of the northerly continuation of the Coin lode. In 1894 the Dead Pine was a mere prospect and received only casual mention in Penrose's report.[a] Between 1894 and 1896, however, an inclined shaft was sunk on the northern part of the claim and some rich ore stoped in the granite near the granite-breccia contact. Later the vertical Oliver shaft was put down and is now the main shaft of the mine.

UNDERGROUND DEVELOPMENT.

The Oliver shaft is situated 285 feet from the south end of the claim and is about 900 feet deep. It is connected with levels at 250, 525, 625, 725, and 825 feet below the collar. The old Dead Pine incline, 425 feet from the north end of the claim, follows the contact between the granite and the breccia, which dips 70° N. There are ten levels connected with this incline, approximately 50 feet apart. The old Dead Pine levels 5 and 9 are connected with the main 250-foot and 525-foot levels, respectively. At the south end of the property is another inclined shaft connecting with four levels. The second of these is continuous with the 250-foot level of the Oliver shaft and is the only level common to all three shafts.

[a] Mining geology of the Cripple Creek district, Colorado: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 209.

The main workings have a generally linear plan and extend longitudinally through the claim. Near the old Dead Pine incline, however, are two series of northwest-southeast drifts following short cross pay shoots.

LODE SYSTEMS.

The fissure zone known in the Gold Coin mine as the Coin vein has an average easterly dip at the Gold Coin and Dead Pine line of about 73°. At the Oliver shaft the average dip is about 82°. At a point 300 feet north of the Oliver shaft the lode is practically vertical, while north of that point the general dip becomes distinctly westward at an average angle between 80° and 90°. North of the old Dead Pine incline the fissure zone passes into the breccia, but becomes very small and obscure after leaving the granite.

In addition to this dominant zone of nearly north-south fissuring, there are in the northern part of the mine two zones of cross fissures. The more northerly of these zones has a general strike of N. 48° W. The more southerly zone, which intersects the main Dead Pine lode about 125 feet south of the other, has a general strike of N. 26° W. The two zones thus converge toward the Ajax ground. Both fissure zones dip to the southwest—the northern one at 70°, the southern one at angles ranging from 35° to 80°, the latter being the usual dip. The southern zone is known as the Montana vein and follows the curved and irregular course of the phonolite dike of the same name.

As the granite-breccia contact, which has locally a nearly east-west trend, dips to the north, while the northern fissure zone dips to the southwest, the two converge upward. The fissure zone, as a consequence of this convergence, meets the contact in the vicinity of the old level 8. If it persists above that level it should pass into the breccia, into which, however, it has not been followed.

There is no perceptible displacement of the lodes at the points where the main fissure zone and the cross fissures intersect.

GEOLOGICAL FEATURES.

All the ore of the Dead Pine mine occurs in granite or in dikes of phonolite cutting the granite. The contact between the granite and the breccia crosses the northern part of the workings in a nearly east-west direction and dips north at 70°. Its position is shown by the old Dead Pine incline, which follows the contact. The latter is fairly sharp and usually accompanied by some pyritization of the neighboring breccia. A few crosscuts have been run into the breccia without, however, the discovery of anything of value. The long crosscut on the 625-foot level to the northeast corner of the claim passes through breccia into massive latite-phonolite.

The granite of the Dead Pine is the same as that forming the principal country rock of the Gold Coin, Granite, and Strong mines and needs no further description.

The two principal phonolite dikes are the Montana dike and the East-West dike. The former is probably a continuation of the Montana dike of the Gold Coin mine and passes northwestward into the Ajax ground, where it is known as the Apex dike. It appears to divide as it crosses the Dead Pine and Ajax line, sending off a northerly branch toward the McKay shaft near the northwest corner of the

Dead Pine claim. The dike itself is so irregular, however, in the vicinity of the granite-breccia contact, and there are so many other small intrusions of phonolite in the granite, that it is impossible to trace its exact course without actually drifting on it. On the old level 8, for example, there is a small curved east-west dike, just south of the incline, which probably joins the Montana dike to the west, and 200 feet southwest of the incline is a nearly north-south dike which probably joins the Montana dike to the south. In the southern half of the Dead Pine claim the Montana dike has not been exposed, though it can not lie very far east of the main drift on the 825-foot level. It probably has here a nearly north-south course. North of the Oliver shaft it is visible on the 250-foot level in a crosscut 115 feet east of the main lode. From this point it swings northwestward, crossing the line of the main lode and continuing into Ajax ground. Its average dip in this part of its course is about 80° SW. The width of the Montana dike varies from 10 to 25 feet.

The East-West dike crosses the Dead Pine claim at the surface about 75 feet north of its south end line. It is usually about 10 feet wider and dips to the north at an angle of 65°. It is cut on the 250-foot level 170 feet south of the shaft, on the 525-foot level 50 feet south of the shaft, on the 625-foot level at the shaft, on the 725-foot level 65 feet north of the shaft, and on the 825-foot level 125 feet north of the shaft.

There are several other small phonolite dikes encountered in the mine, but they are less persistent and usually even more irregular than those described.

FORM AND STRUCTURE OF THE ORE BODIES.

The principal ore bodies thus far discussed have occurred in the northern part of the mine, near the old incline. One of these pay shoots is in the main fissure zone, between the Montana dike and the granite-breccia contact, and attains its maximum development on the old level 5, or 250-foot level of the Oliver shaft. This is a narrow sheeted zone in granite similar in character to the short lodes occurring in connection with the large southwest ore body of the Ajax mine. Another ore body has been stoped in the more northerly of the two cross lodes. This pay shoot begins just above the old level 8 and has been stoped down to the old level 10. On the old level 11, or the present 625-foot level, the ore becomes too narrow to stope. This ore body was rarely over 3 feet wide and probably nowhere more than 50 feet in length.

Between the 250-foot and 725-foot levels bunches of good ore occur on one or both sides of the Montana dike at the intersection of the dike of the main Dead Pine fissure zone (fig. 19). A few small bodies of ore have also been found at other points along the contacts of the Montana dike with the granite, but these have been of little importance.

No pay shoots have yet been found in the Dead Pine lode between the Montana dike and the East-West dike. Throughout this part of its course the lode is a well-defined sheeted zone in granite, occasionally passing through small, irregular dikes of phonolite. Some of these dikes have a general north-south course and are occasionally followed for a hundred feet or more by the fissure zone, as may be seen on

the 250-foot level. On most of the levels the fissuring is rather irregular near the point where the lode changes from an easterly to a westerly dip, but there is nothing to indicate any break in the general continuity of the Dead Pine lode.

South of the East-West dike a few small disconnected bunches of ore have been found in the Dead Pine lode on the 525-foot and 825-foot levels. Near the Gold Coin line the ore has been stoped to a maximum width of 5 feet and to a height of 40 feet above the 825-foot level. At this height the fissure zone shows considerable oxidation and no longer contains paying ore. Although the stopes of the Gold Coin come practically up to the Dead Pine line on nearly all levels, there is no sharp change in the character of the ore precisely at the line. The difference in development in the two mines merely indicates that the Gold Coin mine was able, in connection with its higher-grade ores, to carry its stopes into ore of somewhat lower grade than the Dead Pine mine can profitably handle.

CHARACTER OF ORE.

None of the ore formerly mined in the old north workings was seen at the time of visit. It contained tellurides from which the gold had been partly freed by oxidation. In its general character it probably differed in no essential degree from the ore found at the same depth in the granite of the Ajax mine. The ore of the 825-foot level occurs as a telluride—probably calaverite, with quartz and fluorite within the small fractures in the granite which accompany the dominant fissure of the lode. The vein minerals occur in the usual manner as a drusy incrustation on the walls of the narrow fractures. In the main fissure zone there is usually present a streak an inch or two wide, commonly termed "block quartz," which is used as an indicator in following the lode. This streak is chiefly finely crystalline quartz which apparently owes its dark line to the presence of minute crystals of pyrite. It sometimes has an open or cellular structure and may then contain calaverite, or, if partly oxidized, calaverite and free gold.

VALUE OF THE ORE.

Little could be learned at the time of visit of the range in value of the ore stoped in the northern and hitherto most productive part of the mine. Portions of the main lode on the 825-foot level contain as much as 2 ounces of gold to the ton, but the average tenor of the ore now stoped is probably below this. Ore worth less than $12 per ton can not at present be profitably handled.

GOLD COIN MINE.

INTRODUCTION.

The Gold Coin mine is owned by the Gold Coin Mining and Leasing Company, incorporated in 1895 with a capital of $1,000,000. It is situated in the town of Victor adjoining the south end of the Dead Pine mine, and includes the Gold Coin, Little Montana, Golden Discovery, and other claims. Its shaft house, built to replace one burned in 1897, is substantially constructed of brick, and is the best building of its kind in the district. The company also operates the Economic mill

in Eclipse Gulch, the ore and waste being all hauled by an electric locomotive through the Columbine tunnel, about three-fourths of a mile in length, which passes under Squaw Mountain and connects the mine and mill. Both ore and waste are hoisted to the surface and distributed to chutes which convey it to the bins on the tunnel level. The company began operations on the Gold Coin claim in 1895 and encountered ore the following year. The mine has since been producing steadily.

UNDERGROUND DEVELOPMENT.

The mine is worked through the Gold Coin vertical shaft, situated nearly in the center of the Gold Coin claim, and a little over 1,200 feet in depth. There are twelve main levels at rather irregular distances apart. Of these level 1 is now used merely as a connection with the Columbine tunnel, while level 2 was never of much importance, the stopes having been carried up continuously from level 3 to level 1. The important workings all lie north of an east-west line drawn 200 feet south of the shaft, and are of general linear plan, following the nearly north-south Coin vein. In addition to the main drifts on the Coin lode, there are some important series of divergent and parallel drifts, as will appear in the descriptions of the lode systems. Level 12 was under water at the time of visit. Several of the levels connect directly with the workings of the Dead Pine mine on the north. The shaft is in the foot wall of most of the lodes, which are reached on all levels by a main easterly crosscut. About 1,100 feet a little east of south from the Gold Coin shaft is the old Providence shaft, which connects with a long south drift on the Gold Coin level 6.

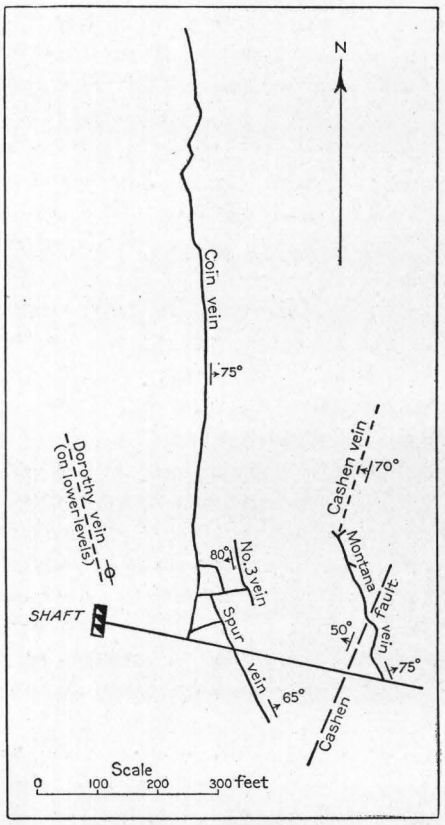

FIG. 64.—Plan of level 7, Gold Coin mine, showing vein system.

LODE SYSTEMS.

The principal lode (fig. 64) is the Coin, striking about N. 8° W., and dipping to the east. Near the shaft the average dip is about 83°, while near the north end of the mine this is reduced to 70°.

East of the Coin lode is the Montana lode, following the Montana phonolite dike. On level 5, at the latitude of the shaft, the Montana lode is about 240 feet east of the Coin lode. It has an easterly dip of about 74° and thus lies farther and farther east of the Coin on successive lower levels. The general strike of the Montana lode is

N. 20° W., in consequence of which it approaches the Coin lode toward the north, and, were this trend maintained, would meet it on level 5, near the old south incline on the Dead Pine claim.

In the angle between the Coin and Montana lodes are two lodes—one nearer the Montana, known as the No. 3 vein, and one nearer the Coin lode, variously known as the Parallel or Spur vein. The Spur vein has a general strike of N. 20° W., running about parallel with the Montana lode. The dip is northeast at an average angle of about 62.° This lode was first clearly recognized on level 4, where it lies only about 25 feet east of the Coin lode, to which it is locally nearly parallel. It was from this fact, before its general divergent relation was discerned, that it received the name of the Parallel vein. The Spur lode joins the Coin lode, the line of junction pitching north at an angle of about 50° from the horizon.

The No. 3 vein is a small lode with the same general strike as the Spur and Montana lodes. Its dip, however, unlike those fissures, is westerly, at an angle of nearly 80°. This lode is not distinct on level 5, but is known on levels 6, 7, and 8. Below level 8 the No. 3 lode joins the Spur vein.

West of the Coin lode and passing close to the shaft is the Dorothy lode, first recognizable on level 9 and continuing through all the lower levels. The Dorothy strikes N. 7° W., being thus essentially parallel with the Coin lode. The dip is practically vertical. Very little is known of the Dorothy lode south of the shaft. The development has been almost entirely northward.

The Cashen lode, the principal fissure zone of the Mary Cashen mine, comes into the Gold Coin ground, east-northeast of the shaft, on the eastern side of the Montana dike and has been worked from levels 6 and 7. It strikes about N. 18° E. and dips at an angle of 70° W. So far as known, the lode does not cross the Montana dike.

About 60 feet east of the Coin lode the main crosscut on level 4 passes through a closely spaced sheeted zone with steep easterly dip and nearly north-south strike. What is perhaps the same fissure is cut in an east crosscut about 400 feet south of the shaft and about 100 feet east of the south drift. At this point a strong stream of water issues from the fissure zone. In the northern part of the same level are several fissures lying east of the main Coin drift and perhaps representing the northward continuation of the fissure zone just described. One of these fissures at a point about 100 feet south of the Dead Pine line and 30 feet east of the main Coin drift has lately been found to contain a body of ore.

There is still another fissure zone in the Gold Coin mine, which, while it nowhere contains ore, appears to have had some influence on ore deposition. It has sometimes been called the Cashen vein, but is an entirely different fissure zone from the Cashen lode proper. As it shows unmistakable evidence of fault movement, it may be conveniently distinguished from the Cashen lode by referring to it as the Cashen fault. The general strike of this zone of fissuring is N. 20° E. It dips northwest at an average angle of 51°. On the fifth and higher levels the Cashen fault lies to the east of the present workings. On level 6 it is probably cut by the Montana dike, though no particular examination was made to determine this point at the time of visit. On the same level a long east crosscut south of the Providence shaft passes, about 75 feet from the drift, through a strong zone of fissuring which is probably

the Cashen fault. On level 7 the Cashen fault is well shown in the main east crosscut, about 60 feet west of the Montana dike, and may also be seen in the drift following the dike. Level 8 apparently does not go far enough east to cut the fault, but it shows on level 9 in the main east crosscut about 35 feet east of the Coin lode and also in the drifts on the Coin and Spur lodes. On level 10 the fault is cut in the main crosscut about 90 feet east of the shaft and also near the end of a west crosscut about 400 feet south of the shaft. At the latter place the fault is apparently represented by a number of nearly parallel fissures forming a zone nearly 50 feet in width. On level 11 the Cashen fault should be very near the main shaft, but its exact position was not determined.

GEOLOGICAL FEATURES.

The general country rock of the Gold Coin mine is the porphyritic granite which underlies the town of Victor and occurs in the Dead Pine, Ajax, Strong, and other mines in the vicinity. This is cut by several irregular dikes and sills of phonolite and by one small basaltic dike. The principal dike is the Montana, which is followed by the Montana lode. This dike varies in width from 10 to 40 feet. Another small dike, rarely over a foot in width, appears at intervals along the sheeted zone constituting the Dorothy lode, and a similar narrow and irregular dike of phonolite occurs along the No. 3 lode.

Irregular sheets or sills of phonolite occur in several parts of the mine, and are usually connected with dikes. The manner in which a dike may locally turn into a nearly horizontal sill is well illustrated in the long west crosscut from the Coin drift, about 500 feet north of the shaft. Here a dike about 1 foot wide, with steep easterly dip, turns sharply west for about 6 feet, forming a nearly horizontal sill about 6 inches thick. It then again bends down into a dike 16 inches in width, dipping steeply to the west. Another good example may be seen at the north end of level 4, where a dike along the Coin lode, instead of continuing down below the drift, turns off to the east as a flat sill. These occurrences show that the phonolitic intrusions in the granite are far from regular, and that it can not be assumed that either dikes or sills maintain their courses for long distances through unexplored ground.

The most important phonolite sheet or sill in the mine is that exposed in level 6, along the drift on the Spur lode. This sill, from 6 to 10 feet thick, is rolling and irregular, but has a gentle easterly dip which carries it about 40 feet below the level at the point where the main crosscut crosses the No. 3 lode. About 60 feet farther east, however, the top of a body of phonolite, probably an anticlinal roll of the same sill, is exposed in the bottom of the crosscut. Still farther east the sill probably connects with the Montana dike. All the phonolite seen in the Gold Coin mine is the usual aphanitic, greenish-gray, altered variety commonly occurring in dikes and sills throughout the district.

The only basic dike seen in the mine is exposed near the face of a west crosscut from the north Coin drift on level 5. It is about 7 inches wide, strikes nearly north and south, and dips about 60° W. It is soft and decomposed and of no economic importance.

The only fault of importance recognized in the mine is the Cashen fault. The productive lodes are generally sheeted zones showing little evidence of differential

movement of the walls, but the Cashen fault is characterized by the presence of more or less crushed and decomposed country rock or gouge. This material is sometimes 4 or 5 feet in width. The net displacement effected by this movement, which may have been oscillatory, does not appear to have been great, as the fissures containing ore on the northwest side of the Cashen fault can in some cases be followed on its southeast side and show no appreciable offsetting at the lines of intersection, and the Montana dike is not noticeably offset where crossed by the Cashen fault on level 7. As most of the lode fissures meet the Cashen fault at an oblique angle, however, the throw of the Cashen fault, assuming it to be later than the formation of the other fissures, is not readily detected. On the other hand, the fault may be older than the fissures that cross it. No decisive structural evidence bearing on this question was discovered, though the occurrence of the ores affords, as will presently be seen, some ground for thinking this explanation the true one. Its acceptance leads to certain corollaries in the shape of suggestive hypotheses as to the source and direction of movement of the ore-bearing solutions or gases.

FORM AND STRUCTURE OF THE ORE BODIES.

With the exception of some small bodies of ore stoped above level 6 near the Providence shaft, in the southern part of the mine, all the ore bodies lie in the northern half of the property. This productive ground extends from a point about 300 feet south of the main shaft northward to the Dead Pine line—a distance of about 900 feet. The Cashen fault is the dividing plane between the generally productive and generally nonproductive territory. On the northwest or hanging-wall side of this fissure zone lie all of the productive portions of the Dorothy, Coin, Spur, No. 3, and Montana lodes. The ore bodies are without exception typical lodes determined by relatively narrow individual zones of sheeting or by the coalescence of such narrow zones into pay shoots of considerable local width.

The Dorothy lode, as seen on levels 9, 10, and 11, is a distinct sheeted zone in granite, usually from 3 to 4 feet wide, but without regular or persistent walls. There are usually two fairly regular narrow cracks or fissures which contain the bulk of the ore, the rest of the lode being made up of less regular fractures containing relatively little value. The stopes rarely exceed 4 feet in width, though in one or two cases little flat seams of ore have been followed for a few feet into the east wall. A narrow phonolite dike usually accompanies the lode, although the two are not always coincident. When the fissure zone does actually follow the dike the ore is of lower grade than when the lode is wholly in the granite. The stopes extend only a short distance above level 9, the fissuring becoming irregular and indistinct as it is followed upward. On level 8 the Dorothy has not been clearly identified, though it may be represented by some indistinct fissuring about 50 feet east of the shaft. Toward the north the pay shoot usually comes to an end with the appearance of the phonolite dike in the fissure zone, a diminution of the fissuring, and a gradual decrease in the value of the ore. The fissuring also becomes less pronounced and the ore of lower grade near the main shaft.

The Coin lode has been stoped almost continuously from the surface to level 9 and between the main shaft and the Dead Pine line. This pay shoot seems to have

reached its maximum length of about 850 feet on levels 5 and 6, where it extended nearly 250 feet south of the shaft. Below level 9 only small isolated bodies of ore have yet been found in the Coin lode, though a new ore body has recently been opened near the north end of level 10 in a fissure zone lying parallel with and about 30 feet to the east of what had hitherto been considered the Coin lode. Whether this is really the Coin or a new lode not known on the levels above could not be ascertained in the stage of development reached at the time of visit. The general dip of the Coin lode, however, as shown in the levels above the tenth, should bring the lode rather nearer to the new ore body than to the old north drift on what was formerly considered the Coin lode on level 10. The lode is a mineralized sheeted zone in granite, the average width of the zone of distinct sheeting being probably about 4 feet. The zone usually consists of two narrow, fairly regular fissures about 4 feet apart, between which are other nearly parallel fissures, usually less regular and persistent, and numerous minor linking fractures. The stopes are often considerably wider than this, however, as the ore is not always limited by the dominant fissures of the zone. Thus on level 4 the average width of the main stope is probably 10 or 12 feet. The widest stope in the mine is near the north end of level 4, where, at the junction of a small branch fissure zone with the Coin lode, the ore was 25 feet wide. An unusually wide body of ore is commonly found also where the Coin and Spur lodes join. On level 8 the Coin pay shoot varies in width from 4 to 10 feet, the average being about 5 feet.

The Coin lode continues both to the north and south, beyond the points where pay ore stops, as a more or less distinct sheeted zone which often shows no visible difference from the productive portions. In some cases, however, such barren continuations of the lode are irregular and indistinct.

There was little opportunity in 1903 of examining typical occurrences of ore in the Coin lode. The valuable minerals, however, seem to be practically confined to the actual fissures, usually less than an inch in width, which make up the fissure zone.

The Spur lode is a mineralized sheeted zone in granite and is of the usual type. It has been stoped from level 4 to level 9, the ore body extending from the junction with the Coin lode a varying distance to the southeast. Its maximum length (about 225 feet) is attained on level 8. On levels 8 and 9 the northeast end of the ore body is very close to the Cashen fault. The strike and dip of this fault are such as to cause its line of intersection with the Coin lode to pitch northward at a lower angle than the line of junction of the Coin and Spur lodes. As a result of this the Spur lode, if it is ever identified on level 10, will probably lie within the hitherto unproductive ground in the foot wall of the Cashen fault.

The general structure of the Spur fissure zone is similar to that of the Coin. Near level 6, where the Spur lode passes through the phonolite sill already described, the ore body contracts in width and decreases in value. There is no noticeable faulting of the phonolite by the lode fissures.

The No. 3 lode is of the same general type as the Spur, but is narrower, the stopes being usually from 3 to 4 feet wide. The fissure zone constituting the lode follows in part a small phonolite dike, the presence of which seems to have no appreciable influence on the character of the ore, which occurs mainly in the fractured

granite. At the main crosscut on level 6, where two or three minor fissures come into the No. 3 from the south, there is a local widening of the ore body to nearly 25 feet. The No. 3 vein is not known much above level 6, while below level 8 it joins the Spur vein, as already described. The pay shoot is rarely over 100 feet in length. Toward the southeast the sheeted zone as a rule passes into a few small and irregular fissures which become indistinct before reaching the main east crosscut and can not be distinguished from the ordinary jointing of the country rock. Unlike the Spur vein, the No. 3 where it cuts through the main phonolite sill 30 or 40 feet below level 6 carries good ore in the phonolite, while in the granite just above and just below the sill the ore has proved of little value. The lode is less regular in the phonolite, the sheeted zone changing to a number of very irregular fractures containing sylvanite or calaverite and pyrite.

The Montana lode is essentially a phonolite dike along which, particularly along its contacts with the granite, there has been a little parallel sheeting. Bunches of ore have been stoped at various points along the dike, sometimes on one side, sometimes on the other, but rarely within the dike itself. On level 9 a good body of ore has recently been found at the point where the Cashen lode meets the Montana dike. This ore occurs chiefly on the east side of the dike, partly in the phonolite and partly in the granite. As a whole, the ore bodies found along the Montana dike have not been important.

The Cashen lode as exposed on levels 6 and 7 is a sheeted zone in granite carrying fairly good ore about 8 inches in width.

CHARACTER OF ORE.

The unoxidized ores of the Gold Coin mine are mineralogically simple and owe their value to the presence of calaverite, with possibly other tellurides not definitely recognized, occurring in narrow fissures with drusy incrustations of quartz and fluorite. Metasomatic alteration of the kind that has changed extensive bodies of granite into ore in the Ajax and Portland mines is practically absent in the Gold Coin mine. At distances greater than a few inches from well-defined fissures the granite is barren, or at least does not constitute ore. In parts of the Gold Coin and Dorothy veins where the sheeting has been intense the vein consists of a mass of crushed granite, quartz, fluorite, and small crystals of pyrite. Such ore frequently shows no telluride mineral to the naked eye. Sphalerite, though not an abundant constituent of the ore, was noted in the Dorothy vein at the 1,100-foot level. At one place near the north end of the mine the Gold Coin vein contains a dark brecciated streak about 4 inches wide, which is veined with quartz and contains disseminated pyrite and fluorite. The microscope shows this material to consist chiefly of granitic fragments, but to contain also some fragments of phonolite. These phonolite fragments may have been derived from some phonolite dike cut by the fissure. The ore occurring in phonolite exhibits the usual character of ores in this rock—small crystals of calaverite occurring with druses of fluorite and quartz in very narrow joint fissures. The ore in the Gold Coin mine is not extensively oxidized below a depth of 650 feet, though partly oxidized ores are found at a depth of 1,000 feet.

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UNDERGROUND WATER.

Water was first reached in the Gold Coin mine at a depth of 369 feet or 9,396 feet above sea level. The maximum flow of 900 gallons a minute was attained at a depth of 1,000 feet. In July, 1903, the water was being held 9 feet below the 1,100-foot level by pumping 740 gallons a minute and by maintaining two bulkheads in wet crosscuts on level 10. The pressure on one of these bulkheads was 93 pounds and on the other 84 pounds, corresponding to heads of about 214 and 193 feet, or to water surfaces 8,979 and 8,958 feet, respectively, above sea level. These conditions had remained unchanged for about a year.

In October, after the opening of the El Paso tunnel, the pressure on the bulkheads began to decrease and in February, 1904, it had fallen to 74 and 68 pounds. In March level 12 was recovered by pumping 700 gallons a minute for ten days and was then kept open by a discharge of 500 gallons a minute. The bulkheads were still left in level 10 and sustained pressures corresponding on April 16 to water surfaces about 8,919 and 8,901 feet above sea level, respectively. At this time the pumps were raising 490 gallons a minute to keep the bottom level open.

SUNSET-ECLIPSE MINE.

The Eclipse, situated at an elevation of 9,700 feet in Eclipse Gulch, just east of the Elkton mine, was one of the earliest producers of the district and is briefly described by Penrose on page 207 of his report. It is developed by a tunnel at an elevation of 9,672 feet and a shaft 500 feet deep situated 70 feet south of the tunnel; the elevation of the collar is 9,689 feet. The Sunset mine, consolidated with the Eclipse, is opened by a tunnel at about the same elevation as the Eclipse tunnel and about 400 feet south of it. There are also some surface workings on the ground of the company on the hill slope north of the Eclipse. The total developments amount to several thousand feet. The total production probably exceeds $100,000. Water has caused much inconvenience. In March, 1904, the shaft was filled to an elevation of 9,465 feet or 224 feet below the collar. Gas filled level 1 so that only the tunnel was accessible. The mine was worked in a small way by lessees.

The country rock is throughout a much oxidized volcanic breccia. The veins exposed in the tunnel are as follows: A north-south vein, dipping steeply westward, 175 feet east of the portal, has been drifted on for a hundred feet north and south from the tunnel. The stopes on this vein were 100 feet long, but descended only 40 feet below tunnel level; the ore was taken out 2 or 3 feet wide and consisted of kaolin with pseudomorphs of gold after calaverite. No ore has been found on this vein in the lower workings. Forty feet farther east in the tunnel is a flat vein dipping 45° or less to the west. This vein is not known below in the Eclipse mine, but is prominent in the Carbonate Queen. Ten feet east of this a third vertical vein is cut; this is the only vein which has proved productive in the lower levels of the shaft. There are two ore shoots 80 and 40 feet long on it, both of which are said to extend down to level 5. A hundred feet north of the tunnel the flat vein, the vertical north-south vein, and a vertical east-west vein intersect and here a large shoot of ore 90 feet high occurred; it was chiefly, however, confined to the vertical vein

and did not appear on the lower levels. The Sunset tunnel has opened the same vein system, with an additional north-south vein from which some good ore has been stoped; but this part of the property has produced a smaller quantity of ore.

CARBONATE QUEEN MINE.

This property consists of a claim adjoining the Eclipse on the east and is owned by the Ophir Mining and Milling Company. It is developed by a tunnel entering under the Midland trestle, 40 feet above the Eclipse and by a shaft 500 feet deep, 350 feet east-southeast of the Eclipse shaft, the elevation of the collar being 9,910 feet. Drifts aggregate about 1,500 feet. No work was done in 1904. The workings connect in part with those on the Eclipse. The production is considerable, but the exact amount could not be ascertained. The Carbonate Queen has the same flat, westward-dipping vein as the Eclipse, and some ore has been extracted from it. There is also a north-south vein and several others trending east and west. The country rock is breccia.

BIG BULL, BRIND, AND STRAUB MOUNTAINS AND GROUSE HILL.

Big Bull Mountain is a large flat-topped granite mountain 1½ miles east of Victor, rising to an elevation of 10,826 feet. Its northern slope is covered with breccia, latite-phonolite, and phonolite. Very few basic or phonolite dikes were noted. Regarding the relations of these rocks in depth there is little information, except that the contact between breccia and granite is steep in some places at least, as for instance at the Safety prospect shaft.

While there are many prospects scattered over the volcanic areas and a few in the granite, there have been no developments of importance thus far and there is practically no production. Encouraging assays have been obtained in many places.

Brind Mountain, 10,500 feet above the sea, is situated 1½ miles south of Big Bull Mountain. Pikes Peak granite is the principal rock. On the north side it is cut by a long dike of diabase and by another of phonolite. Some prospecting has been carried on in the latter, but so far as known without valuable result.

Straub Mountain, the elevation of which is 10,050 feet, lies 1½ miles west of Brind Mountain. It is covered with the sandy detrital deposits discussed on page 22, and in these lie several intruded masses of phonolite. The summit is occupied by one of these bodies, in which many prospects have been opened. It is said that the phonolite contains low-grade gold ores and attempts were made at one time to work these by means of a small cyanide plant situated near the summit of the hill.

Grouse Hill rises to an elevation of 9,800 feet, and is 1½ miles west of Straub Mountain, from which it is separated by the deep gash of Wilson Canyon. Its geological structure is similar to that of the hill just described, though the body of phonolite occupying its upper part is very much larger than the mass on Straub Mountain. A great number of prospects are opened on its east and south sides, but nothing of well-established value has as yet been encountered. Teals tunnel

has been driven into the phonolite in a westerly direction from the east side. A vein which is reported to have given fair assays was encountered 450 feet from the portal; in the face the fresh phonolite contains seams of brown jasper inclosing purple fluorite. Several prospect shafts have been sunk near the southern edge of the phonolite, and some of them have penetrated into the underlying rhyolite.

In the space between Grouse Hill, Straub Mountain, and the town of Victor the granite contains many phonolite dikes, on a number of which prospecting has been done. Some of them yielded fair assays and one contained galena, but nothing of permanent value has been found.

LOWER CRIPPLE CREEK.

The rapidly deepening canyon of Cripple Creek extends southwest from the city of the same name, first through Cripple Creek granite and lower down through Pikes Peak granite. The slopes and uplands on the west side are practically barren. At the junction of Arequa Gulch with Cripple Creek, forming the extreme point of Beacon Hill, some evidences of mineralization are seen. The Newell tunnel is driven from Arequa Gulch into Grouse Hill; 1,000 feet from the portal a vein is reported to have been cut which has been drifted on for 600 feet north and south. It appears to follow a phonolite dike and some paying ore is reported to have been found, as well as a considerable amount of low grade. The ore contains a little galena. The property is owned by the Buffalo and Cripple Creek Gold Mining Company.

One mile farther down the canyon and 3½ miles from Cripple Creek a phonolite dike, called the Gold Watch vein, crops on the west side in the granite. Early in 1904 some very good ore was encountered in this dike near the surface.

About 6 miles down the canyon from Cripple Creek, just outside of the area shown on the map, some evidences of mineralization of a different kind are met. The elevation is here about 7,700 feet. Outcrops of narrow veins occur on the precipitous bluffs of granite and on the summit of the plateau on both sides, about 2,000 feet above the creek. A tunnel has been started here by the Big Twenty Mining Company, and is intended to penetrate the bluff toward the east, with a view to opening the veins cropping high above.

The granite bears evidence of much shearing and crushing, and is intersected by aplite dikes. The veins, which course in various directions, are narrow zones of sheeting carrying in places a little pale-purple or green fluorite and in one case, on the western bluff, tabular crystals of barite. The croppings are said to contain gold values of low grade. It is by no means certain that these veins are of the same age as those of Cripple Creek. They may possibly be considerably older.

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