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ECONOMIC GEOLOGY
OF THE
GEORGETOWN QUADRANGLE
(TOGETHER WITH THE EMPIRE DISTRICT)
COLORADO

BY

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WITH

GENERAL GEOLOGY

BY

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OUTLINE OF RESULTS.

By J. E. Spurr.

Placer gold was discovered in 1859 at Idaho Springs, Colo., and this discovery marks the beginning of mining work in Clear Creek County. In 1859, also, several lodes were discovered both within the Georgetown quadrangle near Georgetown and in the adjacent Gilpin County region, but they were at first worked only for gold, the surface portions being sluiced and washed. Subsequently, however, the difficulties involved in "quartz mining" were overcome, and Clear Creek County became a steady and considerable producer. The total production of the county up to the present time is estimated at about $84,000,000, principally from silver, but including $16,000,000 of gold, nearly $4,000,000 of lead, and $500,000 of copper. Within the last few years some zinc ore has been profitably mined, and there appears to be a good outlook for zinc production in the future.

The steep mountain slopes and picturesque scenery of the area covered by the Georgetown quadrangle have resulted chiefly from the down-cutting in Quaternary time of gentler Tertiary valleys. The Tertiary surface still exists, but little changed, on the mountain uplands, and a complete restoration of the entire topography previous to the down-cutting is not difficult. During the Quaternary and within the period of the formation of the deep valleys there was a period of glaciation, divisible into two chief portions. The extent of the glaciers belonging to the two epochs has been mapped and their effects have been determined.

The rocks of the area, with the exception of porphyritic dike rocks, which are probably Tertiary, are all, so far as can be determined, of pre-Cambrian age. The oldest rocks are represented by a formation of gneisses and schists which probably have resulted from the metamorphism of a great sedimentary series consisting of conglomerates, sandstones, shales, and calcareous beds. These metamorphic schists have been folded, sheared, and intensely injected by a series of holocrystalline pre-Cambrian igneous rocks. The earlier of these igneous intrusives have been considerably mashed by the stresses which produced the schist, but the later have not been much affected.

The oldest igneous rocks are siliceous pegmatites and hornblende gneisses, the pegmatites being the more widely distributed of the two. Next came an intrusion of quartz monzonite, which has changed by subsequent pressure to the condition of a gneiss. Afterwards granite was injected. This was also considerably mashed, so that it is now given the name of gneissoid granite. Later came the intrusion of a quartz monzonite, a granular rock showing comparatively little mashing and covering about one-half of the area. Still later another dioritic rock was intruded, less sheared than the early hornblende gneiss, which was also originally a dioritic intrusive. This later massive diorite is classed as quartz-bearing diorite and associated hornblendite. A biotite granite now called the Rosalie granite was the next rock to be intruded, in the form of batholiths, stocks, and dikes. This is confined to the southern portion of the quadrangle. It was followed by another biotite granite of a distinct type, the Silver Plume granite, which covers considerable areas and is widely distributed throughout the quadrangle.

Nearly every one of these granitic intrusions, certainly much of the granites, was accompanied or followed by the intrusion of pegmatite. Very abundant pegmatitic rocks, grading into alaskite and muscovite granite, were also intruded earlier than any of the massive granites; and later than these granites there were abundant intrusions of pegmatite, with associated granite pegmatite and granite porphyry. Taken as a whole, many of the pegmatites contain magnetite, which in some places constitutes more than one-third of the whole mass. Other minerals are muscovite, zircon, quartz, tourmaline, feldspar, garnet, allanite, apatite, and beryl. These pegmatites have crystallized from a fluid magma, but their composition has been influenced by absorption from the wall rocks, so that characteristic minerals are developed in certain formations.

Residual bowlders of silicified sandstone and quartzite containing pebbles of pre-Cambrian rocks were found in several places. They are similar to the rocks of the Fountain formation found along the foothills of the Colorado Range. The Fountain formation is Carboniferous. If the residuals of Georgetown are of the same age, they represent the only rocks within the quadrangle between the pre-Cambrian and the post-Laramie.

Beginning in very late Cretaceous or early Tertiary time and continuing for an indefinite period in the Tertiary, dikes of porphyry were injected into the pre-Cambrian rocks. Such porphyries have a wide distribution in Colorado, and in the Georgetown area form part of a rough belt striking northeast and southwest, which has been traced from Boulder at least 100 miles southwestward past Leadville and Aspen. The dikes within the Georgetown quadrangle have been classed as dacite, granite porphyry, alaskite porphyry, bostonite, alaskitic quartz monzonite porphyry, biotite latite, and alkali syenite.

In general later than the intrusion of the porphyries occurred the formation of veins by deposition along fault fissures, which were also later than the porphyry in origin.

The mineral veins within the quadrangle lie in distinct areas or belts. The greatest contrast in these veins is offered by those that are silver bearing and those that are predominantly or largely gold bearing. The former class is represented around Georgetown; the latter in the neighborhood of Idaho Springs. However, a belt of gold-bearing veins runs through the silver area of Georgetown. The auriferous area of Idaho Springs is continuous on the north beyond the quadrangle boundary, where there also occur other areas of argentiferous veins similar to that of Georgetown. North of Georgetown the argentiferous veins extend nearly to Empire, but at Empire there is an area of gold-bearing veins with the silver-bearing veins on both sides.

From the phenomena of reopening, renewed cementation of veins, and the crossing and displacement of an older vein by a younger one, it has been determined that the gold-bearing veins are younger than those that carry silver.

The area within the Georgetown quadrangle does not include a complete mining district, but is an arbitrarily taken section of the northeastward-trending mineral belt of considerable extent. Investigation of the literature, combined with the personal knowledge of the writers, establishes the continuity of this belt in a northeast-southwest direction from Boulder to a point beyond Leadville. Within this belt the ores occur as fissure veins, where they lie in the pre-Cambrian crystalline rocks, but in many places where the belt intersects sedimentary rocks the ores occur as more irregular deposits, especially in limestone. Southwest of Leadville, but within the same general zone, there is a mineral belt trending northeast and southwest which extends from the vicinity of Aspen into the Gunnison country. Veins also occur along the Sawatch Range south of Leadville for a considerable distance. All these regions are within a broad northeastward-trending belt in which the area of mineralization coincides with the belt of intrusive Tertiary porphyries. The origin of this belt is due to dynamic movement. It is a zone that has been characterized by yielding to regional stress, which has produced fault fissures along which molten material, forming dikes, and mineralizing solutions, forming veins, have ascended. The development of fractures and faults seems to have been continuous from the late Cretaceous or early Tertiary down to the present day.

When the trend of the ore zone described is followed farther southwest, it is found that other ore deposits are notably massed along its projection. About 15 miles south of Gunnison is the Vulcan mining district, and a short distance south and west of the Vulcan district is the northern portion of the San Juan region. The rocks of the San Juan region are pre-Cambrian granites, gneisses, and schists, overlain by Paleozoic and Mesozoic sediments. During the post-

Laramie uplift this mountain region originated as a broad quaquaversal fold, and subsequently smaller domal uplifts have been superimposed upon various portions of it. After the post-Laramie uplift and ensuing erosion Tertiary formations consisting of a basal conglomerate overlain by thick volcanic beds were deposited. Later monzonitic rocks were intruded in the form of laccoliths, stocks, sheets, and dikes, following which a complex fault system was developed; and these faults, with attendant and largely subsequent fault fissures, have become mineralized and form important veins. The ore deposits in different portions of the San Juan region have many characteristics in common, such as the prevalence of two systems of trend, one northeastward and the other northwestward. The essential features of the San Juan history are similar to those recorded in the mineral belt which stretches from Gunnison to Boulder. It is suggested, therefore, that the intrusions, faulting, fissuring, and vein formation in the San Juan are due to the same general cause which has been found to be responsible in the Gunnison-Boulder belt, namely, the existence of a zone of regional weakness. This zone is shown to have originated contemporaneously with the compression of the Rocky Mountain strata into north-south folds. The approximately horizontal pressure acting in an east-west direction developed two lines of fractures diagonal to the stress. These fractures are represented by the northeast and northwest faults and veins. Subsequent stresses selected especially the northeast direction, and the faulting became localized in this remarkable diagonal belt.

Certain other mining districts in Colorado are definitely outside of this belt, and most of them are connected with volcanic eruptions from a single isolated center. An example of this is at the Spanish Peaks. More important economically are the districts of Silver Cliff and Rosita and of Cripple Creek. These two districts have much in common. Both are situated in an area of pre-Cambrian gneisses and granites and have furnished a succession of various volcanic products. The lavas emitted by each volcano are chemically and mineralogically related to one another, and in each place the magma was marked by an unusual proportion of alkalies.

As the result of the investigation into the important gold, silver, and lead deposits in Colorado two chief natural groups appear—those whose formation followed injections of a monzonitic magma, including a large portion of the northeastward-trending mineral zone running diagonally across the State, and those whose formation followed the outburst of isolated volcanic centers, the varied magmas of which had an alkaline or phonolitic tendency. Both of the consequent periods of ore deposition are of Tertiary age. There is no evidence that the periods covered by the eruption of the two magmas did not overlap, but it appears a better hypothesis to consider the Cripple Creek and Rosita volcanic eruptions as later than the monzonitic eruptions and to conceive of the latter as lasting from the earliest to the middle or later Tertiary and of the former as lasting from the middle to the later Tertiary.

By the aid of the conclusions gained from the study of the principal Colorado ore deposits the special features of the Georgetown quadrangle, which, as already stated, constitutes an arbitrary section of the great northeastward-trending mineral belt, are again taken up. The gold-bearing ores of the Georgetown quadrangle are typically pyritic ores; the argentiferous ores are typically galena-blende ores. Areas covered by these veins coincide with areas of the intrusion of porphyry dikes, and it is demonstrated that the mineralization followed the intrusion immediately, so that a genetic relation between the two is unmistakable. Comparison of the two classes of veins with the different varieties of dikes shows also unmistakable relations. The two mineral districts coincide with distinct petrographic provinces. In the Georgetown district, characterized by argentiferous veins, the dikes consist of alaskite porphyry, granite porphyry, quartz monzonite porphyry, and dacite. In the Idaho Springs district, characterized by auriferous veins, the dikes are bostonite, alaskitic quartz mozonite, biotite latite, and alkali syenite. A study of the dikes near Georgetown shows that they belong to the early Tertiary monzonitic magma, which stands in vital relations to ore deposits of the great mineral belt; the rocks of the Idaho Springs district are referable to the alkaline magma best known and described at the volcanic centers of Rosita and Cripple Creek. Similarly, the two classes of ore deposits in the quadrangle are susceptible of subdivision into groups corresponding with the ores which have in general followed the eruption of these different magmas.

The general features of the argentiferous silver-lead deposits attendant on the monzonitic injection are next examined. These veins contain chiefly galena, blende, and pyrite, with quartz as gangue. Cold descending surface waters are very active along these veins in dissolving and redepositing, and have brought about a considerable change of composition and concentration. A study of the paragenesis of the vein minerals makes it appear probable that the gangue materials are derived from the wall rocks, and that a large part of the material in the veins is immediately due to the precipitation from ordinary atmospheric waters, though the original derivation of the metals is not shown by this study. The wall rocks of the veins have been altered to quartz, sericite, carbonates, and kaolin. The latter is probably the result of descending waters. As a result of the study of many of these veins it is concluded that the original ore deposit consisted of predominant blende with galena and pyrite; that these ore minerals were laid down throughout a considerable vertical range, and that the veins have been actively eroded, while at the same time descending waters have rearranged and concentrated the ores, the effect being to make the concentrated upper portions more valuable. Thus the more persistent veins have an enriched upper zone a few hundred feet in depth, while the veins whose bottoms were at first relatively high have been eroded downward to their roots or even below, so that along such vein fissures there are now exposed on the surface ore deposits which either represent enriched roots or are secondary veins formed below the original root by the transference of materials from the eroded portion to what was formerly the underlying barren fracture.

In like manner the main features of the auriferous pyritic deposits have been studied. Their essential constituent is pyrite, with a quartz gangue. The pyrite contains gold, with a little copper and silver. Galena and blende are present in varying quantity. The wall rocks have been altered to quartz, sericite, carbonates, pyrite, and kaolin; and adularia has also been observed. The deposition of the auriferous veins followed closely the intrusion of certain dikes which contain fluorite, representing the pneumatolytic stage of consolidation. The mineralizing agents can have nothing else than ascending hot waters, and by comparison of the chemical composition of the mineralizing solutions, which has been reasoned out from the alteration of the wall rocks, and of the nature of the vein materials, with the known sequence of volcanic emanations, it appears probable that the mineralizing waters, as well as the contained gases, were of magmatic origin. In the Idaho Springs district the intrusion of a phonolitic magma was followed by the deposition of a certain type of veins, whereas in the Georgetown district the intrusion of a monzonitic magma resulted in the formation of another distinct type. These facts can be explained only by considering the metals also to have been given off by the respective magmas, since the rocks which have been traversed by the ascending solutions are similar. Since the auriferous veins have been shown to be probably younger than the argentiferous veins, it is probable that the alkaline igneous intrusion was more recent than the monzonitic intrusion. It also results from this that the argentiferous veins have been exposed to erosion and concentration longer than the auriferous veins, so that the effects of descending waters are much more important in the former than in the latter.

Along the veins the ore has been for the most part especially deposited at the intersection of different branches. Where no such branches are plainly visible it is probable that many ore shoots have formed at the intersection of different fracture fields. Although in these places the ores have been deposited by the reaction of one solution on the other, in others it has been deposited by the reaction of the mineralizing solutions on the solid wall rock, bringing about replacement. In the process of replacement the fineness of the material replaced, which controls the area of reaction faces, appears to be an important factor. It is probable that the crushed material or gouge along faults, if permeable by solutions, is replaced more rapidly than the coarse material, and that such areas of gouge produce ore shoots or relatively more highly mineralized portions of the vein.

The nature of the movements along the faults which have become the seats of ore deposition has been carefully studied. On the walls of the veins of the argentiferous type near Georgetown the striæ indicate a general nearly horizontal movement along the steeply dipping or vertical fault planes. In the veins of the auriferous group the striæ dip steeply, recording in general the movement of one wall past the other with a strong downward plunge. These observations support further the conclusions as to the essentially different age of the silver-bearing and the gold-bearing veins, and it is likely that the fault fissures which they occupy were formed at different periods.

In connection with the ore deposition the hot springs at Idaho Springs are described. These occur near the contact of intrusive alkali syenite belonging to the group of alkaline Idaho Springs dikes. These springs dissolve portions of the rock completely. They also precipitate barite, quartz, and iron carbonates that on exposure to the air become iron oxides. It appears probable that the bases contained in the spring solutions have been derived form dissolution of the wall rock. The acids, however, can not have had this origin, and are regarded as having been given off from portions of the alkali syenite magma which are now cooling in depth. Moreover, the water is also regarded as of magmatic origin. These springs are believed to occupy the same relation to the alkali syenite intrusion that the hot mineralizing waters which deposited the auriferous veins did to the older dike intrusions.

For the purpose of comparison, the hot spring waters at Glenwood, Colo., and at Steamboat Springs, Nev., are cited. The comparison of these two springs with those of Idaho Springs shows that the waters of Steamboat Springs, which are the hottest, contain a large proportion of potash, a substance present in much smaller quantity in the Glenwood Springs waters and lacking in those of Idaho Springs. Moreover, the Steamboat Springs waters contain various metals and other elements, including gold, silver, copper, and lead, and the proportions of constituents in solution approach those which have been inferred for the hot waters which produced the mineralization at Tonopah, Nev.[a] Comparisons between the composition of the waters of these different springs which emerge at the surface emphasize the conclusion that many of the mineral bases present in such emerging hot waters are more the result of reactions with the wall rock than of original composition or of magmatic emanations, and that the acids and the rarer metals, with very likely some other bases, such as potash, may be original and magmatic. Another conclusion which follows this is that with the same or different solutions different wall rocks have produced, by reactions, different minerals. Thus a limestone wall rock at Aspen has been changed to dolomite and quartz, with some iron, by solutions similar to those which have altered igneous wall rocks to quartz, sericite, siderite, and pyrite.

The conclusion as to the origin of the ores within the Georgetown quadrangle applies also to the districts with which the Georgetown and Idaho Springs districts have been correlated, and the greater portion, at least, of the gold, silver, and lead deposits of Colorado are concluded to be probably of magmatic origin.

The studies of recent years make it probable that ores which are due directly to emanations from heated igneous magmas are not of slight importance, as was supposed a short time ago, but on the contrary are of the very first importance. It appears that as compared with these magmatic processes the other modes of formation of the ores of all save the most common metals shrink into insignificance.

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[a] Spurr, J. E., Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 22.

GEOLOGY OF THE GEORGETOWN QUADRANGLE (TOGETHER WITH THE EMPIRE DISTRICT), COLORADO.

By J. E. Spurr, G. H. Garrey, and S. H. Ball.

PART I.—GENERAL GEOLOGY.

By Sydney H. Ball.

INTRODUCTION.[a]

The Georgetown quadrangle lies in the center of the north half of Colorado (see fig. 1), between the meridians 105° 30′ and 105° 45′ west longitude and the parallels 39° 30′ and

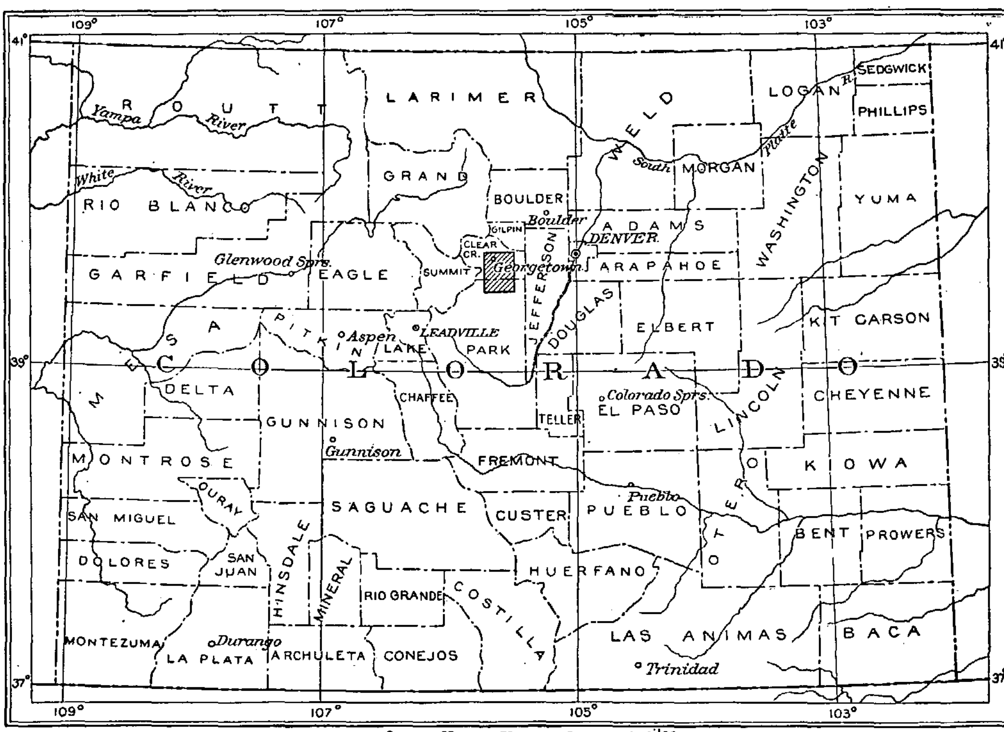


Fig. 1.—Index map of Colorado, showing position of Georgetown quadrangle.

39° 45′ north latitude. Denver is 26.5 miles east of the northeast corner. The quadrangle is about 17.4 miles long (north and south) and 13.5 miles wide (east and west) and contains approximately 230 square miles. The northern three-fourths is situated in Clear Creek County, and the southern portion is in Park County. The quadrangle lies on the east slope of the Colorado Range. It is named from Georgetown, the county seat of Clear Creek County. (See Pl. I, in pocket.)

[a] The writer of this part wishes to acknowledge his indebtedness to Mr. O. H. Hershey, to whose keenness in the field is due much of any value which this report may possess.

TOPOGRAPHY AND GEOGRAPHY OF THE GEORGETOWN QUADRANGLE.

RELIEF.

The Georgetown quadrangle is a rugged and mountainous region, with an average elevation of about 10,500 feet above sea level. Massive Mount Evans, its most striking topographic feature, is 14,260 feet high and is the highest peak of the Colorado Range not situated on the Continental Divide. No summit in the range overtowers it more than 200 feet. A saddle, cut by the headwaters of Geneva and South Clear creeks, deeply indents the east-west ridge which connects Mount Evans with the crest line of the Colorado Range. This peak is the center from which the main ridges of the quadrangle radiate, and streams which drain over one-half of the quadrangle rise from the straight-walled cirques sapped in its mass. An unnamed peak 1½ miles west-southwest of Mount Evans, nearly cut by cirques into three sister peaks, is 14,046 feet high. The flowing contour of Chief Mountain (11,710 feet high) is typical of the nonglaciated peaks. Clear Creek flows across the eastern border of the quadrangle at an elevation of 7,450 feet, and this is the lowest point in the quadrangle.

DRAINAGE.

The Georgetown quadrangle is situated in the southwest corner of the drainage basin of Missouri River, its streams being tributaries of the South Platte and of North Fork of the South Platte. The divide between the South Platte and North Fork of the South Platte follows the crest of the ridge from Meridian Hill westward to Rosalie Peak, thence northwestward to a point 2 miles beyond Mount Evans, and thence, in a sinuous line, south-southwestward to the western border of the quadrangle. The principal streams of the quadrangle include Clear Creek and its affluents, Chicago and Soda creeks, and Bear Creek, tributaries of the South Platte, and Geneva, Deer, and Elk creeks, tributaries of North Fork of the South Platte. The streams are all mountain torrents of steep grade, and with the exception of Clear Creek even the larger ones fall 300 or more feet per mile. Clear Creek, a shallow, rapid stream from 30 to 60 feet wide, has an average fall of about 85 feet per mile from the junction of South and West forks to the eastern border of the Georgetown quadrangle. Two distinct types of stream profile, present in the quadrangle, are well illustrated by Soda and Chicago creeks. Soda Creek heads at a comparatively low altitude and has a normal compound-curved profile. Chicago Creek heads in glacial cirques and in consequence has a bench and scarp profile in its upper reaches.

CLIMATE.

The Georgetown quadrangle, in consequence of the great range in elevation, has a varied climate. Complete meteorological data are lacking, but Georgetown and Idaho Springs have a mean annual temperature of about 41° F. The temperature seldom rises above 80° in summer or falls lower than 5° below zero in winter. The climate in the higher country is more rigorous and the annual range in temperature greater.

The valley towns have an annual recorded precipitation of 17.5 to 24.8 inches, 19.5 inches being an average. The precipitation on the higher peaks is doubtless considerably greater, and Mount Evans is one of the storm centers of the Colorado Range. April, May, June, July, and August are the months of greatest and January that of least precipitation. During the summer there are showers almost every afternoon.

The heaviest snowfall of the year often occurs about the middle of October. The lower valleys are usually free from snow much of the winter, but snow lies on the highest peaks almost all the year.

VEGETATION.

When first settled much of the quadrangle was heavily timbered below timber line, which ranges from 11,250 to 12,000 feet above sea level. In the southeast corner trees are rather widely spaced and grassy glades are characteristic. Western yellow pine and Douglas fir grow on dry areas to altitudes somewhat over 8,500 feet. These trees are replaced on higher and moister ground by lodgepole pine and Engelmann spruce, which in turn are superseded by dwarf spruce and near timber line by mountain white pine. Larger areas have been burnt over and are now covered with second-growth lodgepole pine and aspen. In summer the aspen's light green and in autumn its yellows and reds contrast strongly with the dark green of the conifers and add much to the beauty of the mountain sides. Above timber line there is an alpine flora comprising many species.

CULTURE AND INDUSTRIES.

The population of the Georgetown quadrangle is largely confined to the mining districts in its northern portion, though a few stockmen and lumbermen live in the southern and east-central portions. Idaho Springs, whose population in 1900 was 2,502, is situated on Clear Creek in the northeast corner of the quadrangle. Georgetown, the county seat of Clear Creek County, had in 1900 a population of 1,419. Each town is a mining camp, a distributing point for the surrounding mines, and also a summer resort of some note. Silver Plume, Freeland, and Lamartine are mining camps.

The Georgetown branch of the Colorado and Southern Railroad follows Clear Creek canyon, terminating above Silver Plume, and connects the northern portion of the quadrangle with Denver. Numerous wagon roads, which follow the lower reaches of the main streams and traverse the more level ridges, lead to the more accessible mines. Of the many trails, some are practically impassable through disuse.

Mining is by far the most important industry of the quadrangle. For forty years the mines of Clear Creek County have been continuous producers of silver and gold. Small sawmills furnish lumber for mining and other local needs. A few cattle pasture on the hills, and the alluvial flats and glacial meadows furnish pasturage that is luxuriant but not easily accessible. The alluvial flats are suitable for farming, but only hardy vegetables, such as potatoes, turnips, radishes, and lettuce, thrive. The rigorous climate with its killing frosts, which sometimes occur in the valleys in June, and the small area of tillable soil are hindrances to extensive farming.

EVOLUTION OF THE TOPOGRAPHIC FORMS.

From a point commanding a wide view of this portion of the Colorado Range three distinct topographic forms are recognizable—first, an old, mature mountainous upland; second, younger V-shaped valleys incised in this upland; and, third, glacial cirques developed at the heads of some of the streams, passing downstream into U-shaped valleys.

MOUNTAINOUS UPLAND.

Over considerable areas in the east-central and southeastern portions of the quadrangle the old upland surface is little modified by recent erosion, and throughout the quadrangle remnants are preserved on the crests of ridges. From a study of these and other remnants in adjoining areas a topographic map of this old land surface, with 500-foot contours, has been constructed (Pl. III) and may be compared with the map on the same scale showing the present topography (Pl. VI).

The mountainous upland was an ancient land surface with about the same relief as the present surface. Dome-shaped mountains and broad, smoothly contoured ridges, however, stood where sharp peaks and rugged ridges now are, and the valleys between were broader and less steep than those of the present streams. Maps of remnants of the mountainous upland contrast with those of the surrounding younger areas in the greater distances between the contour lines. The surface was well adjusted to the structure of the underlying rocks and to the varying resistances to erosion of the different formations. Precipitous slopes, except those dependent on differential resistances to weathering of hard and soft rocks, were largely lacking. The precipice in the southeast corner of the quadrangle, at the contact of the quartz monzonite and the Rosalie granite, and the one southeast of Alps Mountain, at the contact of the Silver

Plume granite and the Idaho Springs formation, were as well developed as now. The dip slope of the area north of the divide between Soda and Bear creeks was more prominent than the present slope. Mount Evans then, as now, was the striking topographic feature.

The drainage was dendritic and mature. One example of the shallow valley heads which led down gently from the dome-shaped mountains of the old upland is preserved at the head of Bear Creek, from the lower end of Summit Lake to the 11,500-foot contour. As the glacier which formed in the cirque on the north side of Mount Evans cut a deep notch northward and joined the Chicago Creek glacier, this portion of Bear Creek was unglaciated and remains to-day practically as it was prior to the dissection of the mountainous upland. The old valleys throughout their courses were wider and gentler than those of the present day, and at the quadrangle borders those of Clear, Bear, Deer, and Elk creeks were broad and basin-like. In unglaciated areas the difference in the profiles of the former and present streams decreases upstream until the greater grade of the present stream carries its valley up onto a remnant of the mountainous upland and to the head of the former stream. The old streams had normal profiles. Lakes did not then exist.

The remnants of this old topographic surface are covered by rock residuals and in many places by deep soil. Doubtless this sheet of residual soil and talus covered a large portion of the old surface, and rock exposures were comparatively uncommon, except on the steepest slopes.

The extreme differences of relief between this old topography and that of the present day, amounting to about 1,000 feet, occur where glacial cirques have been gnawed into the broad valley heads of the old upland. Of the streams Clear Creek has cut its way deepest into the upland, and in consequence the present stream at Idaho Springs is sunk beneath the old creek bed about 400 or 500 feet. The dissection of the ancient surface is also most intense along Clear Creek, the largest stream within the quadrangle. This dissection seems greater than is warranted by the size of the stream alone, and it may indicate that the tilting which rejuvenated the streams had a southern as well as an eastern component.

The period at which this mountainous upland was formed is not definitely known, but it was probably in late Tertiary time. Cross[a] has shown that near the end of Mesozoic time andesitic lavas probably covered the Colorado Range in this latitude. Prior to the formation of this upland surface these lavas were completely removed, indicating that the surface was not developed very early in Tertiary time. Further, the size of the canyons cut into the mountainous upland prior to the earlier glaciation indicates that the land surface is presumably pre-Pleistocene. Similar mature uplands have been noted in the vicinity of Pikes Peak by Cross[b] and in the Sierra Madre near Encampment, Wyo., by Spencer.[c] Examination of topographic maps of Colorado[d] shows remnants of a similar mature and ancient land surface widely distributed over Colorado. It is probable that these are all approximately contemporaneous and of late Tertiary age. Perhaps in a broad way to be correlated with this land surface is that described by Lawson,[e] which developed in the Sierra Nevada at the close of Tertiary time, as well as similar land surfaces remaining on the crests of some of the basin ranges in southwestern Nevada and eastern California recently studied by the writer.[f] The latter surfaces are without much doubt of late Pliocene age. It is probable, then, that in late Pliocene time, over considerable areas from the Great Plains of Colorado to the Sierra Nevada, the mountains were comparatively low and characterized by topography in old age.

INCISED VALLEYS.

After the mountainous upland had developed in the Georgetown quadrangle the gradient of the streams was increased, presumably by an eastward tilting of its surface, and in consequence the streams carved and are still carving valleys in this upland. The valleys are of vary-

[a] Cross, Whitman, Mon. U. S. Geol. Survey, vol. 27, 1896, p. 202.
[b] Cross, Whitman, Geologic Atlas U. S., folio 7, U. S. Geol. Survey, 1894, p. 1.
[c] Spencer, A. C., Prof. Paper U. S. Geol. Survey No. 25, 1904, p. 12.
[d] Hayden, F. V., U. S. Geol. and Geog. Survey Terr., Atlas of Colorado, 1877.
[e] Lawson, Andrew C., The geomorphogeny of the upper Kern basin: Univ. California Publ., Bull. Dept. Geol., vol. 3, no. 15, 1904, p. 302.
[f] Ball, S. H., Bull. U. S. Geol. Survey No. 308, 1907.

ing width, from the canyon of Clear Creek, which is in places 2½ miles wide, to the gorges along Deer, Elk, and Bear creeks, which are for the most part not over one-half mile wide. Upstream the valley walls approach each other, and the valleys become narrow, V-shaped notches in the old upland surface. The young valleys are steep, and perpendicular elements in their walls are common. Rugged ribs of rock project from the valley sides, and huge bowlders, wedged from the cliffs, dam the rushing waters of the streams.

STREAM ADJUSTMENT DURING THE DISSECTION OF THE MOUNTAINOUS UPLAND.

Evidence that important stream adjustment has occurred since the mountainous upland developed is lacking, and the drainage lines of the upland, except for minor lateral shifting and a few unimportant changes, persist to-day. Bard Creek, however, in early preglacial time appears to have flowed eastward into Clear Creek through the low gap known as Empire Pass instead of turning abruptly to the north and flowing into West Clear Creek, as it does now. This change probably occurred in late preglacial time. The restoration of the mountainous upland (Pl. III, p. 30) and the presence of a few river cobbles on the low gap in the divide between Chicago Creek and Barbour Fork of Soda Creek indicate that Barbour Fork was formerly a tributary of Chicago Creek. The most southerly affluent of Deer Creek in the quadrangle has captured the upper 2 miles of its course from an eastward-flowing stream which empties into Deer Creek immediately south of the quadrangle boundary.

GLACIAL FORMS.

After the rejuvenated streams had cut back their courses in the Georgetown quadrangle the higher valley heads were occupied by alpine glaciers of two distinct epochs of glaciation. The changes wrought in the surface of the quadrangle by the earler glaciers (Pl. IV) have been largely obliterated by later glacial and interglacial erosion. The glaciers modified the topography in two ways, by erosion and by deposition, the former process being particularly effective in the upper portions of the glaciated areas and the latter in the lower portions.

The principal glaciers of the second epoch occupied the valleys radiating from Mount Evans, and other glaciers, heading in the Continental Divide to the west, descended the eastward-flowing streams and pushed into the quadrangle (Pl. V).

Cirques are the most striking feature of glacial erosion in the quadrangle. Glaciers which headed below an elevation of 12,000 feet did not form well-developed cirques, although those with compound cirque heads, such as that above the lower Chicago Lake, formed as low as 11,700 feet. The deepest cirques are in the vicinity of Mount Evans, where the upper Chicago Lake, for example, lies at the base of a slope which rises 1,700 feet in less than a mile. The steeper cirques have bare, rocky, impassable walls, in many places with postglacial talus accumulations along their bases, while less steep cirques are covered in summer by luxuriant grasses, well watered by melting snows. The compound character of the cirques of many of the larger glaciers is well exemplified by the glacier which formed Summit and Chicago lakes. Its profile shows three well-developed cirques, situated at different elevations on the same stream. In such glacial valleys streams, some of them sunk in shallow canyons, fall from cirque to cirque like silvery ribbons.

Where two cirques headed opposite each other the mountainous upland was eroded away by mutual headward retreat, and a knife-edge ridge or arête was formed. The best example of this is 1 mile west of Mount Evans, where the precipitous walls of two cirques unite, forming a narrow, rugged, and impassable crest. Similar topographic forms were produced by the lateral abrasion of parallel glaciers. Hanging valleys formed by abrasion will be mentioned in another place (p. 34).

Of the lakes of the quadrangle three types originated during the later glacial epoch, and a fourth is of more recent origin. The glacial lakes are either (1) glacier hewn, lying in a basin scooped out by the ice, or glacier dammed, (2) by the irregular deposition of ground moraine, or (3) by a lateral moraine. The fourth type may be called talus-dammed lakes. The first two kinds of lakes, which reach a maximum length of one-half mile, are situated upon the floors of cirques. Cirque walls as a rule rise steeply on three sides of the lake; the fourth side is a low barrier of rock (glacier-hewn lakes) or of morainal material (glacier-dammed lakes). Of these the latter is the more common type in the quadrangle. Several of the most elevated lakes are covered by ice the greater portion of the summer. The third type of glacial lakes, located in the lower reaches of the glaciated valleys, is represented by Edith and Echo lakes, small bodies of water occupying preglacial valleys which have been dammed by lateral moraines. The upstream shores are smooth and gently sloping, and a morainal wall rises at the lower end of the lake. Two small lakes on the border of the quadrangle northeast of Meridian Hill and a larger lake just without the quadrangle are examples of the fourth type. These lakes lie in a broad, shallow valley, are surrounded by an alluvial flat, and appear to be formed by broad dams of talus from the hills to the southwest and northeast.

From the cirque downstream to the lower limit of glaciation the valleys in cross section present a lower glaciated U-shaped portion and an upper portion due to rock weathering. Near the cirques the latter component is subordinate or lacking, while near the lower limit of glaciation the U-shaped portion is poorly developed.

Lateral moraines which form prominent narrow ridges of till on either side of the valley walls are the most striking of the glacial deposits. These moraines are in some places double, the outer strand containing débris of more local origin.

The floors of cirques and glaciated valleys are very irregular, through unequal deposition of material in ground and recessional terminal moraines, although the latter deposits are unimportant. Striated and smooth rock ledges protrude from the till here and there. Stream grades are variable, and the streams themselves divide and reunite or spread out into marshes and ponds. Most of the streams, however, are sunk slightly below the valley floor, and have bowlder beds which are in many places bordered by a narrow strip of marsh.

The terminal moraines have an irregular surface characterized by hillocks, ridges, and depressions. Many of these moraines have very steep fronts, over which the streams descend in a succession of waterfalls, forming a hanging valley. A second type of hanging valley is formed by a moraine crossing the channel of another stream. The moraine of East Geneva Creek glacier crosses the valley of Geneva Creek, and from its gently graded course in Geneva Park the latter stream falls 300 feet in 0.15 mile. Differential abrasion formed a third type of hanging valley. The Clear Creek glacier eroded more powerfully than the South Clear Creek glacier, and in consequence at their junction the bed of the united glacier was sunk 250 feet below that of the South Clear Creek glacier. South Clear Creek has since trenched the cliff faces above the junction.

POSTGLACIAL TOPOGRAPHIC CHANGES.

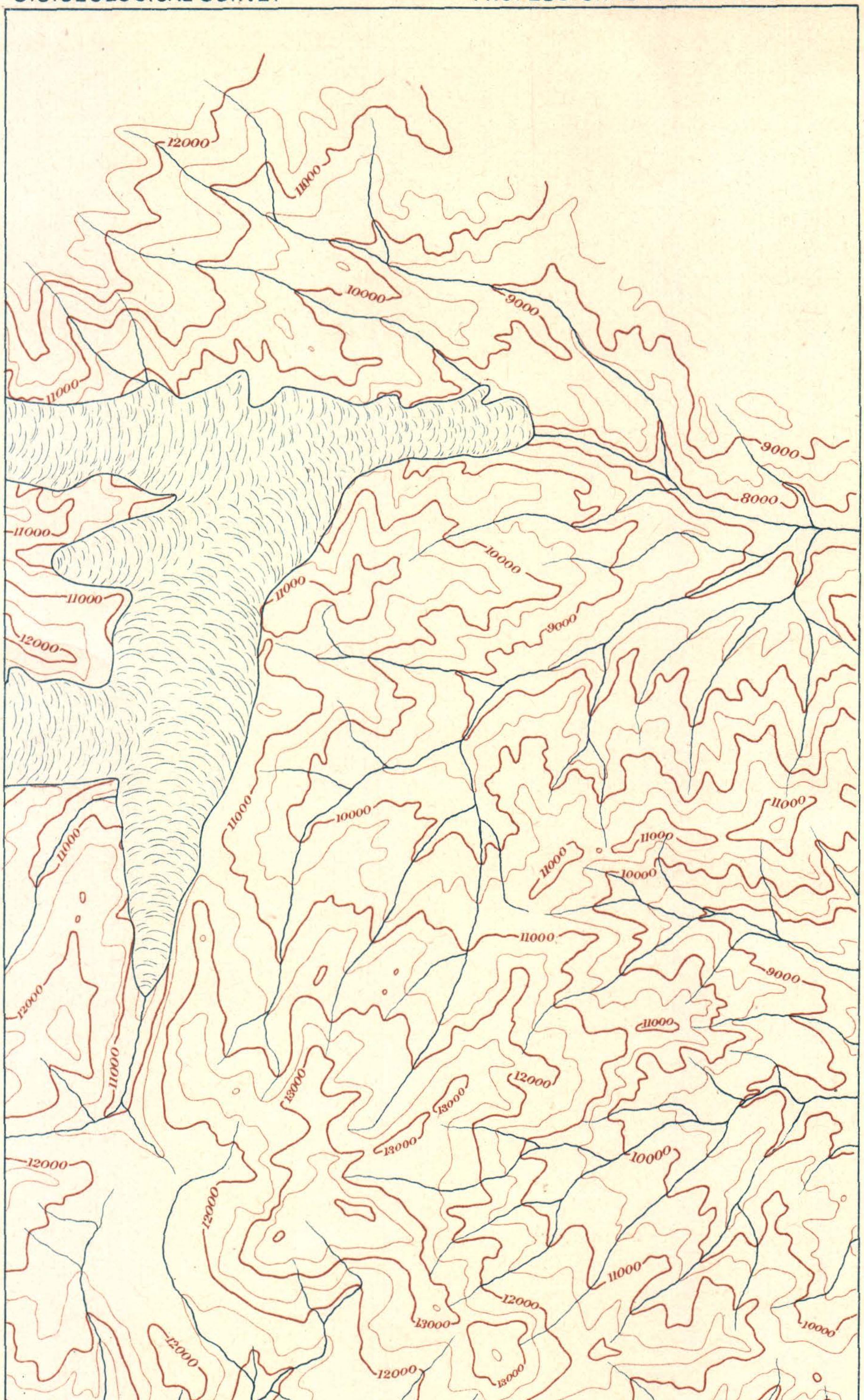
Since the retreat of the glaciers of the later glacial epoch a few minor topographic changes have occurred. Small tributaries of streams in the glaciated area were in places deflected downstream by lateral moraines, whose outer border they follow. The streams have cut into the glacial till and somewhat deepened their channels in bed rock. Alluvial fans have been formed at the mouths of some of the gulches. Alluvial flats, through which streams now meander, have been filled in behind terminal and recessional moraines. Of these the flat on Clear Creek between Georgetown and Empire station is a good example. Alluvial flats like Geneva Park have also been formed behind moraines which dam other channels, and irregular patches of alluvium have accumulated in the small stream valleys which abut against lateral moraines. Glacial lakes have been partially or completely filled. Glacier-smoothed surfaces have been roughened by weathering and rock ribs and pinnacles formed upon them. In comparatively recent time the upper one-fourth of the east fork of Lost Creek wandered over a level basin of débris from the surrounding hills and was turned into the west fork of Indian Creek. (See Pl. VI.)

THE OLD MOUNTAINOUS UPLAND RESTORED

1 0 1 2 3 4 5 miles

Contour interval 500 feet

1906



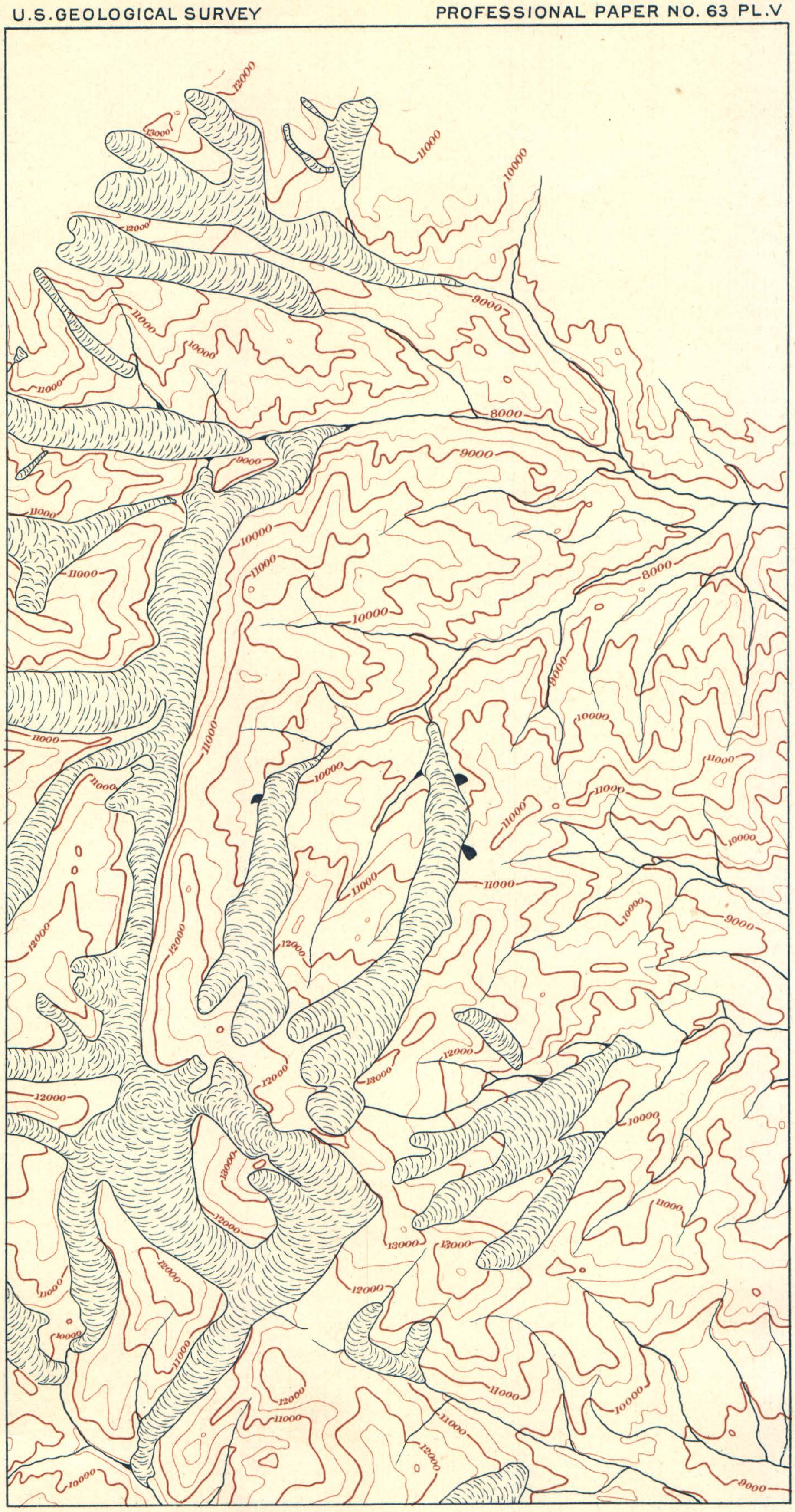
GLACIERS OF EARLIER GLACIAL PERIOD

If other glaciers existed during this stage all evidence of them has disappeared

1 0 1 2 3 4 5 miles

Contour interval 500 feet

1906

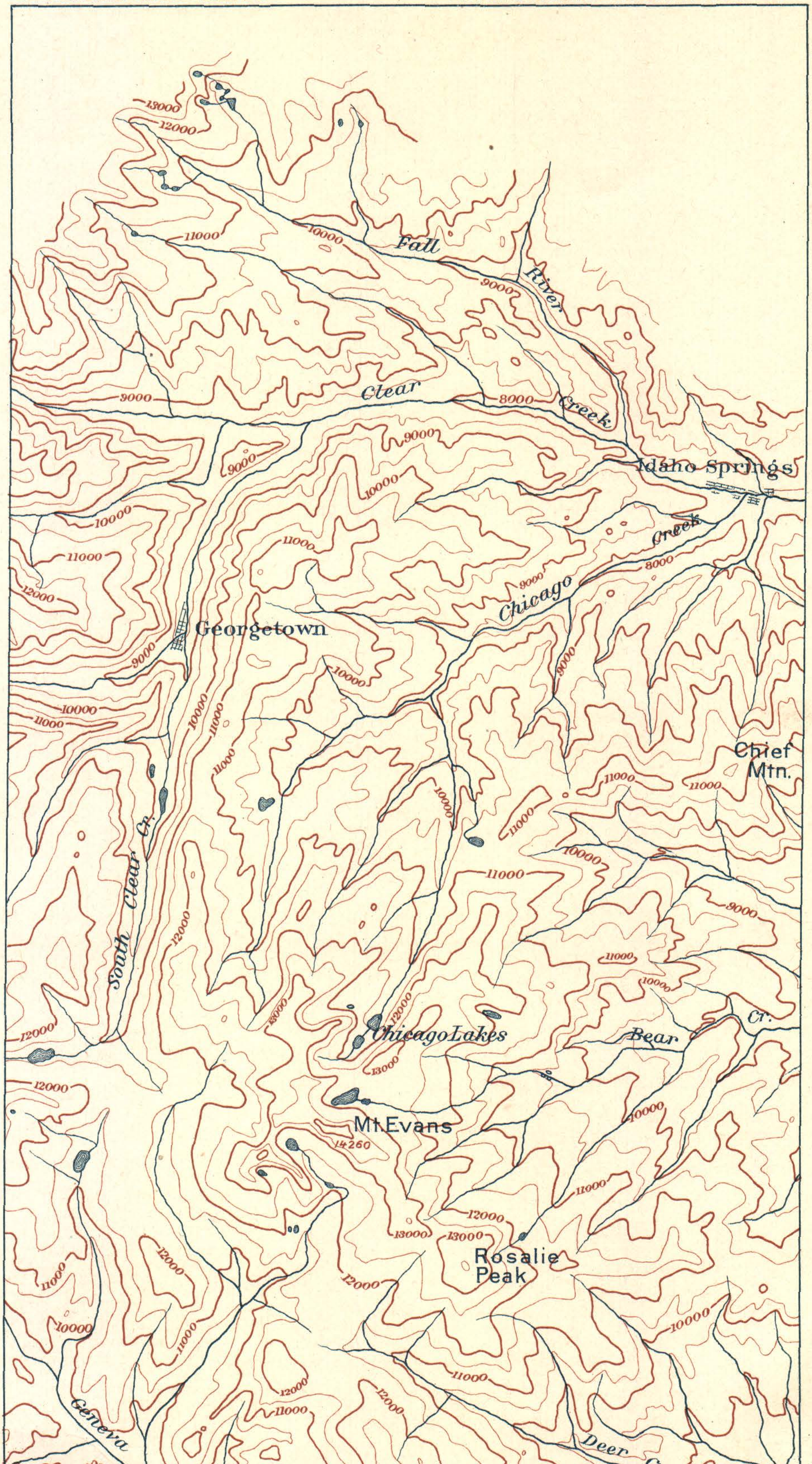


GLACIERS OF LATER GLACIAL PERIOD

1 0 1 2 3 4 5 miles

Contour interval 500 feet

1906

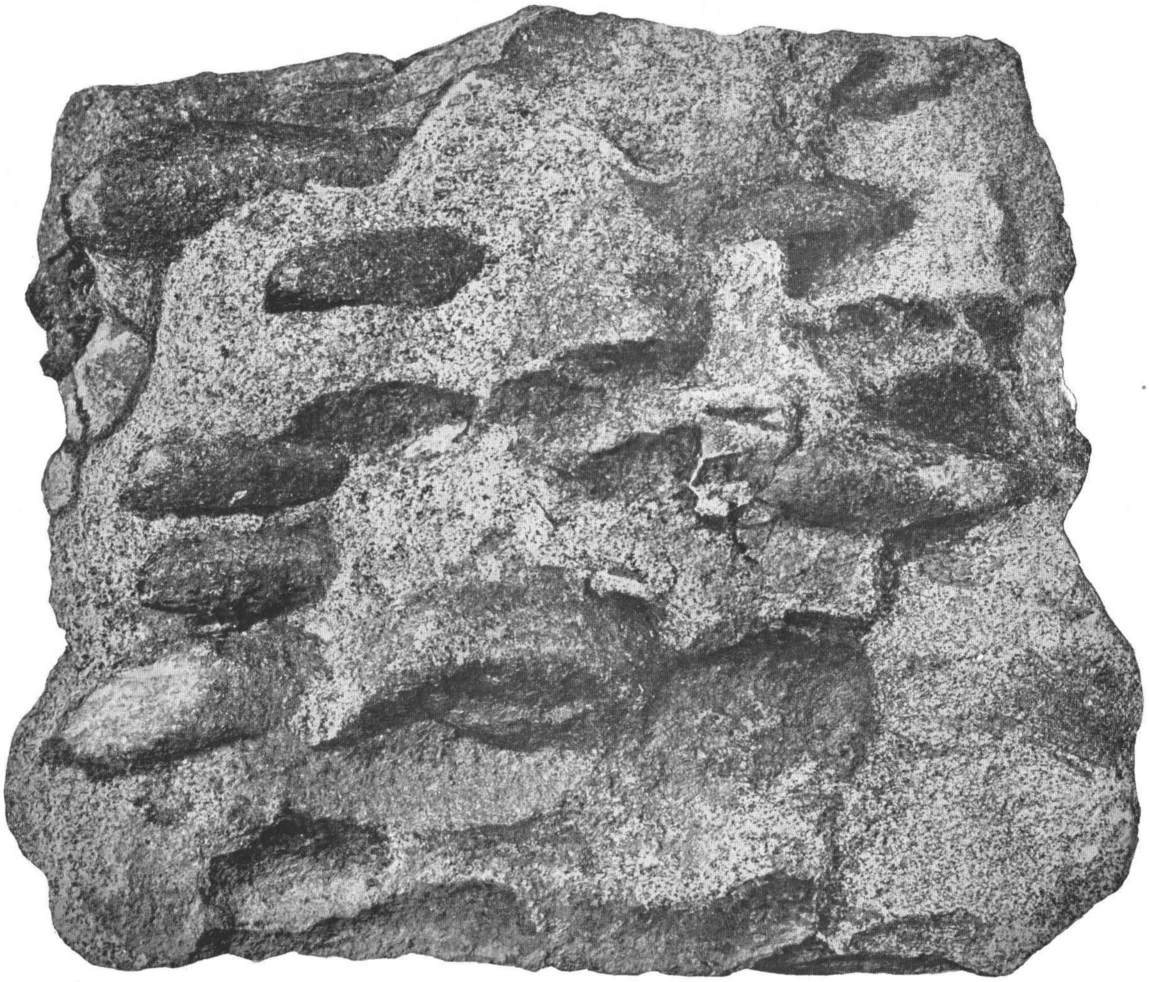


PRESENT TOPOGRAPHY

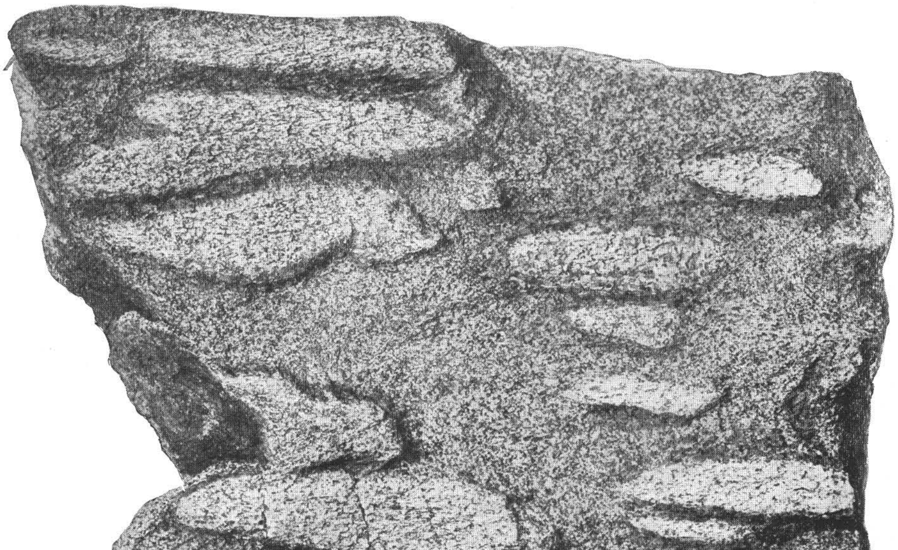
1 0 1 2 3 4 5 miles

Contour interval 500 feet

1906



A. CONGLOMERATIC TYPE OF IDAHO SPRINGS FORMATION, SHOWING PEBBLES.



B. CONGLOMERATIC TYPE OF IDAHO SPRINGS FORMATION, SHOWING PEBBLES SOMEWHAT ELONGATED NEAR THE PLANE OF SCHISTOSITY.

Note cross fractures.

TOPOGRAPHY IN ITS RELATIONS TO ROCK FORMATIONS.

The formations of the Georgetown quadrangle are crystalline rocks, which for the most part resemble one another closely in mineralogical composition. In consequence they offer to erosion approximately equal resistance, and no single formation persistently occupies either mountain tops or valleys. Nevertheless, two scarps are determined by the differential resistance to erosion of adjacent rock formations. One of these is on the south slope of Alps Mountain, the Silver Plume granite being elevated and the Idaho Springs formation being depressed; the other is south of Meridian Hill, quartz monzonite forming the scarp and the Rosalie granite the lowland.

To weathering and stream corrasion the rocks, with the exception of the biotite-sillimanite schist of the Idaho Springs formation and the hornblende gneiss, appear to offer approximately equal resistance. Of the two rocks excepted each breaks down readily, the first physically, the second chemically, some of its bowlders being rotten to the core. Above timber line exfoliation by the flaking off of platy ellipsoidal fragments produces a peculiar uneven surface on most of the rocks. Where these flakes are opposite one another, holes are formed in many of the thinner slabs.

It will be convenient in describing the topographic effect of the various formations to group them into (1) schists, including the biotite-sillimanite and biotite schists of the Idaho Springs formation, together with locally schistose varieties of the quartz monzonite gneiss; (2) gneisses, including the quartz gneiss and the lime-silicate rocks of the Idaho Springs formation, the hornblende gneiss, the quartz monzonite gneiss, and the gneissoid granite; (3) massive granular rocks, including the less gneissoid varieties of the gneissoid granite, the quartz monzonite, the quartz diorite, the Rosalie and Silver Plume granites, and the granite-pegmatite; and (4) the intrusive porphyries. Each of these rock groups produces a characteristic topography, which, however, is restricted by the small areal extent of each of the rocks.

The country underlain by schists is one of rather uninterrupted curves. Dip slopes, best exemplified by the rather gentle slope on the north side of Chief Mountain, tend to form along the well-developed schistosity. Outcrops, which are comparatively rare upon the old mountainous upland, are characteristically depressed heaps of bowlders, with slabs between, where the dip of the schistosity is approximately flat. Where the schistosity dips steeply, slabs protrude 4 or 5 feet from the soil, and the surface resembles a cemetery, long deserted, with many of its closely crowded gravestones overturned. Along streams schists form less prominent and continuous outcrops than the other rocks. Where the dip of schistosity is low, undulating, smoothly contoured exposures occur, and where the schistosity is approximately vertical, craggy and serrated forms are common.

The gneisses weather into bedlike exposures which from a distance resemble those of sedimentary rocks. With the prominent development of joint systems the gneisses produce forms similar to those of the granites.

On the old mountainous upland the massive granular rocks underlie rounded ridges and hills covered by large and small fragments, with here and there a conical heap of bowlders. Along stream valleys almost continuous exposures of rugged crags, whose minor details are controlled by the rectangular joint systems, are characteristic. Here masonry-like piles, turrets, and buttresses are characteristic and are particularly well seen in the granite-pegmatite, which seems the most resistant of these rocks, while quartz diorite is the least resistant.

The well-known domal weathering of granite is developed in but two of the six massive granular rock formations, and in these two but locally. Below timber line (approximately 11,500 feet) the old mountainous upland, underlain by quartz monzonite, is beset with many domes from 200 to 300 feet high and from 300 to 400 feet in diameter. These are unusually well developed upon the Captain Mountain ridge, where the bare gray rocky hemispheres appear to occupy about one-fifth the surface of the dark-green, forest-clad hills. Where the original gneissic structure is rather highly developed the domes are low; where joints are highly developed the domes are represented by huge hemispherical piles of bowlders. Above timber line rock disintegration, due to temperature changes, does not permit the formation of these domes, and the surface is covered by huge residual masses of monzonite.

The comparatively low-lying area of Rosalie granite in the southeast corner of the quadrangle is a topographic unit, bounded on the north by a scarp of quartz monzonite and on the west and northwest by country underlain by a complex of gneisses and granular rocks. It is a tract of rounded divides with mammillary hills and gently sloping stream valleys with narrow flood-plains. Cliffs are present only where the wandering streams under-cut the hillsides. Small inclosed basins mark areas of more rapid disintegration from which the wind has swept a portion of the detritus. Sparse trees of unusual size and luxuriant grass give a parklike aspect to the lower lands, and the higher areas are thickly covered with trees of fair size. The granite outcrops as flat circular bosses, low domes, or depressed piles of rounded residual bowlders. The ground between is covered with coarse yellow or yellowish-pink granite soil. In disintegration to soil wavy cracks first rim the large feldspar areas of the granite; biotite is partially removed in solution, forming cavities, and then the mass crumbles into angular pieces from half an inch to 3 inches long. Later these blocks break down into the constituent minerals or into cleavage fragments of them. The weathered surface of the granite is slightly rough through the almost complete removal of biotite, the partial removal of feldspar, and the relief of quartz. Certain spheroidal planes in the granite are resistant to weathering, and these limit both the depressed domes and the round residual bowlders. The domes, which range from 20 to several hundred feet in diameter, are either intact or represented by heaps of residual fragments. In the destruction of the domes some force, probably frost, first cracks the outer and more resistant granite and, on exposure, the interior rapidly disintegrates. The hard crust is undermined and the solid granite shell partially breaks down, resulting in the formation of partial domes with overhanging caps, somewhat resembling mushrooms. (See fig. 2.) Finally the crumbling pedestals collapse and granitic soil, with here and there a fragment of the hard crust, remains. There are other resistant layers parallel to the outer crust, and by disintegration partial mushroom forms may be superimposed upon the domes. These resistant crusts, from the variety of surface forms which they assume, are of secondary origin and are due to the deposition, upon surfaces exposed to the sun, of cementing material held in solution by water in the rock mass. Other areas underlain by the Rosalie granite are not characterized by well-developed domes.

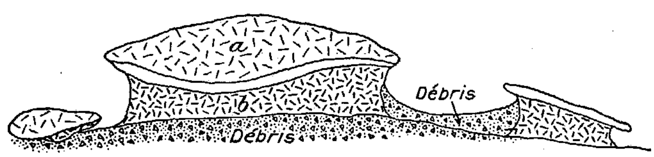


FIG. 2.—Sketch showing domal structure of Rosalie granite, southeastern part of quadrangle. *a*, Hard crusts; *b*, readily disintegrating centers.

It has already been said that domal weathering in the Georgetown quadrangle is confined to the quartz monzonite and the Rosalie granite, and only in certain areas of these formations is it well developed. In consequence it is inferred that in this region such weathering is primarily determined by inherent qualities of the rocks themselves, and only secondarily by topographic and climatic conditions. Of the inherent qualities, the most evident is the lack of closely spaced joints, and a mean resistance to mechanical and chemical disintegration is probably also favorable. The domal weathering is, however, dependent to a certain degree on topographic conditions, since in a general way the domes are rudely concentric to the surface and, furthermore, they characterize mature surfaces away from streams. Climatic conditions also partly control the position of the domes, for they are poorly developed above timber line, where temperature changes are greatest.

The intrusive porphyries are characterized by few outcrops, as they break down readily into angular blocks, most of which are less than a foot in diameter. Dikes as a rule weather flush with the surface of the pre-Cambrian rocks and only in a few places do ruined walls mark their course.

GENERAL GEOLOGY.

PRELIMINARY OUTLINE.

The rocks of the Georgetown quadrangle, with the exception of igneous rocks, probably of late Cretaceous age, and of Quaternary deposits, belong to the pre-Cambrian complex of the Colorado Range. The pre-Cambrian age of these rocks, which can not be demonstrated in the quadrangle, is inferred from relations elsewhere in these mountains. Thus Peale[a] describes a series of crystalline rocks at Glen Eyrie, Colo., on the east front of the Colorado Range, that are in a broad way comparable with those of the Georgetown quadrangle. Upper Cambrian sandstone overlies these rocks unconformably, and the pebbles of the older rock in the sandstone are metamorphosed similarly to the corresponding rocks now in place at Glen Eyrie. The oldest pre-Cambrian rocks of the Georgetown quadrangle, constituting the Idaho Springs formation, are crystallines, presumably of sedimentary origin. This formation, while deeply buried, was subjected to mountain-building forces which folded it in a complex manner and produced in it a regional schistosity. Later, but undoubtedly also in pre-Cambrian time, it was most intensely intruded by a series of holocrystalline igneous rocks. The earlier of these rocks were considerably affected by the mountain-making forces which produced the regional schistosity in the Idaho Springs formation, while the later are mashed only along lines of intense local movement. From the different degrees of schistosity developed in the different pre-Cambrian rocks, the period between the deposition of the Idaho Springs formation and the intrusion of the latest pre-Cambrian granite must have been of vast length, and during the long period of intrusion, to judge from the granitoid habit of the igneous rocks, the surface as we now see it must have been buried beneath a great thickness of overlying rocks.

During early and middle Paleozoic time the area was presumably subjected to enormous erosion and fragmental material derived from the Colorado Range was deposited in the sea to the east of the present front of the range.

It is probable that during at least a portion of late Carboniferous or early Mesozoic time the quadrangle or a part of it was submerged beneath an arm of this sea.

Probably in very late Cretaceous and Tertiary time dikes, sheets, and stocks of siliceous and intermediate igneous rocks intruded the pre-Cambrian complex.

Later a rugged mountain surface was reduced to a mature mountainous upland, and then after an uplift subjected to two periods of Pleistocene alpine glaciation and to unimportant postglacial erosion.

IDAHO SPRINGS FORMATION.

NAME.

The name Idaho Springs formation is applied to a series of interbedded metamorphic crystalline rocks, presumably of sedimentary origin, which are typically exposed in the vicinity of Idaho Springs.

DISTRIBUTION AND GENERAL STRUCTURE.

The Idaho Springs formation is widely distributed over the quadrangle and there is scarcely a square mile in which it does not occur intruded by igneous rocks or as shattered fragments included in them. It is the groundwork through which the igneous rocks have been injected and probably at one time covered the whole plane which is now the surface. The surface exposure, about 53 square miles, is a trifle less than one-fourth of the area of the quadrangle. In the northeast corner the formation occurs as a rudely triangular body covering about 25 square miles. The next largest area forms the crest of the ridge from Griffith Mountain southward almost to the divide between South Clear and East Geneva creeks. Other large areas lie on the western and southern borders of the quadrangle, east of Geneva Creek. The

[a] Peale, A. C., Seventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., pt. 1, 1874, p. 202.

biotite-sillimanite schist and the biotite schist members are highly schistose, the planes of schistosity in some places corresponding with the supposed bedding planes, but more commonly cutting them at high angles. Peculiar features of the distribution of this formation are certain dikelike forms northwest of Georgetown and the narrow lenses of schist 4 miles east of Lincoln Lake, between the Rosalie granite and the quartz monzonite. In explanation of the first it may be stated that the Idaho Springs formation had a highly developed schistosity prior to the intrusion of the granite near Georgetown and so perfect was the consequent parting that the inclusions of the schist in the granite affect a dikelike form. The cause of the lenses between the monzonite and granite is less certainly known, although the intrusion of the monzonite probably hardened the adjacent schist and cemented the contact firmly. In consequence, when the younger granite was intruded a shell of schist clung to the monzonite, fracture occurring between the intensely and less intensely metamorphosed schist rather than between the schist and monzonite. The wavy lines in the color pattern of the Idaho Springs formation on the map (Pl. II, in pocket) show the general strike of the planes of schistosity. The metamorphism of the formation is so intense that in most places the determination of the planes of stratification is impossible and in consequence the thickness of the formation is unknown and its structure can not be unraveled.

The Idaho Springs formation includes four intensely metamorphosed crystalline members, three of which, the biotite-sillimanite schist, the biotite schist, and the quartz gneiss, are interbedded with and grade into one another, while the fourth, consisting of the lime-silicate rocks, although interbedded with the others, appears to grade into the quartz gneiss only. The unity of the formation is further indicated by the equal or approximately equal degree of metamorphism to which each member has been subjected and by their common structural relations to all other formations.

The terms schist and gneiss as here used, in accordance with the interpretation of Van Hise,[a] are wholly structural. Schists, then, are "cleavable rocks the cleavage pieces of which are like one another and the mineral particles of which are for the most part so large as to be visible to the naked eye." A gneiss, on the other hand, is "a banded rock the bands of which are petrographically unlike one another and consist of interlocking mineral particles."

BIOTITE-SILLIMANITE SCHIST.

PETROGRAPHY.

The biotite-sillimanite schist is a foliated and in many places intensely crenulated, normally fine-grained rock. In color it is dark gray or black, but on weathered outcrops it has a rusty appearance. Biotite, clear quartz, white, semitransparent feldspar, and sillimanite are everywhere recognizable megascopically in approximately equal amounts, and in some of the rock muscovite, garnet, tourmaline, and corundum are prominent. White or greenish-white sillimanite occurs in single rods and bundles of rods, elongated in the plane of schistosity, which are cut by transverse fractures whose interstices are filled by biotite flakes and magnetite or pyrite grains. In places the component rods of the aggregates cross one another, forming confused meshes.

The schistosity is due to the parallel orientation and great elongation of biotite and muscovite blades and sillimanite rods and aggregates, to the less perfect orientation and smaller elongation of the quartz granules, and to the still less perfect alignment of feldspar and the accessory minerals. Biotite forms folia of interlocking blades along the planes of parting. The schistosity is emphasized by two lit-par-lit injections of pegmatitic material; one very ancient and the other the youngest of the probable pre-Cambrian formations. Isolated pencils of pegmatite also lie in the planes of schistosity, and in cross section appear as quartz or feldspar "eyes" around which the biotite plates curve (fig. 3). These are locally abundant near pegmatite bands and resemble phenocrysts rounded by granulation. The deformed condition of

[a] Van Hise, C. R., Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 779, 782.

their constituent minerals indicates that they are not the segments of pegmatite dikes separated by shearing, but that their form is original and due to the power of crystal growth. (See p. 63.)

The microscope shows that the rock has the highly linear interlocking texture of a typical schist in which all original sedimentary characters have been destroyed. The larger constituents characteristically inclose crystals and blebs of one another. Biotite occurs in blades with partially developed basal faces and frayed ends. In certain places the elongation of the biotite is at right angles to its cleavage, indicating extreme recrystallization in the production of the present schistosity, a characteristic also of some muscovite folia. Biotite is mainly fresh, but is more or less altered in some thin sections to chlorite and magnetite with or without muscovite or sagenitic webs of rutile. The quartz ellipsoids are characterized by abundant lines of fluid inclusions which pass through several quartz grains and even into feldspar grains. These are evidently secondary and are distributed along minute cracks. Of the feldspar ellipsoids orthoclase is predominant, an acidic plagioclase (albite-oligoclase or oligoclase, rarely andesine) common, and microcline rare. Both the albite and pericline twinning of plagioclase are notably discontinuous and of varying width. Quartz and orthoclase are micropegmatitically intergrown in much of the rock.

Sillimanite has the transverse parting well developed and in many places aligned segments, broken parallel to the basal pinacoid, are embedded in the other essential constituents. By slight displacement of segments at the parting the columns are bent. Macropinacoidal cleavage is

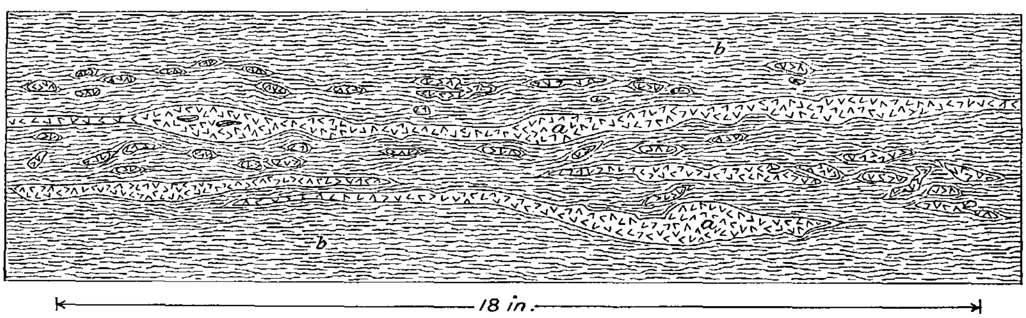


FIG. 3.—Biotite-sillimanite schist of Idaho Springs formation injected by dikes and eyes of pegmatite. *a*, Pegmatite; *b*, gneiss. The large number of the eyes shows how completely the schist was saturated with the pegmatitic fluid. North side of Chicago Creek at the mouth of Spring Gulch.

visible only in the larger rods. In the crystallization of the schist sillimanite and feldspar appear to have been formed from the same material, and in consequence sillimanite-rich laminæ are poor in feldspar. Rude pseudomorphs of sillimanite after feldspar grains also occur, while as certainly sillimanite here and there replaces biotite. Since sillimanite is also a product of contact metamorphism (see p. 40), this mineral appears to have crystallized at three distinct periods. It is for the most part fresh, but in places sericite is pseudomorphic after it. Muscovite is in part intergrown with and contemporaneous with biotite and in part secondary to it. The constant though nowhere abundant accessories are zircon in grains and crystals, apatite in grains and short prisms, and magnetite in grains and crystals. The last two in particular show locally a distinct orientation parallel to the plane of schistosity. Fluid inclusions elongated parallel to the prism axis are common in some apatite individuals. Blebs and sievelike crystals of pink garnet are in no way peculiar. The more uncommon accessories include pyrite intergrown with magnetite and tiny tourmaline crystals; rutile crystals and andalusite grains are very rare.

Since the schist was formed mass mechanical action has bent and fractured biotite and muscovite blades, broken sillimanite rods, and crushed quartz and more particularly feldspar grains, or produced in them undulatory extinction. Here and there this wavy extinction in orthoclase appears to pass into the crosshatching of microcline. These phenomena are most prominent in the quartz gneiss, somewhat less prominent in the lime-silicate rocks and the biotite schist, and least prominent in the biotite-sillimanite schist.

TYPE LOCALITIES.

Biotite-sillimanite schist is the most widely distributed member of the formation. It occurs interbedded with comparatively few bands of the other members on Chicago Creek and in the vicinity of Idaho Springs and Freeland.

CONTACT METAMORPHISM.

In this regionally metamorphosed rock certain minerals are developed near igneous masses apparently through contact metamorphism. Some of these minerals are formed by recrystallization of constituents of the schist through the agency of heat; others, in part, at least, are emanations from the intrusive magma.

On the ridge between Devils Canyon and Barbour Fork of Soda Creek, 1 mile east of the mouth of Eclipse Gulch, residual bowlders of schist contain from 30 to 50 per cent of corundum, which occurs in barrel-shaped crystals from one-half to three-fourths of an inch long and from one-fourth to three-eighths of an inch wide. Under the microscope the colorless corundum shows well-developed cleavage and polysynthetic twinning parallel to 1011. The crystals are mere skeletons filled with biotite and muscovite shreds and quartz and feldspar grains. Fine opaque needles similar to those in quartz are characteristic inclusions. Large plates of muscovite, evidently contemporaneous with the corundum, inclose grains of the latter mineral, and all of these have the same orientation. The structure is then allied to that of micropegmatite. From the abundance of sillimanite in this member of the Idaho Springs formation it is evident that it is rich in alumina. Sillimanite formed during the recrystallization of the gneiss, a process long antedating the intrusion of the quartz monzonite. Since the corundum-bearing rock, however, contains no sillimanite, it is probable that the corundum was produced at the expense of sillimanite, quartz being simultaneously formed.

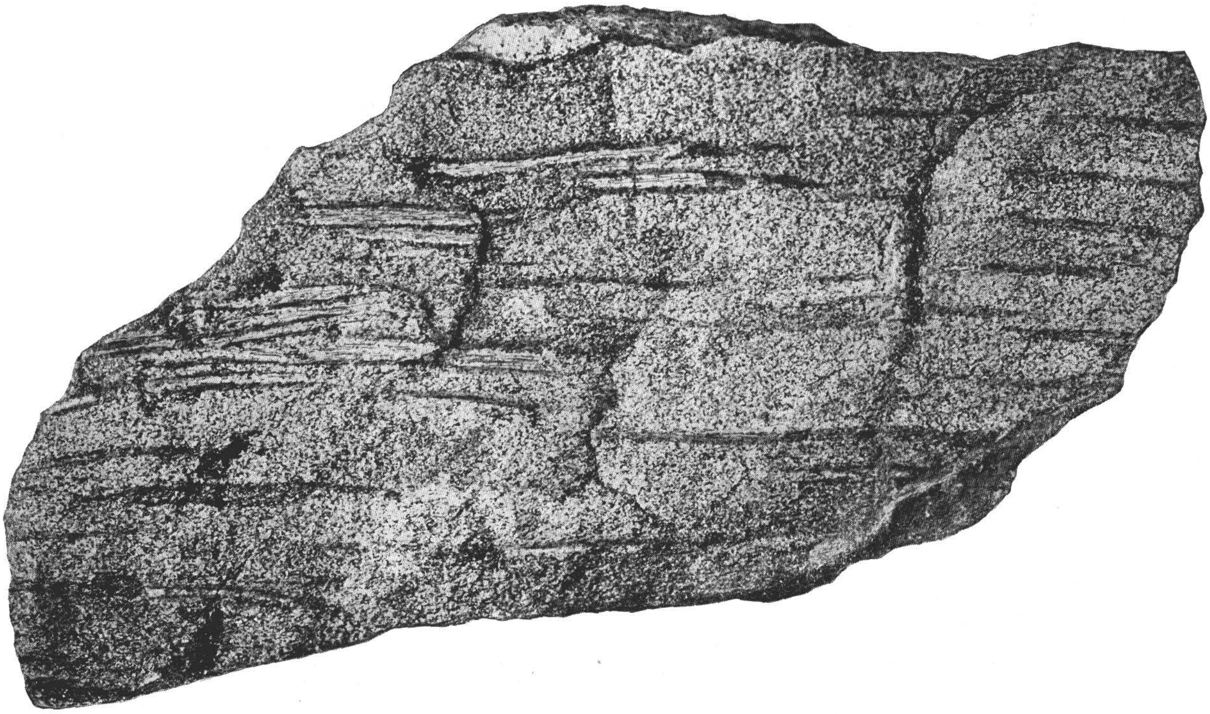
In addition to the tourmaline in microscropic grains already mentioned as an original accessory of the schist, large prisms of black tourmaline are embedded at right angles to the schistosity near pegmatite dikes containing similar tourmaline. Pink garnets up to 2 inches in diameter, some of them surrounded by white halos from which they have abstracted all the ferromagnesian materials, are developed by regional metamorphism, while garnets without such halos are very abundant near garnetiferous pegmatite dikes. It is probable that tourmaline and garnet near pegmatite dikes were derived from solutions originating from the pegmatitic magma. Garnet, probably of contact-metamorphic origin, is relatively abundant in small masses of schist caught up in pre-Cambrian plutonic rocks.

Unusually large plates of biotite and muscovite and aggregates of sillimanite rods, some of the latter being as large as a man's hand, cut the schistosity at high angles near igneous masses and appear to be statically developed through contact metamorphism. Such plates of unoriented muscovite spangle the schist east and north of Chief Mountain and in the northwest and southwest corners of the quadrangle. Microscopic examination shows that the schist near the muscovite is poor in feldspar and it is probable that feldspar was recrystallized into muscovite. Large sillimanite aggregates of static origin occur in garnetiferous schist inclusions 4 miles east of Rosalie Peak.

BIOTITE SCHIST.

PETROGRAPHY.

The biotite schist is differentiated from the type just described by a finer grain, by a medium or light-gray color, and by a less perfect schistosity, due to the smaller biotite content and the almost total absence of muscovite and sillimanite. Minute plates of biotite, well aligned, but not forming continuous films, set in granules of quartz, and feldspar with only a suggestion of a linear arrangement, give a pepper-and-salt effect to the rock. Small segregations of magnetite surrounded by white halos from which they have abstracted the ferric materials are rather common. Fine-grained facies in the southwest corner of the quadrangle are friable, perhaps through mashing. Pegmatitic bands in the biotite schist are comparatively rare, since this rock offered



A. CONGLOMERATIC TYPE OF IDAHO SPRINGS FORMATION, SHOWING PEBBLES ELONGATED INTO BANDS.

B. QUARTZ-MAGNETITE PEGMATITE.

to lit-par-lit injection less highly developed planes of weakness than the more schistose biotite-sillimanite schist.

Under the microscope the biotite schist shows approximately the same minerals as the biotite-sillimanite schist, although they are present in different proportions. Sillimanite and muscovite are relatively rare and quartz and feldspar are more abundant than in the biotite-sillimanite schist, and of the feldspars microcline is most abundant. Epidote, not observed as an alteration product of biotite in the biotite-sillimanite schist, is associated with secondary chlorite.

TYPE LOCALITIES.

The biotite schist is less widely distributed than the biotite-sillimanite schist, but occurs typically exposed near the head of West Chicago Creek and in the southwestern portion of the quadrangle. Small inclusions are abundant in the quartz monzonite. (See p. 52.)

QUARTZ GNEISS.

PETROGRAPHY.

The quartz gneiss is a well-banded rock formed of fine to broad laminæ, varying in color from gray to brown, red, or black. The texture is, as a rule, dense and vitreous, although in places it is saccharoidal. Lit-par-lit pegmatitic injections are rare, as is natural in a rock with imperfect gneissic banding. Under the microscope quartz is shown to be the essential constituent. The accessory minerals include all the minerals present in biotite-sillimanite schist, with the addition of shreds of green hornblende. The gneissic parting is due to the elongation of intricately interlocking quartz lenses, to the variation in granularity of the quartz of adjacent bands, and to the linear arrangement of discontinuous sheets of biotite blades and magnetite cubes. The darker color of certain bands of the gneiss is due to an unusual abundance of this biotite and magnetite.

TYPE LOCALITIES.

The quartz gneiss is less widely distributed than the two facies previously described. It is exposed for a distance of half a mile on Sugarloaf Peak.

ELLIPSOIDAL MASSES.

Distributed in bands parallel to the lithologic boundaries of the members of the Idaho Springs formation already described, but more characteristic of the biotite schist, are white or gray ellipsoidal masses which range in length from one-half inch to 4 inches. The masses are flattened in the plane of schistosity, in some places into paper-thin sheets. (See Pls. VII, VIII, *A*.) The thickness, width, and length range in proportion from 1:2:2 in the less mashed ellipsoids to 1:8:100 or more in those which are more mashed. The latter are cut by sharp fractures that cross the elongation at angles ranging from 60° to 90°. In each band the masses are remarkably even, not only in size, but also in spacing, both parallel to and across the schistosity. They are sharply bounded and the schistosity of the matrix curves around them. The ellipsoids are composed of predominant quartz and subordinate sillimanite. The other minerals of the series are present only in small amounts, feldspar being absent in the thin sections examined. These masses are widely distributed in the quadrangle, but they are particularly well developed on Chief and Pendleton mountains. (For further description see "Pebble-bearing gneiss," p. 177.)

LIME-SILICATE ROCKS.

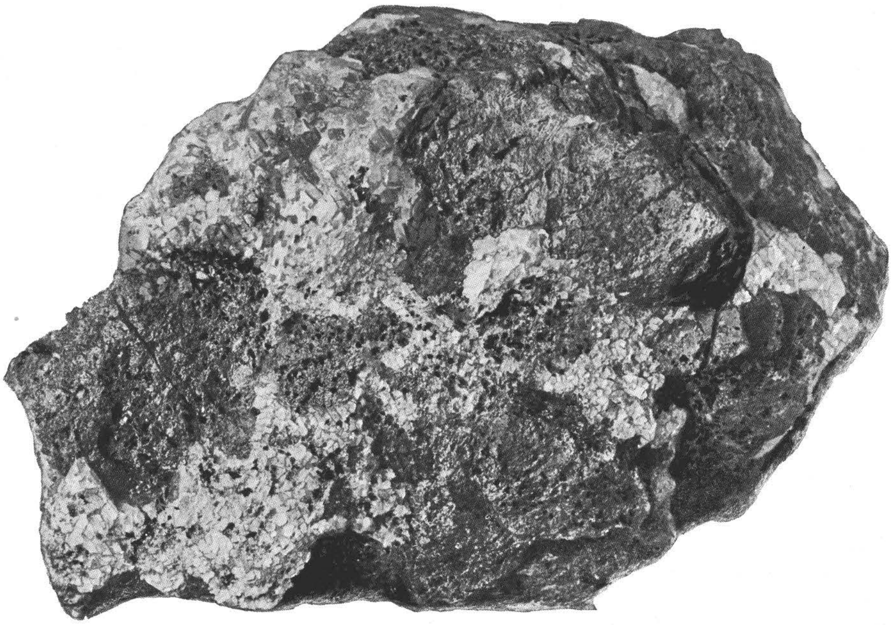
The rocks called here for convenience the lime-silicate member include several intergrading facies of varying composition and texture—quartz-magnetite gneiss, hornblende-diopside gneiss, and two massive rocks, the one composed essentially of quartz, epidote, and garnet, the other of calcite and lime silicates.

Quartz-magnetite gneiss is a finely banded steel-gray heavy rock of fine grain, which on weathered outcrops is heavily iron stained. Imperfect parting occurs along laminæ of the diverse minerals. Under the microscope irregular grains of magnetite form from 20 to 40 per cent of the area of the thin section, quartz, brown or pink garnet, and hornblende being the other essential constituents. Biotite, epidote, chlorite, and zircon are accessory minerals. The quartz-magnetite gneiss is associated with other facies of the Idaho Springs formation near the head of Little Bear Creek and on Trail Creek.

Hornblende-diopside gneiss is a well-banded, fine-grained rock composed of alternating bands of white quartz and feldspar and black or greenish-black hornblende and pyroxene, and as the latter increase the rock changes in color from dark gray to black. Under the microscope the straight or gently curved gneissic structure and consequent parting is seen to be due to the segregation of the dark and light minerals in bands and to the elongation and dimensional arrangement of hornblende and pyroxene parallel to the schistosity. The pyroxene is a greenish diopside and occurs as rude columns which are in places partially altered to hornblende. Hornblende, however, in greater part is an original constituent of the gneiss, and in some thin sections is present to the exclusion of diopside. Epidote occurs here and there as an original constituent of the gneiss and, with or without chlorite, as an alteration product of hornblende. Epidote, zoisite, sericite, and calcite are products of altering hornblende and feldspar. Quartz and the feldspars, predominant oligoclase or a related plagioclase, and subordinate orthoclase, with rarely a little microcline, present no unusual features, although micropegmatitic intergrowths of the two are locally present. In some places tubular areas of these minerals also extend into epidote, the texture closely resembling a micropegmatitic intergrowth. Titanite is an exceedingly abundant accessory mineral, occurring in well-developed crystals or in irregular grains that have mutually interpenetrating borders with the essential constituents, which are evidently contemporaneous with them. Polysynthetic twinning is present in some of the titanite. Magnetite, also an abundant accessory, is as a rule clearly an original constituent of the gneiss. In a few places, however, it forms rude crystals with abundant inclusions of the other constituents of the gneiss, and these may be of later origin. Of the other original accessories, apatite is constant, calcite common and in places abundant, pyrite common, and zircon rare. Hornblende-diopside gneiss is widely distributed in the quadrangle and occurs in most of the areas mapped as the lime-silicate member of the Idaho Springs formation.

This gneiss grades into lenses or bands of quartz, epidote, and garnet, parallel to or cutting its schistosity at low angles. The bands, clearly an alteration of the gneiss, are from 3 to 4 inches wide, but expand and contract irregularly. In many places they occur in series from a foot to several feet apart. Numerous stringers of gneiss remain in the altered rock, the ferromagnesian minerals being as a rule rudely pseudomorphed by epidote. Isolated crystals of garnet and grains of magnetite in interrupted sheets appear to form more freely in the quartz-rich portions of the rock. In some places the partially epidotized hornblende columns sweep around the garnet crystals; and although this may be due to the fact that garnet acted as a buttress by which the orogenic movements were concentrated, it is believed that the columns may have been pushed away from the garnet by the pressure exerted by the growth of crystals, some of which are 6 inches in diameter (fig. 4).

These rocks in which the gneissic structure is only partially destroyed grade into massive aggregates of large or small, mutually penetrating individuals of epidote, garnet, quartz, and magnetite. In many places the coarse-grained rocks with component minerals 6 inches in diameter have the texture of a miarolitic pegmatite with crystals of brown garnet and green epidote lining its cavities. There are facies in which the rock is all quartz, all epidote, quartz and epidote, epidote and garnet, and quartz and garnet. (Pl. IX.) The rocks vary in color from white to brown or green, according as the colorless or snow-white quartz, the cinnamon-brown garnet, or the epidote predominates. Although in certain places these rocks are the hornblende-diopside gneiss recrystallized, in others they form the whole outcrop and may possibly be contemporaneous in origin with that rock. Microscopic examination shows that the rock is massive and in a general way the constituents interpenetrate one another and are



A. GARNET-QUARTZ ROCK OF LIME-SILICATE MEMBER OF IDAHO SPRINGS FORMATION.

Showing partial crystals of garnet. The garnet is dark, the quartz white.

B. EPIDOTE-QUARTZ ROCK OF LIME-SILICATE MEMBER OF IDAHO SPRINGS FORMATION.

Showing pegmatoid structure. The epidote is dark, the quartz white.

all contemporaneous, although quartz and calcite, the latter rarely prominent macroscopically but constantly seen in thin sections, are in general younger than the other components. Brown garnet occurs in large sievelike partial crystals or small and more homogeneous grains. Waldemar T. Schaller, who has made qualitative analyses of this garnet, finds that it contains much aluminum and calcium oxides and considerable ferric iron, the garnet in consequence being between grossularite and andradite. Epidote occurs in sievelike grains or homogeneous crystals and is also intergrown with zoisite, and these minerals have under crossed nicols a moiré appearance. Greenish diopside, the presence of which was not suspected in the field, occurs in rather abundant grains and short prisms in every thin section. It is mainly fresh, but in places is slightly altered to epidote or hornblende. Tremolite in partial columns was observed in a single section, and green hornblende is also in a few sections an original member of the series. Chlorite is secondary to hornblende. Of the accessory minerals titanite, polysynthetically twinned in the larger crystals, and apatite are invariably abundant; pyrite and magnetite are less uniformly present. All these accessory minerals tend to form well-defined crystals, with the exception of apatite, whose borders interpenetrate those of the essential constituents. Apatite in consequence was evidently one of the last minerals to recrystallize. Perhaps the most striking textural peculiarity of the quartz-garnet-epidote rock is the presence of intergrowths closely allied to the micropegmatitic. Epidote and zoisite, epidote and garnet, epidote and hornblende, and calcite and garnet each acts for the other the part of host, all areas of the included mineral being in similar optical orientation. Fluid inclusions are also particularly characteristic, being present in quartz, calcite, garnet, epidote, and diopside.

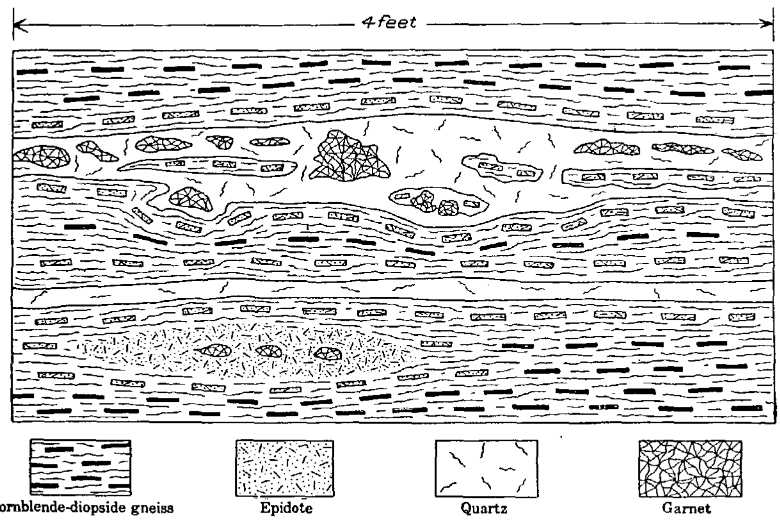


FIG. 4.—Hornblende-diopside gneiss of Idaho Springs formation altered to quartz-epidote-garnet rock in a band parallel to the schistosity. Shows displacement of hornblende columns by the power of crystal growth of the garnet. One-third mile south of Edith Lake.

The extensive wandering and intense segregation of the chemical constituents of the hornblende-diopside gneiss in its alteration to the quartz-garnet-epidote rock are suggestive in indicating the manner in which certain lenslike ore bodies, particularly magnetite, may develop in gneissic metamorphic rocks.

The quartz-garnet-epidote rock is well developed south of Freeland, on Democrat Mountain, and in many other places in the quadrangle.

Associated with the hornblende-diopside gneiss one-half mile west of south of Alpine Mountain is a massive rock composed of predominent calcite grains with some partial crystals of bottle-green pyroxene and brown garnet. The weathered surface of this rock, which resembles a metamorphosed limestone, is roughened by protruding bunches of silicates. As seen under the microscope the rock is a rather finely granular aggregate, composed of calcite, scapolite, diopside, grossular garnet, quartz, tremolite, titanite, and ilmenite, named in the order of abundance. The twinning planes of the calcite are in places slightly bent by deformation. The scapolite grains, many of which are inclosed by rims of grossular garnet, are somewhat altered to muscovite, calcite, and quartz, and epidote is formed at the junction of scapolite with calcite.

ORIGIN.

The Idaho Springs formation has been so greatly metamorphosed that all original textures have been destroyed. The lithologic variation across apparently bedded bands, some mere laminæ, others several hundred feet thick, suggests a sedimentary series, while the bands containing the ellipsoidal masses are most naturally regarded as conglomerates. (See Pls. VII, VIII, *A*.) The quartz gneiss is present in masses so thick that it can scarcely be of pegmatitic or vein origin and probably represents intensely metamorphosed sandstone. The lime-silicate rocks would in this interpretation of the origin of the formation represent calcareous sandstones and impure limestones, and the biotite-sillimanite schist and biotite schist would be metamorphosed shales and arkoses. The abundance of aluminum silicates in the series and the similarity to metamorphic rocks of known sedimentary origin support the view of the supposed sedimentary origin of the Idaho Springs formation. This formation may be regarded, then, as an intensely metamorphosed series of shales, arkoses, sandstones, conglomerates, and impure limestones.

No regular stratigraphic sequence of the various members of the formation can now be worked out. This lack of regularity is perhaps partially original, the members having been laid down in lenses—an inference strengthened by the erratic distribution of the ellipsoidal masses—but it is doubtless in the main due to the intense folding, faulting, shearing, and injection to which the formation has been subjected. Solution may in part account for the discontinuity of the bands of lime-silicate rocks.

AGE.

The Idaho Springs formation is the oldest member of the pre-Cambrian in the Georgetown quadrangle, since it is cut by all the other formations.

The investigation of the pre-Cambrian rocks of Colorado has not progressed far enough to correlate with certainty formations described by various authors; nevertheless suggested correlations may have some value. In the vicinity of Pikes Peak, Cross[a] found schists included in pre-Cambrian granites. He says: "These seem to represent earthy Algonkian quartzites metamorphosed by a great development of mica or of fibrolite." In the northwest corner of the Cripple Creek quadrangle is an area of schist which widens to the northwest toward the Georgetown quadrangle, 40 miles distant. A ridge near by "consists of fibrolitic quartzite with a small and variable amount of feldspar. This is also cut by granite dikes and is entirely surrounded by granite."[b] Careful examination of these schists shows some to be similar to the quartz gneiss and others to the biotite schist of the Idaho Springs formation. Tentatively these ancient rocks in the Cripple Creek and Georgetown quadrangles are correlated with one another. In the Crested Butte quadrangle Cross[c] also found schists among the Archean (or pre-Cambrian) rocks. He writes: "The quartzose mica schists are sometimes fibrolitic." Notwithstanding the fact that the Crested Butte area lies 75 miles southwest of that under discussion, these mica schists are identical with gradational facies between the biotite-sillimanite schist and the quartz gneiss, and it is possible that the two are approximately contemporaneous.

The pre-Cambrian quartzite of South Boulder Creek, described by Van Hise,[d] lies unconformably upon a granite which in the amount of mashing suffered and in lithologic character somewhat resembles the Silver Plume granite. (See p. 58.) The gap of 18 miles between Idaho Springs and South Boulder Creek has not been traversed, but it is believed that the Idaho Springs formation is vastly older than Van Hise's pre-Cambrian quartzite.

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[a] Cross, Whitman, Geologic Atlas U. S., folio 7, U. S. Geol. Survey, 1894, p. 1. Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 26.
[b] Cross, Whitman, Geologic Atlas U. S., folio 7, U. S. Geol. Survey, 1894, p. 1.
[c] Idem., folio 9, U. S. Geol. Survey, 1894, p. 6.
[d] Van Hise, C. R., Bull. U. S. Geol. Survey No. 86, 1892, p. 325.

HORNBLENDE GNEISS.

DISTRIBUTION AND GENERAL STRUCTURE.

The hornblende gneiss has a wide distribuiton, especially in the southern portion of the quadrangle. It injects the Idaho Springs formation in sheets parallel to the supposed bedding planes or it cuts across them as dikes. Dikes, well exposed on the west side of Soda Creek near the mouth of Little Bear Creek, cut not only the biotite-sillimanite schist, but the associated lit-par-lit pegmatitic sheets. On the southeast slopes of the hill northwest of Geneva Park (elevation 10,193 feet) a dike sharply cuts the hornblende-diopside gneiss of the Idaho Springs formation and sends out short, jagged arms along the planes of schistosity. The smaller dikes and sheets occupy clean-cut fractures and rarely include fragments of older rock. They are further characterized by comparatively few apophyses in contradistinction to the masses of more acidic igneous rocks. Portions of the basic igneous rock, now a gneiss, may have been a surface flow, although there is no positive evidence that such was the case. The original lenslike form of the sheets and dikes and the intense folding, faulting, and later intrusion suffered by the igneous rock explain the small extent of most of the hornblende-gneiss areas.

PETROGRAPHY.

The hornblende gneiss is a fine-grained, well-banded rock in which black or greenish-black layers of hornblende alternate with white laminæ of quartz and feldspar. Some of the exposures in the southern portion of the quadrangle are formed of a slightly coarser, though still fine-grained gneissic aggregate that is medium gray, of lighter shade because quartz and feldspar are more abundant. Biotite is developed at the expense of hornblende where maximum movement has occurred, and along shear planes the rock passes to a biotite-hornblende schist. Rounded aggregates of hornblende or biotite, or both, give a porphyritic aspect to certain facies. Dark massive rocks grading into normal hornblende gneiss and closely resembling dolerite form the central portions of the Soda Creek dikes already mentioned.

As seen under the microscope hornblende and biotite together form approximately one-half of the volume of the rock, and either may be present to the almost total exclusion of the other. Besides the replacement of hornblende by biotite through mashing, hornblende alters locally to epidote, to chlorite, or to epidote and some chlorite, calcite, and magnetite. Biotite is in the main fresh, its most common alteration product being epidote with or without chlorite and magnetite. Of the feldspars a plagioclase, as a rule labradorite, generally predominates over orthoclase. Microcline is present in some thin sections. The feldspars are notably fresh, although alteration to sericite and less commonly to sericite, zoisite, quartz, and calcite occurs. The original basic rock contained quartz, but in the gneisses a portion probably represents the excess of silica produced in the recrystallization of the constituents of the igneous rock, and a further portion is clearly a by-product of feldspar alteration. Micropegmatitic intergrowths of orthoclase and quartz occur on the borders of some of the grains of these minerals.

A pale-greenish augite in short columns, sparingly present in some thin sections, is evidently contemporaneous with hornblende, and some compact hornblende is secondary to it. Apatite, magnetite, in places titaniferous, and titanite are constant and rather abundant accessory minerals, and titanite is also derived from the alteration of titaniferous magnetite. Pyrite is a less common accessory, while rutile is rare. Besides the secondary production of epidote and zoisite already mentioned, granular aggregates of epidote and zoisite are derived from the interaction of altering biotite or hornblende and feldspar, and both minerals form along shearing planes.

The foliation of the gneiss is in general strongly developed. Under the microscope the straight or gently curved parting planes are found to be situated along alternating bands of light and dark minerals. The longest axes of the rude columns of hornblende, and to a less degree its cleavage, are aligned in the plane of schistosity, although the mean axes of the columns are not oriented in it. Ragged rods of biotite are less perfectly oriented, while quartz and feldspar ellipsoids and the iron ores are oriented but slightly. The texture is in consequence that of a typical schistose rock, and the interpenetration and inclosure of each of the essential constituents by the others, characteristic of many metamorphic rocks, is highly developed.

The banded aspect is increased by lit-par-lit pegmatitic injections. These resemble the older pegmatite which occurs in the Idaho Springs formation, but, since in some places the laminæ of the latter stop abruptly on encountering the hornblende gneiss, the intrusion of this siliceous rock must have begun before the solidification of the basic igneous rock that is now the hornblende gneiss and continued for some time after its solidification.

Since the recrystallization of the gneiss mass mechanical action has deformed the mineral constituents in like manner and degree to those of the Idaho Springs formation.

Under the microscope the massive rock from the Soda Creek dikes proves to be a metadolerite or diabase of ophitic texture, and the hornblende gneiss prior to its recrystallization was probably all dolerite or a related rock. The abundant lath-shaped feldspar crystals, seen in the hand specimen, are labradorite. Green hornblende, like that of the gneiss, a little biotite, and wedges of orthoclase and quartz, in places micropegmatitically intergrown, lie between the plagioclase laths. Tubules of quartz also extend from the quartz wedges into hornblende. Apatite, titanite, pyrite, and titaniferous magnetite are present as accessories.

AGE.

The hornblende gneiss cuts the Idaho Springs formation, and is therefore younger. The gneiss itself is cut by the other igneous rocks of the quadrangle. A well marked schistosity is developed in the hornblende gneiss over wide areas, indicating that it is a very ancient rock, although the Idaho Springs formation, prior to the injection of this basic igneous rock, had locally at least a well-developed schistosity. (See fig. 5.) Spencer[a] has described in the Sierra Madre near Encampment, Wyo., hornblende schists somewhat similar lithologically to the hornblende gneiss. The two formations have suffered broadly equal deformation and each is much older than a series of acidic and basic granular igneous rocks. The intrusion and extrusion of basic igneous rocks were evidently important events in the early pre-Cambrian history of the Colorado and Wyoming mountains.

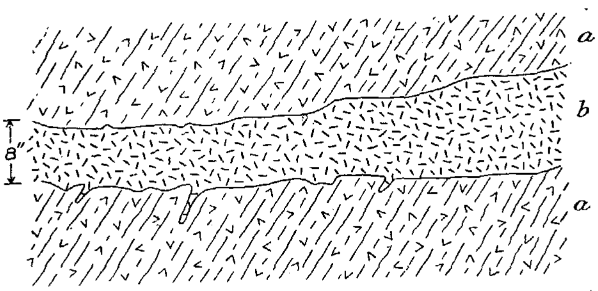


FIG. 5.—Hornblende gneiss (*b*) (mashed metadolerite) intruding hornblende-diopside gneiss (*a*) of Idaho Springs formation, Geneva Park.

QUARTZ MONZONITE GNEISS (ADAMELLITE GNEISS).

DEFINITION.

Brögger[b] defines monzonite as a granular plutonic rock chemically and mineralogically between the syenites and diorites. It is characterized by the presence of nearly equal amounts of orthoclase and plagioclase, together with hornblende, biotite, or augite. Where a considerable amount of quartz is present the rock is a quartz monzonite, which is very closely related to both granite and granodiorite. Where such a rock has a gneissic structure it is designated a quartz monzonite gneiss.

DISTRIBUTION AND GENERAL STRUCTURE.

Quartz monzonite gneiss occurs at many places, especially in the central and southern portions of the quadrangle. The largest area is on Paines Mountain, and the other areas lie

[a] Spencer, A. C., Prof. Paper U. S. Geol. Survey No. 25, 1904, pp. 21-24.

[b] Brögger, W. C., Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo, etc.: Die Eruptivgesteine des Kristianiagebietes, pt. 2, Kristiania, 1895, pp. 21-23.

on the north slope of the ridge between Rosalie Peak and Meridian Hill, 0.8 mile east of the lower Chicago Lake, and on Mount Evans.

The igneous rock, now a gneiss, was intruded as sheets, dikes, and irregular masses into the Idaho Springs formation and the hornblende gneiss, and the schistosity of these rocks, which even then was well developed, controlled in no small degree the form of the monzonitic masses. The lack of continuity and symmetry of the quartz monzonite gneiss masses is to no considerable extent due to the intrusion of younger rocks. Although in some exposures the age relations of the gneiss, the Idaho Springs formation, and the hornblende gneiss are clear, the contacts between these formations are usually sharp lines with parallel gneissic structure, it being evident that the monzonite when intruded did not eat its way into the older rocks. Southeast of Naylor Lake the monzonite gneiss and the Idaho Springs formation seem to grade into each other, apparently as a result of absorption of the schist by the quartz monzonite when injected. The granular texture of practically all portions of the pre-Cambrian igneous rocks, irrespective of the size of the intrusive masses, probably indicates that the intruded rocks were themselves highly heated at the time of intrusion.

The close resemblance in mineral composition of the quartz monzonite gneiss to the younger quartz monzonite, described on page 74, is striking, these rocks furnishing a good example of two similar monzonitic intrusions, separated by a granitic intrusion.

Slight differentiation of the monzonite magma occurred prior to its solidification, and finer grained, more basic segregations are characteristic of some exposures.

PETROGRAPHY.

The quartz monzonite gneiss is a medium-grained gneissic rock, normally porphyritic, of gray and rarely pinkish color. Many weathered exposures are stained reddish or brown by iron oxides. Black mica, smoky quartz, white, striated, and pinkish-white unstriated feldspar, and less constantly greenish-black hornblende, are the prominent macroscopic constituents. Crystals of pyrite and magnetite and wedges of reddish-brown titanite are the only accessories visible to the naked eye.

The gneissic structure varies considerably in the perfection of its development, and the rock is massive only under very exceptional circumstances. The gneissic structure is due to the segregation in alternating straight or gently curved bands of quartz and feldspar and of biotite and hornblende. Under the microscope the parting parallel to the gneissic structure is seen to be due to the parallel orientation and elongation of biotite blades through recrystallization and to a slight elongation of the hornblende columnar grains parallel to the schistosity. Apatite, zircon, and titanite in certian sections show marked parallelism to the gneissic structure, indicating the extreme recrystallization to which the rock has locally been subjected.

Rudely ellipsoidal white striated feldspar phenocrysts from 0.15 to 1 inch in length lie embedded in the groundmass. These feldspars are aligned parallel to the gneissic structure and have suffered the same deformation as the smaller constituents. The rock in consequence is a mashed porphyritic quartz monzonite.

The quartz monzonite gneiss near Geneva Park and inclusions of this gneiss in the quartz monzonite batholith, described on page 89, contain also pink feldspar phenocrysts, some of them 2 inches long and many of them twinned according to the Carlsbad law. Biotite blades, quartz globules, and the accessory minerals present as inclusions are in places zonally arranged. These phenocrysts have perfect crystal outlines, with their longest axis at right angles to the gneissic structure, even in the most metamorphosed groundmass. Microscopic examination shows that these microcline phenocrysts, chiefly microperthitic, are uncracked, whereas the feldspars of the groundmass are fractured. The phenocrysts are probably of metamorphic origin and were formed after the rock became a gneiss. In certain exposures they have been mashed by later deformation into ellipsoids and even into ribbon-like masses.

Microscopic study shows that the rock was a porphyritic quartz monzonite of hypidiomorphic granular texture which was characterized by unusually abundant accessory minerals. In some facies, however, there is so little alkali feldspar that it passes into a granodiorite.

Plagioclase is more abundant than the other essential constituents—quartz, microcline, orthoclase, and biotite—and of these latter any one may predominate. Hornblende, however, although in general abundant, is not present in all thin sections. The plagioclase phenocrysts and the smaller plagioclase individuals vary in composition from calcic oligoclase to andesine. The plagioclase phenocrysts in particular are characterized by zonally arranged tiny magnetite cubes and by minute rods, hexagonal plates, and dots which are typically opaque and black, although translucent and red on the thinnest edges. They are probably ilmenite or hematite. Similar interpositions occur locally in orthoclase and microcline. Orthoclase, in some places with a few microperthitic bands, forms small grains showing slight zonal growth. The microcline of the groundmass is in part a product of the recrystallization of the rock into a gneiss, a phenomenon better developed in the gneissoid granite. (See p. 50.) The feldspars are somewhat altered to sericite and kaolin, and epidote is also developed at the expense of plagioclase, particularly adjoining biotite or hornblende. The fluid inclusions in quartz are mainly secondary and lie in distinct planes. The opaque hairlike interpositions characteristic of much granitic quartz are developed in this rock only in secondary quartz. Micropegmatitic intergrowths of quartz and each of the three feldspars occur along the borders of the grains, and tubules of quartz protrude into the hornblende grains. Disks of micropegmatitic orthoclase and quartz lie between the other constituents. Some of the biotite in almost every thin section is partially altered, the initial step being either the partial loss of color or a change from brown to green. By further alteration epidote is formed if hornblende is present; in its absence chlorite and magnetite or these minerals with either muscovite or rutile needles are formed.

In many sections hornblende and biotite are intergrown. Inclusions of the other rock constituents are so abundant in the hornblende columnar granules that they are in places mere skeletons. Hornblende alters to either biotite or epidote, the former having developed apparently during the gneissic recrystallization of the rock, the latter alteration being a later process. The uncommonly abundant and large accessory minerals are magnetite, titanite, apatite, zircon, and pyrite. Magnetite and titanite locally form skeleton growths around quartz and feldspar, probably a result of the gneissic recrystallization. Magnetite in part is titaniferous, and titanite is secondary to it, although ilmenite may also be present. Both primary and secondary titanite are in general altered, and even where the other constituents are fresh a whitish or brownish semitransparent flocculent aggregate partially replaces it. Short, stocky columns of apatite are common, and long rods are characteristic inclusions in feldspar. In several sections segments of once continuous apatite crystals are embedded in quartz grains, apparently indicating movement in the magma between the crystallization of the apatite and quartz. Pyrite is generally surrounded by or intergrown with magnetite. Allanite in crystals is not an uncommon accessory mineral.

The effects of deformation to which the gneiss has been subjected since its recrystallization are similar in every way to those already described in the discussion of the Idaho Springs formation.

The quartz monzonite gneiss in the vicinity of Georgetown and on Leavenworth Creek is unusually rich in biotite and lacks plagioclase phenocrysts. Microscopically these rocks are without hornblende and titanite and contain a little muscovite intergrown with biotite.

Rather massive varieties of the gneiss, which to a remarkable degree show the porphyritic habit, are included in later plutonic rocks at two places, one 0.4 mile west of the summit of the trail from Elk Creek to Indian Creek and the other 1.1 miles N. 55° W. of the same point. The very fine granular groundmass of biotite and feldspar contains small phenocrysts of biotite, feldspar, and hornblende. Under the microscope the allotriomorphic granular groundmass is proved to consist of calcic oligoclase, hornblende or faintly yellowish-green augite, orthoclase, and quartz, named in the order of abundance. The plagioclase phenocrysts are perfectly formed, but those of hornblende, augite, and biotite are mere skeleton growths in which the groundmass individuals are inclosed. Augite, in particular, occurs as small disconnected areas of similar optical orientation, between which the groundmass mosaic lies. The accessories are similar to those of the granitoid facies.

AGE.

The quartz monzonite gneiss intrudes the Idaho Springs formation and the hornblende gneiss and includes fragments of both. It is in turn cut by the gneissoid granite and the igneous rocks which succeed it.

GNEISSOID GRANITE (MASHED BIOTITE GRANITE).

DEFINITION.

Granite is a wholly crystalline, granular igneous rock consisting of orthoclase (or some other alkali feldspar), quartz, and either muscovite, biotite, or amphibole. Where biotite is the predominant mineral of the three last named the rock is designated biotite granite. The prefix "gneissoid" indicates that the granite has suffered considerable mashing.

DISTRIBUTION AND GENERAL STRUCTURE.

Gneissoid granite covers considerable areas in the southwest corner of the quadrangle and smaller masses are widely distributed, being particularly abundant east of Georgetown and west of Idaho Springs. Dikes, sheets, and irregular stocklike masses cut the Idaho Springs formation, the hornblende gneiss, and the quartz monzonite gneiss. Planes of weakness parallel to the schistosity of the older formations controlled in a marked degree the form assumed by the injected magma. The continuity and symmetry of the gneissoid granite masses have been considerably modified by intrusions of younger igneous rocks.

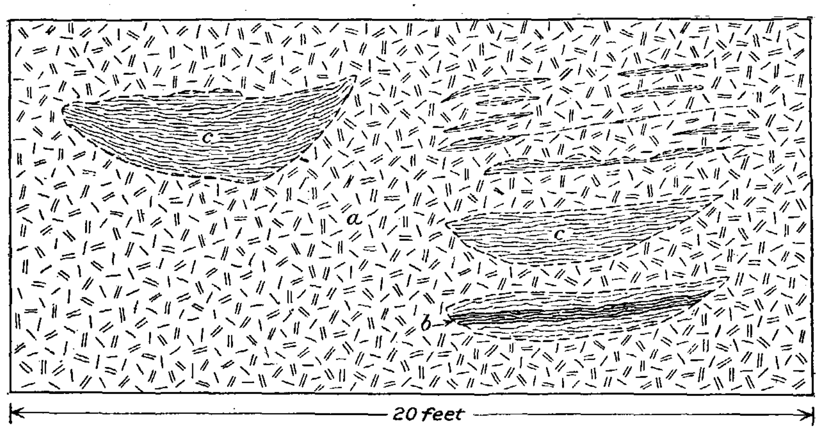


FIG. 6.—Gneissoid granite (*a*) with inclusions of biotite-sillimanite schist (*c*) of Idaho Springs formation, one of which is cut by hornblende gneiss (*b*), partly eaten and shredded by magma. One-half mile west of mouth of Spring Gulch, on north side of Clear Creek, Central City quadrangle.

The granite magma when injected must have been very fluid, for it inserted itself between the folia of the earlier gneisses and replaced in a notable degree inclusions of the biotite-sillimanite schist of the Idaho Springs formation. In proof of this, dark bands in scroll-like patterns of more basic granite preserve the outlines of schist inclusions, while in many places lacelike shreds of biotite suggest the forms of original inclusions now almost totally absorbed (fig. 6). Similar phenomena, referred to at greater length on page 60, characterize the granite-pegmatite.

PETROGRAPHY.

The gneissoid granite is a fine-grained rock of even texture, which is light to medium gray when fresh and flesh pink to yellowish brown when weathered. Some of the gneissoid granite in the southwestern portion of the quadrangle is of rather uneven, medium grain. White to pinkish-white feldspar, slightly smoky quartz, and black mica are visible to the naked eye, although the mica is in some of the rock practically lacking. Facies poor in biotite belong in mineralogical composition with the siliceous granites for which Spurr has proposed the name alaskite.[a] Muscovite plates which reach a maximum diameter of an inch and inclose

[a] Spurr, J. E., Am. Geologist, vol. 25, 1900, p. 230.

the other constituents poikilitically are locally prominent. Magnetite, pink garnet in small sporadic grains, and sillimanite in matted fibrous aggregates are visible here and there. The sillimanite aggregates, which are one-fourth of an inch in diameter, are associated with muscovite.

At several exposures west of Idaho Springs the normal rock grades into a coarse granite, which in turn passes into a pegmatite characterized by the presence of both biotite and magnetite.

The microscope shows the texture of the more massive facies to be allotriomorphic granular. The quartz is of the normal granitic type, except for the abundant inclusion in many of the grains of curved, opaque, threadlike microlites. The plentiful fluid inclusions are either in sporadic bunches and original or in planes crossing from one quartz grain to another and secondary. The secondary inclusions are smaller than the original ones, and are ellipsoids elongated parallel to the fracture on which they are situated. Orthoclase and microcline greatly predominate over oligoclase or a closely related acidic plagioclase. Micropegmatitic intergrowths of each of the feldspar species with quartz occur, and quartz and the feldspars inclose blebs of one another micropoikilitically. The content of microcline, much of it microperthitic, increases proportionately with the amount of recrystallization to which the rock has been subjected, and in consequence this mineral is absent in some slides and is the predominant feldspar in others. In still others it is confined to one portion of the thin section. Although some microcline is probably original, the larger portion is certainly of secondary origin. It occurs in wedges and hooklike masses which in places separate quartz or orthoclase fragments of similar orientation (fig. 7); in other places elongated areas are arranged end to end as if forced into planes of weakness (fig. 8). In still other places altered plagioclase or orthoclase grains are dotted by fresh areas of microcline similarly oriented and elongated parallel to the cleavage of the orthoclase or the albite twinning of the plagioclase. In many sections the host is fractured and unshattered microcline bridges the crack.

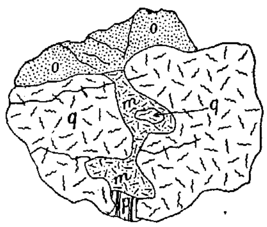


FIG. 7.—Recrystallized microcline in fractured quartz (of gneissoid granite). *q*, Quartz with undulose extinction; *o*, orthoclase, highly altered and fractured; *m*, microcline, perfectly fresh and unfractured; *p*, plagioclase. ×12.

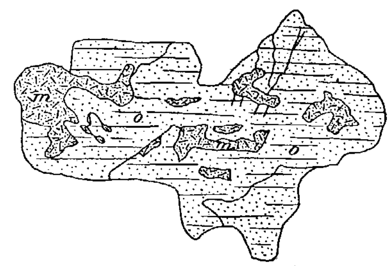


FIG. 8.—Secondary microcline (*m*) filling fractures or deposited along them in fractured and altered oligoclase (*o*) (in gneissoid granite). ×24.

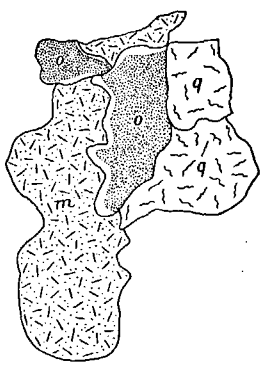


FIG. 9.—Orthoclase with the rim recrystallized in junction with secondary microcline (in gneissoid granite). A narrow rim of orthoclase was recrystallized when the later microcline was formed. *o*, Orthoclase; *q* quartz; *m*, microcline. ×24.

Microcline incloses globules of the other feldspars, which have a narrow fresh rim adjacent to the microcline, in contradistinction to the altered feldspar of the main mass (fig. 9). Such fresh rims of the older feldspars stop sharply where the bordering mineral changes from microcline to quartz. This microcline is clearly later than the other feldspars and formed after the solidification of the magma and probably prior to the mashing of the rock, since here and there oriented muscovite blades replace it. It may have formed, however, in the early stages of mashing, the formation of the muscovite perhaps being a late phenomenon of that process. Orthoclase and oligoclase are considerably altered to sericite, granules of zoisite are locally associated with these minerals derived from oligoclase, but kaolin is less abundant. In some thin sections biotite and muscovite are intergrown. Biotite is in general considerably altered, its most common change being to chlorite and magnetite, in many places with the separation of needles of rutile. The alteration to epidote with or without chlorite is more uncommon. In some thin sections muscovite is an original accessory, in others it is secondary to and replaces biotite, and in still others it is a product of recrystallization during mashing.

The poikilitic muscovite plates, already mentioned, are so associated with and grade into sericite shreds, the alteration products of feldspar, that they are themselves doubtless secondary. Zircon, apatite, and magnetite are abundant accessory minerals. Magnetite, which in some thin sections appears to be titaniferous, rarely incloses zircon and apatite. Ilmenite is also probably present in some of the rock. Original titanite is confined to the medium-grained gneissoid granite from the southwest corner of the quadrangle. The mineral is also secondary to titaniferous magnetite. Pyrite, seen in a single thin section, may be original. The rounded grains of garnet contain no inclusions. In the granites of the Georgetown quadrangle garnet is confined to this granite and to the granite-pegmatite and associated granites, each the solidified product of a rather siliceous magma.

The aggregates of interwoven sillimanite rods are rimmed by narrow bands of muscovite. The two minerals are approximately contemporaneous in age, and although it is probable that the muscovite is a product of mashing, both may be original.

The granite varies not only from place to place, but in many single exposures, ranging from an almost massive rock to a banded rock in which quartz and feldspar layers are separated by discontinuous sheets of aligned biotite plates. The gneissoid bands are straight or gently curved, being sharply folded only near later eruptive masses. Microscopic examination shows that the gneissoid structure is due largely to recrystallization and partially to granulation. During recrystallization biotite and muscovite blades formed parallel to the present gneissic structure, and quartz and feldspar were in some places slightly oriented. The more gneissoid facies occur about the border of large areas of granite or around gneiss inclusions. The banding is broadly parallel to that of the neighboring masses of gneiss and schist.

Since the partial recrystallization of the granite the constituents have been deformed by later mass mechanical action.

AGE.

The gneissoid granite injects and incloses portions of the Idaho Springs formation, the hornblende gneiss, and the quartz monzonite gneiss, and in turn is included in and cut by the quartz monzonite and the succeeding igneous formations.

QUARTZ MONZONITE (ADAMELLITE).

DISTRIBUTION AND GENERAL STRUCTURE.

Quartz monzonite covers about one-half of the area of the quadrangle. Minor intrusive masses of this rock are rather widely distributed, and a single body 10 miles square occupies the central, north-central, and east-central portions of the quadrangle. This large body is a portion of a batholith which extends far beyond the eastern boundary. The contact of this batholith and the older gneisses and schists on the north side of the monzonite dips to the north at an angle of 10° to 30°; on the west and south sides it is steeper and in some places dips toward the batholith. In the northwestern portion of the batholith considerable areas of the Idaho Springs formation upon ridge crests probably represent remnants of the now eroded covering of older rocks. Many exposures of rock wholly massive in hand specimens have in the field a gneissic structure, which near the center of the batholith is horizontal and near the edges dips parallel to the contact. This gneissic structure, apparently original (see p. 45), is probably concentric with the roof of the batholith, and its curved plane indicates that the batholith was originally asymmetrical, for the western and southern portions extended much farther upward into the covering of older rocks than the central and northern portions.

The concentric strike of the schistosity of the older rocks around the batholith shows that the igneous mass made room for itself by thrusting aside these older rocks. This process was aided to an unknown extent by that of "overhead stoping," concerning which our ideas have been much clarified through recent articles by Daly.[a] According to this hypothesis the covering of older rocks is shattered by the expansion due to the heat of the adjacent igneous mass,

[a] Daly, R. A., Am. Jour. Sci., 4th ser., vol. 15, 1903, pp. 269-298; idem, vol. 16, 1903, pp. 108-126; Bull U .S. Geol. Survey No. 209, 1903, pp. 93-100.

and the partially loosened fragments are broken off and engulfed in the magma, in which they sink to abyssal depths and by which they probably are eventually assimilated. Two facts of observation argue for the application of "overhead stoping" as a process by which the space now represented by the batholith was partially formed. These are, first, the presence of an unusual number of apophyses, many of which are too small to map, extending from the main mass into the older rocks, indicating that the surrounding rocks were profoundly shattered, and, second, the presence in the monzonite of myriad inclusions of the older rocks, varying from small fragments to masses half a mile in diameter. These inclusions, the larger of which alone are shown on the map, are so abundant that scarcely any large exposure is free from them and many exposures are literally filled with them (fig. 10). The contact between the monzonite and the inclusions is sharp, although the corners have been somewhat rounded by the corrosive action of the magma. As a rule the inclusions are somewhat more abundant near the periphery of the batholith than in its center, although in this area such an arrangement is not essential to the application of the hypothesis, since it is probable that the present land surface is nowhere at great depth beneath the original roof of the batholith.

Waldemar T. Schaller determined the specific gravity of the biotite schist of the Idaho Springs formation to be 2.737, that of the biotite-sillimanite schist of the same formation 2.844, and that of the quartz monzonite 2.830. These figures probably account for the relatively greater proportion of the biotite schist inclusions in the quartz monzonite than of biotite-sillimanite schist, notwithstanding the fact that the former, lighter rock is subordinate in bulk to the latter, heavier rock, as far as indicated by surrounding areas of the Idaho Springs formation. This follows from the fact that in the process of "overhead stoping" blocks of biotite-sillimanite schist, being heavier than the monzonite magma, would sink to great depths, while those of biotite schist would be buoyed up by the magma. In consequence, the blocks of the heavier rock included in the monzonite are only those fragments that were broken from the covering rocks during the last stages of "overhead stoping" and held in the almost viscous magma; whereas the blocks of the lighter rock include a considerable proportion of all the biotite schist fragments which were wedged from the roof. It must be admitted that the alignment of the longer axis of some of the biotite-sillimanite schist fragments parallel to the hypothetical roof is against this assumption, since theoretically all the fragments of the heavier rock should occupy a vertical position. The strong tendency, however, of the biotite schist fragments to be everywhere aligned and of those of the biotite-sillimanite schist to be in comparatively few places aligned is on the whole corroborative evidence of the application of "overhead stoping" as an important process in forming the space now occupied by the batholith. That this space was probably not enlarged to an important degree by the corrosive action of the magma is indicated not only by the sharp contact between the older rocks and the monzonite, but also by the absence of important differentiation of the monzonite in contact with gneisses and schists of varying composition. The rounded corners of the inclusions, however, show that some assimilation has occurred.

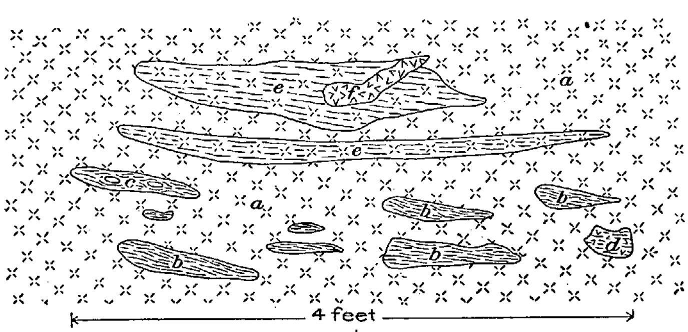


FIG. 10.—Quartz monzonite (*a*) with inclusions of biotite-sillimanite schist (*b*) and conglomeratic biotite schist (*c*) of Idaho Springs formation, hornblende gneiss (*d*), and quartz monzonite gneiss (*e*). The last-named inclusions are cut by an ellipsoidal dike of granite-pegmatite (*f*). West side of Chicago Creek.

PETROGRAPHY.

The quartz monzonite is a gray to bluish-gray, moderately coarse-grained, granular rock, much of it more or less porphyritic in habit. Megascopically, white and pinkish-white feldspar, slightly smoky quartz, black mica, and greenish-black hornblende are essential constituents, and magnetite grains, reaching one-half inch in diameter, and titanite wedges with a maximum length of one-fourth inch are abundant accessories. In the porphyritic facies rude crystals of pink microcline, rarely orthoclase, mainly Carlsbad twins, reach a maximum length of 1 inch. In many places black mica flakes are present as inclusions. A matted coating of tiny epidote crystals, with quartz crystals locally associated, occurs along many joint fractures.

The quartz monzonite grades into irregular equidimensional masses and more rarely is cut by dikes of a genetically related pegmatite. Where Bear Creek crosses the east border of the quadrangle one and the same mass of pegmatite grades into monzonite in one part of an exposure and sharply cuts it at another. The pegmatite is composed of predominant pink orthoclase and subordinate semitransparent quartz, which is milky white on account of being cut by myriad lines of fluid inclusions. Biotite and magnetite, one or both, are present in places. The rounded octahedrons of magnetite reach a maximum diameter of one-half inch and locally form one-third of the rock. The pegmatite is as a rule coarsely granular, although some masses are slightly banded with quartz in the middle.

On microscopic examination the texture of the quartz monzonite is observed to be hypidiomorphic granular, rather even grained in the nonporphyritic and uneven in the porphyritic facies. With variation in relative amounts of the lime-soda and alkali feldspars, the rock ranges from an acidic quartz monzonite with granitic affinities to a basic quartz monzonite with granodioritic affinities. The essential minerals, in the order of their abundance, are oligoclase or andesine, microcline, much of it microperthitic, quartz, and biotite. Orthoclase and hornblende, which are present in approximately half of the thin sections examined, are in such sections equal in amount to quartz or biotite. The rock is characterized by the abundance of the accessory minerals, magnetite, titanite, apatite, pyrite, and zircon. Titanite, magnetite, and biotite are equal in bulk in some thin sections. The order of the solidification is normal to a granite, although the periods of separation of biotite and titanite, of biotite and plagioclase, and of quartz and the feldspars overlapped. The accessory minerals are in many places in contact with one another and they separated from the magma in the following order: Zircon, apatite and pyrite, magnetite, and titanite.

The quartz is characterized by the presence of abundant opaque threadlike microlites, which also occur, although sparingly, in the feldspar. Rarely intersecting cracks indicate a poor cleavage parallel to the rhombohedron. The irregular grains and rude rectangular areas of oligoclase and andesine inclose abundant interpositions, in general centrically arranged. These include tiny magnetite cubes, blood-red or yellow semitransparent hexagonal plates, probably hematite, and opaque black dots and minute rods of undetermined character. Orthoclase is uniformly original, but microcline, as in the two formations previously described, is in places a product of recrystallization. Quartz is micropegmatitically intergrown with each of the feldspars, and small disks of quartz and orthoclase micropegmatite lie between the other constituents. Biotite occurs in irregular areas and blades. In a number of thin sections minute flocculent areas of biotite in optical continuity with an adjacent biotite mass are embedded in plagioclase, indicating an overlap in the separation of the two minerals. Biotite, which is for the most part fresh, in altering first becomes green, then bleaches, and finally is altered to chlorite, magnetite, and rutile. Epidote is a less common product of its alteration, and muscovite in parallel position with chlorite is very rare. Green hornblende occurs in partial columns many of which are intergrown with biotite, the cleavage of the two minerals being in parallel position. Epidote granules form in numerous places at the junction of altering biotite and hornblende individuals. Magnetite grains and partial crystals are abundant, and skeleton growths of magnetite are here and there included in biotite. The magnetite seems to be somewhat titaniferous. Coffee-brown titanite, much of it polysynthetically twinned, forms abundant partial crystals and irregular grains. This titanite, like that of the quartz-monzonite gneiss, alters readily. Apatite occurs in short or long columns which were in places broken and displaced before inclosure in younger minerals. Rarely the apatite crystals are deeply embayed as if corroded magmatically prior to the solidification of the essential constituents. Pyrite is rimmed by or intergrown with magnetite. Allanite crystals of chestnut-brown color occur rather abundantly in a number of thin sections, and some zircon is also present. Small shreds of original muscovite are intergrown with biotite in a few thin sections.

The quartz monzonite, as already stated, has in a broad way a poorly developed original gneissic structure parallel to the assumed roof of the batholith. Under the microscope this proves to be due to the flow orientation of the feldspar phenocrysts and biotite blades in a common plane. On the borders of the large batholith and near large inclusions of older rocks a secondary gneissic structure, nowhere strongly developed, has been induced by recrystallization and granulation. The secondary gneissic planes, marked by discontinuous films of biotite, are as a rule straight or gently curved, being highly flexed only along faults or near later igneous intrusions. Orogenic movements have fractured some constituents and bent others.

AGE.

The quartz monzonite is younger than the gneissoid granite and older than the Rosalie granite. Its relation to the quartz-bearing diorite is discussed in the description of that formation in the next section.

QUARTZ-BEARING DIORITE AND ASSOCIATED HORNBLENDITE.

DEFINITION.

By diorite is meant a granular igneous rock composed essentially of plagioclase (in general andesine) and either hornblende or biotite, with or without subordinate pyroxene. Most of the diorites of the Georgetown quadrangle contain a little quartz, and hence may be designated quartz-bearing diorites. Such diorites, with the introduction of orthoclase, grade into granodiorites.

DISTRIBUTION AND GENERAL STRUCTURE.

Quartz-bearing diorite occurs in small stocks and dikes, which are confined largely to the northern quarter of the quadrangle and are particularly abundant south of Idaho Springs and northeast of Georgetown. Contacts with older formations are poorly exposed and the dynamics of intrusion of the diorite are not clear. The formation is poor in inclusions of older rocks, and the magma on the whole appears to have been comparatively dry. In these respects it resembles the other basic magma, that of the hornblende gneiss.

PETROGRAPHY.

The quartz-bearing diorite is a medium- to coarse-grained, rather uneven, granular rock, composed essentially of grayish-white striated feldspar and greenish-black hornblende. Tiny wedges of quartz between these minerals are visible in some hand specimens. In many places bronze-brown mica blades may be seen macroscopically, and at the exposures at the mouth of Spring Gulch and 1.7 miles N. 75° W. of Lamartine ragged plates, which reach a maximum diameter of 2 inches, inclose poikilitically the other constituents. Epidote occurs in matted films on joint faces and in rude pseudomorphs after hornblende and biotite in the rock mass. Although the texture is mainly granular, here and there globular masses of hornblende lie in a ramifying web of feldspar and quartz. The most abundant facies, a mottled black and white rock, contains approximately equal amounts of hornblende and feldspar, but the series varies from a practically pure plagioclase rock (anorthosite) of medium-gray color to a pure greenish-black hornblende rock (hornblendite). Many steps in this gradation may be present in a single exposure. Small acidic or basic segregations, examples in miniature of the differentiation of the magma, are not uncommon. Such phenomena make it impossible to regard these rocks as anything but local modifications or variants of one and the same mass. However much the types vary among themselves in mineralogical composition, together they form but a single geologic unit.

Under the microscope the texture proves to be allotriomorphic or, with the partial development of plagioclase laths, hypidiomorphic granular. The order of crystallization of the minerals was usually first the accessories, then plagioclase or hornblende and pyroxene, followed by biotite, orthoclase, and quartz. Biotite, however, in some places solidified simultaneously with orthoclase and quartz. Of the accessory minerals, rutile, zircon, apatite, and pyrite are older, and magnetite, ilmenite, and titanite are younger. Plagioclase, which occurs in irregular grains or partially developed laths, ranges from oligolase andesine to bytownite, a basic labradorite being the most common species. It is characterized, as are quartz, orthoclase, and apatite in a less degree, by a vast number of centrally arranged minute tabular and circular interpositions that are black and opaque or clove-brown and translucent. Many of the round inclusions are arranged in lines which cross one another at angles of 60°. Some of these inclusions appear to be closely associated with pink fluid inclusions, and the coloring matter in the translucent ones is irregularly distributed in globular areas as if by the drying up of a solution. In part, at least, they probably represent dried-up fluid inclusions. Plagioclase is altered more or less completely to sericite, zoisite, calcite, and quartz. Tremolite is a rare alteration product. Small irregular areas of orthoclase are present in most of the slides, and some of the larger of these contain the other constituents poikilitically. Sericite is the common alteration product. Quartz, which forms wedges between hornblende and plagioclase in most of the thin sections examined, is also micropegmatitically intergrown with biotite, hornblende, and each species of feldspar. Fluid inclusions are comparatively rare. Green-hornblende, in grains or rude prisms, many of them twinned parallel to 100, with the twinning in a few repeated in thin laminæ, is as a rule filled with blebs of the other constituents. In places hornblende and plagioclase occur in micropegmatitic intergrowth. By deep-seated metamorphism hornblende is locally altered to biotite; epidote and more rarely chlorite are products of later alteration. Epidote occurs as the common product of altering hornblende or biotite and plagioclase.

Diallage, in grains and irregular columns, filled with the opaque inclusions characteristic of the species (probably iron oxides) and surrounded by secondary rims of hornblende, is present in a few slides. The interpositions which here and there completely replace the diallage disappear in the alteration to hornblende, their substance apparently being absorbed in the production of that mineral. Although small masses of the diorite are gabbros, properly so called, it is not probable that the distribution of diallage was originally much more extensive than now. Since the hornblende has its own original form, the hypothesis that the diorites are in reality metagabbros would assume complete recrystallization of the rock, a view incompatible with the small amount of demonstrable recrystallization. Biotite is a more uncommon alteration product of diallage. In a single thin section grains and partial columns of pale-green augite partly altered to hornblende are present. Large poikilitic plates of biotite have already been mentioned as characterizing some outcrops, and small biotite blades occur rather constantly. The large plates, which are either disconnected or joined to one another by narrow necks, are embayed on their borders by tubules of quartz and orthoclase, and flocculent aggregates of biotite in common orientation with the larger areas are embedded in adjacent quartz and feldspar. Biotite alters to chlorite, in part at least pennine, and rutile needles, these secondary minerals being in places accompanied by epidote. The common accessory minerals include ilmenite, pyrite, titanite, magnetite, and large and abundant crystals of apatite. Zircon and rutile are less common. Titanite is not only an original accessory, but also an alteration product of ilmenite. Many of the pyrite crystals are rimmed by ilmenite or magnetite. The short columns of apatite are in some places embayed, as if by magmatic corrosion, and in others the columns were broken into segments prior to the solidification of the inclosing essential constituents.

Associated with the diorite and linked to it by gradational facies are fine- to medium-grained allotriomorphic granular rocks of greenish-black or dark olive-green color, which are perhaps best styled hornblendites. The gradation from diorite to hornblendite may occur in a single thin section. The microscope shows that some of these rocks, which contain minor quantities of plagioclase, orthoclase, biotite, quartz, and accessory minerals, are formed in the main of green hornblende; others are made up of large irregular green hornblende individuals inclosing poikilitically laths of biotite, grains of enstatite showing schillerization, and partial columns of a colorless orthorhombic amphibole, anthophyllite. Enstatite is completely or partially altered to serpentine. In slides of the olive-green facies anthophyllite, which alters to talc, is as abundant as hornblende, with which it is locally in parallel intergrowth. It occurs in raggedly terminated columns with the prism and clinopinacoidal faces well developed. It is in some slides secondary to common hornblende and in others to enstatite. Anthophyllite has been noted as an alteration product of bronzite and hypersthene [a] and of olivine.[b] In this series anthophyllite is secondary to enstatite, a pyroxene closely related to bronzite and hypersthene, while the presence of olivine in the original rock is by no means impossible. Still another of these rocks is in one portion of the slide composed entirely of hornblende and in another of a white monoclinic pyroxene near malascolite inclosing hornblende grains poikilitically. Titanite, an abundant accessory mineral, is in some places intergrown with hornblende and crystallized contemporaneously with it (fig. 11). These more basic members of the formation appear to have suffered considerable recrystallization and their original character is in doubt. They were in part at least pyroxenites.

The diorite on its borders is in places mashed, partly through recrystallization and partly through granulation, to a rudely banded gneissoid rock. Microscopic examination shows that hornblende, feldspar, and quartz are segregated into lenses rudely elongated parallel to the parting, and blades of biotite and columns of anthophyllite are developed parallel to the gneissic planes. The albite twins of the plagioclase are locally aligned parallel to the gneissic structure, and the undulose extinction of orthoclase passes into the grating structure of microcline, the latter mineral being clearly a derivative product of the former, probably through recrystallization, and occurring solely in mashed facies of the diorite.

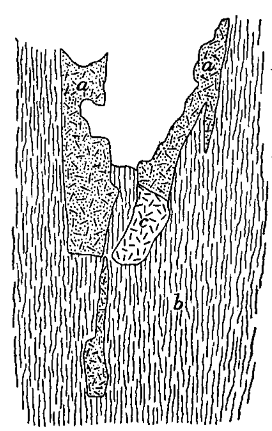


FIG. 11.—Titanite and hornblende intergrown and contemporaneous (*a*), in hornblendite or quartz diorite (*b*). *c*, Zoisite after feldspar. × 12.

Mass mechanical action has slightly granulated and deformed the constituents of the quartz-bearing diorite, but the resulting phenomena are not unusual.

AGE.

The quartz-bearing diorite bears the same structural relations to the other formations of the Georgetown quadrangle as does the quartz monzonite. The contact of these two formations is nowhere well exposed in the quadrangle. At the mouth of Spring Gulch, however, poor exposures of quartz monzonite on the east bank of Chicago Creek appear to be genetically related to quartz-bearing diorite on the west side of the stream. Rocks which are intermediate petrographically between the two in composition, and hence difficult to assign definitely to either formation, indicate that the two are variants of the same magma. Near St. Marys Lake, north of the Georgetown quadrangle, the two appear at some places to grade into each other, and in other exposures the diorite clearly cuts the quartz monzonite. The two are believed to be differentiation products of the same magma, the quartz diorite being, on the whole, slightly younger. Such being the case, the small areal development of diorite indicates that by far the greater portion of the magma first solidified as monzonite, and then the basic residuum formed the quartz diorite and its associated rocks. It is probable that considerable time intervals may have intervened between the separation of the quartz diorite and the more basic hornblendites. Spencer [c] has described from the vicinity of Encampment, Wyo., a somewhat similar series of basic igneous rocks, but this series is probably younger than that of the Georgetown quadrangle.

[a] Van Hise, C. R., Mon. U. S. Geol. Survey, vol. 47, 1904, p. 282.

[b] Becke, F., Tschermaks Min. u. petr. Mittheil., new ser., vol. 4, 1882, pp. 450–452; Belowsky, Max, Zeitschr. Deutsch. geol. Gesell., 1905, p. 47.

[c] Spencer, A. C., Prof. Paper U. S. Geol. Survey No. 25, 1904, pp. 28–36.

In the Empire mining district (see p. 385) certain facies of a monzonite which is younger than the Silver Plume granite closely resemble the pre-Cambrian quartz diorite. These rocks at Empire appear, however, to be of late Cretaceous age.

ROSALIE GRANITE (BIOTITE GRANITE).

DISTRIBUTION AND GENERAL STRUCTURE.

Batholiths, stocks, and dikes of the Rosalie granite are confined to the southern portion of the quadrangle, and the largest batholith, extending for at least 15 miles beyond the quadrangle, covers the southeast corner. An irregular area forms the ridge from Rosalie Peak, whence the granite's name, almost to Mount Evans and extends beneath glacial drift west of Lake Fork of East Geneva Creek. A third important area lies northwest of the junction of Bear and Truesdale creeks. The granite is comparatively free from inclusions of older formations and, except for dikes of the pegmatite and the associated granite and granite porphyry, from intrusive masses of later rocks.

PETROGRAPHY.

The Rosalie granite is a pink, coarse-grained, massive, granular rock whose predominant constituent is a salmon-pink, rarely gray microcline, much of which shows Carlsbad twinning. The feldspar masses, which vary in length from half an inch to 2½ inches, are rudely tabular in form and inclose blebs of quartz and flakes of black mica. They are separated from one another by ramifying bands of quartz, feldspar, biotite, and magnetite, all of medium size. The rock resembles a mosaic of salmon-pink rectangular or ellipsoidal blocks embedded in a black or gray cement. The granite 1.5 miles N. 70° E. of the mouth of East Geneva Creek is a porphyritic granite of gray color, with large pink feldspars of rectangular or ovoid form.

The Rosalie granite grades into and is cut by small pegmatitic dikes, which in turn grade into quartz veins. The pegmatite is formed of light brick-red feldspar and white and semi-translucent quartz. A little biotite is locally present, but ferromagnesian minerals are absent in most places.

Under the microscope the texture of the granite is seen to be uneven and hypidiomorphic granular. The essential constituents of the rock began to solidify from the magma in the order usual in granites, but the periods of separation of all overlapped, and in consequence each constituent incloses blebs and partial crystals of the others. Magnetite sometimes separated simultaneously with biotite, quartz, and feldspar and occurs in skeleton growths with them. The minerals named in the order of their abundance are microcline, quartz, orthoclase, alkali oligoclase, and biotite. Microcline, much of it microperthitic, contains hexagonal plates, dots, and rods of blood-red hematite. These inclusions also occur abundantly in plagioclase and in less amount in quartz, and in association with them in quartz and rarely in microcline are opaque hairlike inclusions. In many places plagioclase, an alkali oligoclase, has partial crystal faces against quartz and the alkali feldspars. Kaolin and sericite are the alteration products of the feldspars, calcite accompanying them in plagioclase. Quartz at its contact with the various feldspar species and with biotite forms micropegmatitic intergrowths. Biotite occurs in blades, idiomorphic against the feldspars and quartz, and in irregular plates which lie between quartz and feldspar granules and are apparently a contemporaneous or later product of solidification. It is in the main fresh, but in a few thin sections it is altered to chlorite, with the simultaneous separation of magnetite and a granular substance resembling leucoxene. Zircon, apatite, and magnetite are constant and rather abundant accessory minerals. The first two are locally included in the last. Tiny shreds of muscovite are intergrown with biotite in some thin sections. Titanite and pyrite occur as accessory minerals in a single slide.

The Rosalie granite has locally been subjected to slight strain, but apparently in no place has this process been accompanied by changes in the relative positions of the mineral constituents.

AGE.

The Rosalie granite cuts the quartz monzonite. The contacts between the Rosalie and Silver Plume granites are few and poorly exposed, but at three places—namely, 2½ miles east of Lincoln Lake, 1.7 miles northwest of Rosalie Peak, and 2½ miles east of the same peak—dikes, apparently of Silver Plume granite, cut the Rosalie granite. Locally, the Silver Plume granite has been mashed, but the Rosalie granite wherever seen is massive. It is in consequence possible, although not probable, that better exposures may prove the Rosalie to be younger than the Silver Plume granite.

One of the granites of Pikes Peak, Colorado, described by Mathews[a] and designated by him the Pikes Peak granite, is strikingly similar to the Rosalie granite in mineralogical composition, in deformation suffered, and in mode of weathering. Since the Pikes Peak granite is one of the older of the granites of that vicinity, it and the Rosalie granite may well be contemporaneous.

SILVER PLUME GRANITE (PORPHYRITIC BIOTITE GRANITE).

DISTRIBUTION AND GENERAL STRUCTURE.

Stocks, dikes, and irregular intrusive masses of the Silver Plume granite cover considerable areas north of Meridian Hill, on Alps Mountain, and in the vicinity of Georgetown and Silver Plume, and from the latter mining camp the granite is named. It is, indeed, widely distributed throughout the quadrangle except in the extreme northeast and southeast corners.

The older rocks do not have a concentric schistosity around masses of the Silver Plume granite, and in consequence the space now occupied by the stocks was probably not alone formed by forcing aside the older rocks. The straight element bounding many of the masses indicates that faults partially determined the form of the stocks. In many places older rocks are included in the Silver Plume granite and "overhead stoping" may also have been an auxiliary process. The magma appears to have been, on the whole, relatively dry, and in consequence assimilation was probably of no importance in determining the form assumed by the cooling mass.

PETROGRAPHY.

The Silver Plume granite is a medium-grained, porphyritic, granular rock composed of grains of white or pinkish feldspar, smoky quartz, and blades of black mica. Muscovite, locally in half-inch plates poikilitically inclosing the other constituents, is also visible to the naked eye in many exposures. Magnetite is less common. The granite, where rich in biotite, is dark gray mottled by pink porphyritic feldspars; where the biotite content is lower it is pinkish gray in color. At a distance exposures appear terra-cotta red or brown.

A porphyritic variety of the Silver Plume granite occurs in the northwestern portion of the quadrangle, with phenocrysts of pinkish-white feldspar, chiefly microcline, less commonly orthoclase. Many of the phenocrysts are Carlsbad twins. These rudely tabular crystals vary from 0.1 to 1 inch in length. The rock becomes a granite porphyry, the "corn rock" of the miners, as these phenocrysts increase in size and the encircling constituents become finer grained. It is the border facies of some of the larger stocks and alone forms some of the smaller dikes. Since these phenocrysts are aligned near the border in flow orientation, it is evident that they solidified before the magma came to final rest. To the south and west of the divide, between Soda Creek and South Fork of Clear Creek, the phenocrysts become smaller and less abundant and are associated with irregular equidimensional feldspar areas from one-fourth to one-half inch across. Even such areas are wanting north of Meridian Hill.

The Silver Plume granite grades into a pegmatite with predominant pink feldspar, some quartz, and less biotite, which occurs characteristically in long blades. The biotite content decreases with the increase in the size of the pegmatitic dikes. Magnetite, which is an acces-

[a] Mathews, E. B., Jour. Geol., vol. 8, 1900, pp. 217-225.

sory, is in general rare, although locally abundant. Most of the dikes are rudely banded, biotite being segregated near the center of the mass and either feldspar or quartz next the wall.

Under the microscope the texture of the granite is proved to be hypidiomorphic granular. Essential constituents of the rock are alkali feldspars, quartz, biotite, and oligoclase and oligoclase albite, named in the order of abundance. The order of the solidification of these minerals from the magma is normal, although the periods of separation all somewhat overlapped one another. The accessory minerals separated out in the following order, the first named being the oldest: Rutile, zircon, titanite and pyrite, and apatite and magnetite. Quartz is of interest on account of the opaque threadlike inclusions which it uniformly contains and which are present, though less abundantly, in feldspar. Of the alkali feldspars microcline, much of it with microperthitic bands, predominates in some slides and is lacking in others. Some of the microcline is a product of recrystallization, like that of the gneissoid granite (see fig. 12), but it is in the main an original constituent. The alkali-feldspar phenocrysts contain many rounded blebs of quartz and feldspar. Micropegmatitic intergrowths of quartz and the three species of feldspar occur along the borders of feldspar grains and in disklike areas between the essential constituents. Of the feldspars, orthoclase is as a rule considerably altered to sericite and kaolin; plagioclase is similarly altered, but in general to a less extent; and microcline is still less altered or even wholly unaltered. Calcite is also locally developed from plagioclase. Biotite for the most part forms well-developed basal faces against feldspar; but in some thin sections it appears to have solidified after the feldspars. Its alterations to chlorite with or without magnetite and rutile, to chlorite and epidote, to epidote alone, and to muscovite are in no way peculiar. Shreds of original muscovite are intergrown with biotite in many of the thin sections examined. The poikilitic plates of muscovite already mentioned grade into and are so associated with sericite shreds secondary to feldspar that they themselves are doubtless secondary. Of the accessory minerals zircon and apatite are abundant, magnetite rather common, and ilmenite, pyrite, titanite, and rutile rare. Magnetite alters to hematite or limonite, ilmenite to titanite and hematite, and titanite to a flocculent dark-brown semitransparent substance.

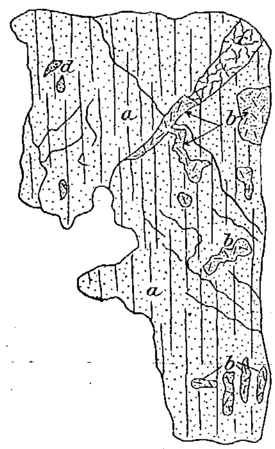


FIG. 12.—Plagioclase (*a*) cut by veinlet of secondary quartz (*c*) and microcline (*b*). Various areas of microcline in other portions of slide have similar optical orientation to that of veinlet. Plagioclase fractured and altered to kaolin and sericite (*d*). Microcline unfractured and fresh. Silver Plume granite. × 12.

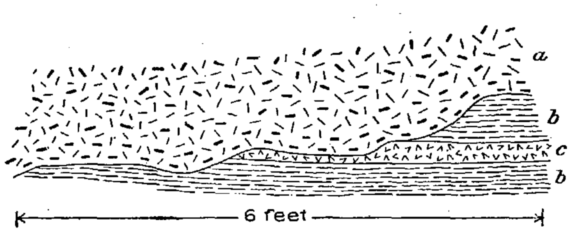


FIG. 13.—Flow orientation of phenocrysts of Silver Plume granite (*a*) at contact with biotite-sillimanite schist (*b*) of Idaho Springs formation and pegmatite (*c*). Shows development of phenocrysts in a granitic magma prior to cessation of movement in magma. Clear Creek.

The phenocrysts in the more porphyritic facies near the borders of granite masses are arranged in well-defined planes which follow the sinuous contacts of the older rocks (fig. 13). The granite has not been recrystallized and the parallel orientation and the consequent poorly developed cleavage are original structures due to movements in the magma prior to final solidification. The granite, though normally massive except for this original gneissic structure, has been locally mashed along planes of maximum movement, the mashing being accompanied by a rude alignment of biotite blades through recrystallization. Thin sections show the usual deformation phenomena.

AGE.

The Silver Plume granite cuts the formations previously described and with the exception of the pegmatite and associated granite and granite porphyry is the youngest of the pre-Cambrian rocks. Petrographically this granite resembles the Cripple Creek type[a] of the Pikes

[a] Mathews, E. B., Jour. Geol., vol. 8, 1900, pp. 229–232.

Peak quadrangle, a granite cutting the Pikes Peak type, which is considered the equivalent of the Rosalie granite. It is not improbable that the Silver Plume and Cripple Creek granites are contemporaneous.

PEGMATITE, GRANITE-PEGMATITE AND ASSOCIATED GRANITES, AND GRANITE PORPHYRY.

DEFINITION.

The term pegmatite, first applied to the intimate interpenetration of quartz and orthoclase individuals now more often designated graphic granite, is here employed for igneous rocks of unusually coarse texture. Granite-pegmatite is, then, a coarse rock of granitic composition. Granite porphyry is a rock of granitic composition consisting of a holocrystalline groundmass, generally of orthoclase and quartz, which contains larger, more or less perfectly bounded crystals, called phenocrysts, of orthoclase, quartz, and biotite or hornblende.

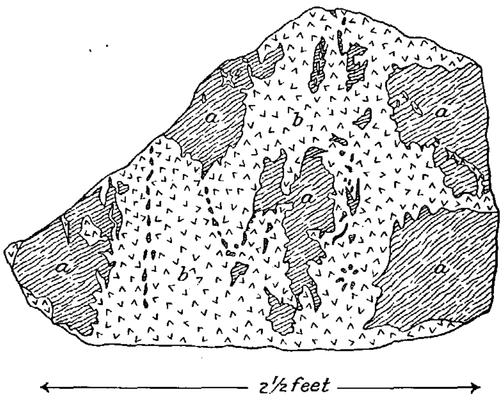


FIG. 14.—Sketch showing intense injection of hornblende gneiss (*a*) by granite-pegmatite (*b*). On trail midway between Maximilian and Eclipse gulches.

DISTRIBUTION AND GENERAL STRUCTURE.

The granite-pegmatite and associated granites and granite porphyry are present as small bodies throughout the quadrangle, although the scale of the map used permits only the larger masses to be shown. The largest area, approximately 1½ miles long, is east of south of Duck Lake. The rocks occur as dikes and intrusive masses, many of which are of exceedingly irregular form. The dikes were injected along planes of schistosity of the gneisses and schists and along joints and faults and planes between the contacts of the older rocks. The intrusion is in many places exceedingly intricate (figs. 14 and 15). In a single exposure the pegmatite, granite, and granite porphyry may grade into one another at one point and at another one rock may cut the others, the pegmatite as a rule being younger than either the granite or the granite porphyry. The pegmatitic magma was accordingly in most places later than that of the particular granite with which it is connected and related, and was probably introduced from below; in other places it was merely the residuum of that of the granite, the pegmatite forming in place.

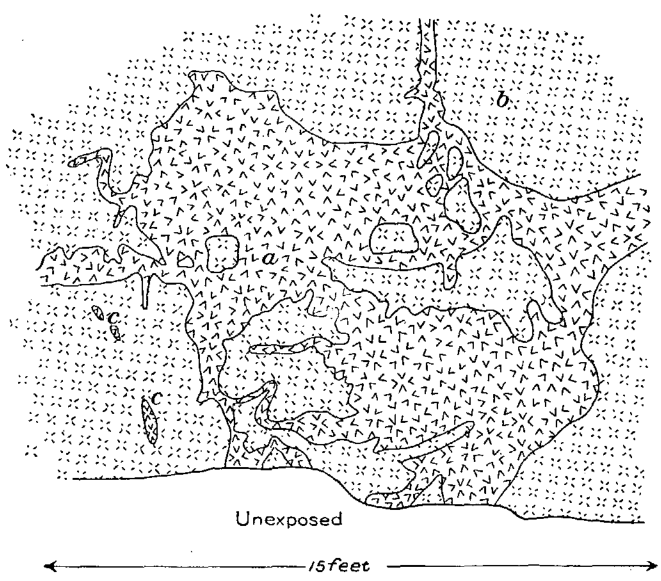
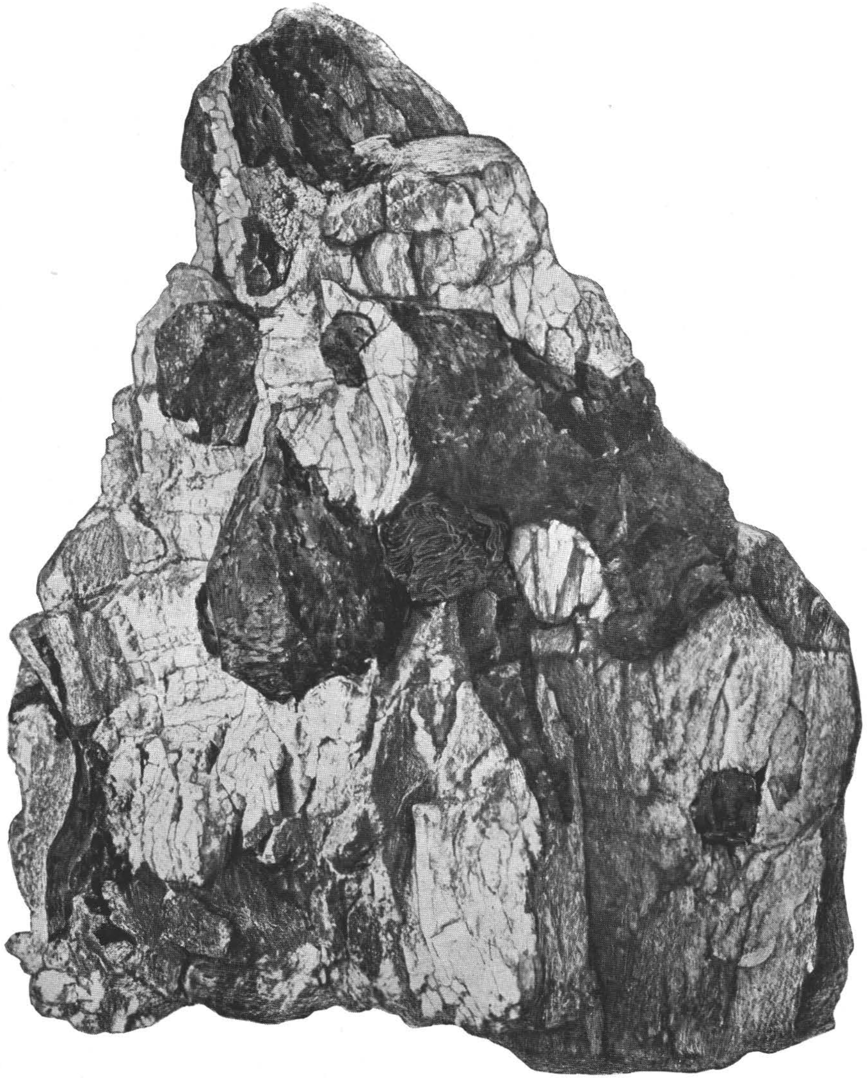


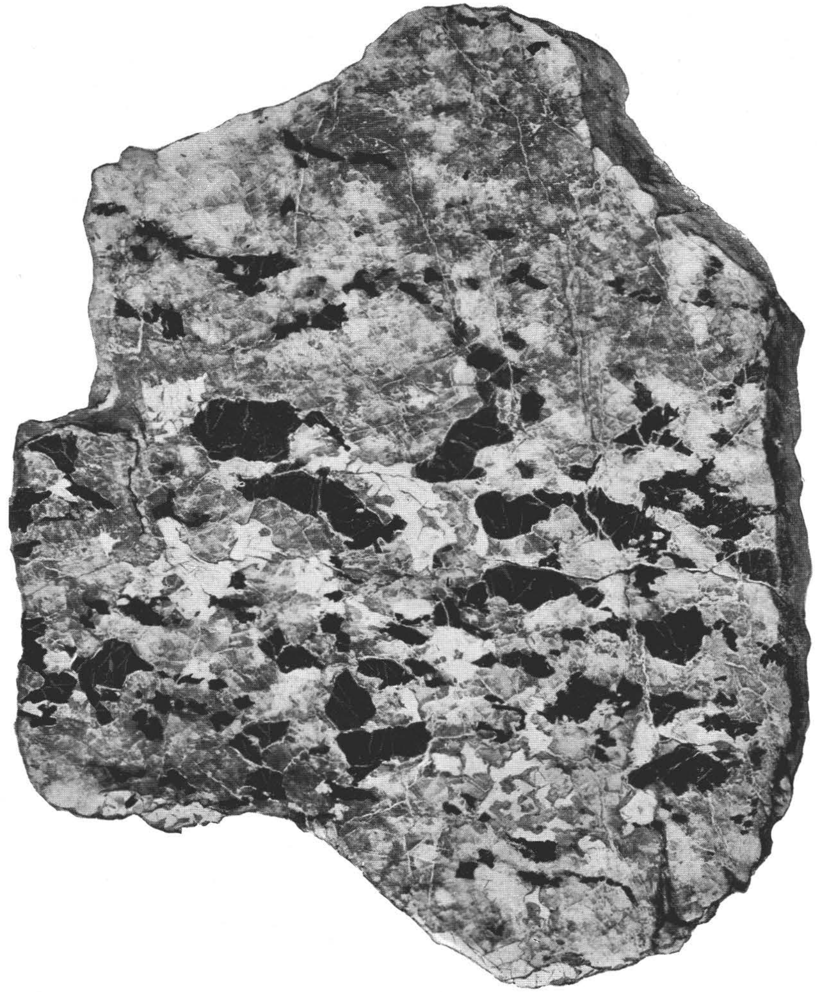
FIG. 15.—Sketch showing intense injection of quartz monzonite (*b*) containing inclusions of quartz monzonite gneiss (*c*) by granite-pegmatite (*a*). Mouth of Cascade Gulch.

Just as there have been repeated intrusions of granite in this region, there have also been repeated intrusions of pegmatite, and as the different granites are of very similar composition the pegmatites are also, so that in many places the pegmatitic intrusions of different ages can not be distinguished and separated from one another. It is demonstrated, however, that pegmatites were freely injected into the ancient schists among the earliest igneous intrusions, and perhaps formed the very earliest. Such ancient pegmatites are very abundant, for example, in the area shown on the Silver Plume special map (Pl. XXI, p. 176).



A. FELDSPAR-MAGNETITE PEGMATITE.

Showing crystal formation of magnetite.



B. GNEISSIC TYPE OF QUARTZ-MAGNETITE PEGMATITE.

Showing magnetite (metallic gray), quartz (light gray), and feldspar (white).

Pegmatite intrusions accompanying and following granitic intrusions have been well observed and studied, as, for example, that consequent on the intrusion of the Silver Plume granite at Silver Plume and Empire. (See p. 181.) Within the area shown on the Silver Plume special map three distinct periods of pegmatitic intrusion are recorded, the first and the most abundant being the oldest igneous intrusion, or in general contemporaneous with the hornblende gneiss (p. 178), which also represents one of the first intrusions; the second a differentiation phase of the massive quartz diorite intrusion, and the third representing the final product of consolidation of the Silver Plume granite magma. That pegmatitic phases were associated with later eruptives there is no doubt. Finally great quantities of granite-pegmatites and associated granites crystallized from a magma which was injected into the rocks of the region subsequent to all of the igneous intrusions above recorded. These pegmatites therefore are the youngest of the probably pre-Cambrian rocks of the quadrangle, and it is to them that the following discussion particularly relates.

It is, however, impossible in many places to distinguish between the pegmatitic intrusions of one period and those of another, and in consequence all the masses of pegmatite large enough to be shown have been represented by the same pattern on the map.

PEGMATITES.

PETROGRAPHY.

Salmon-pink feldspar which bleaches on weathering is as a rule the predominant mineral of the pegmatite. On microscopic examination this proves to be either orthoclase or microperthitic microcline. A light-gray acidic plagioclase is restricted in its distribution to pegmatite dikes in quartz monzonite. Slightly smoky quartz, which microscopic examination shows to contain abundant opaque threadlike interpositions and myriad fluid inclusions, is invariably present, and in the siliceous end product of the pegmatite, the tiny banded quartz apophyses that are given off from the large dikes, it is the only constituent. Plates of biotite are more common than those of muscovite, and the two micas characteristically occur in separate bodies of pegmatite, although they are locally associated in the same masses and in rare instances a core of biotite is surrounded by a muscovite border. An interesting form of pegmatite is one composed of diamond-shaped muscovite plates up to 1 inch in diameter embedded in quartz, each mineral being present in nearly equal amount. The rock is closely allied to beresite from the Ural Mountains and to a rock described by Spurr from Belmont, Nev.[a]

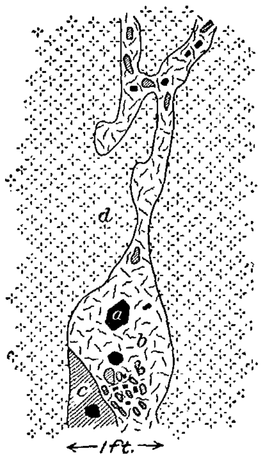


FIG. 16.—Quartz-feldspar pegmatite containing crystals of magnetite. Crest of ridge three-fourths mile east of upper Chicago Lake. *a*, Magnetite; *b*, quartz; *c*, feldspar; *d*, quartz monzonite.

In Warren Gulch near the Chemsker mine and in small areas between that point and Chief Mountain is a pegmatite that contains in places crystal masses of muscovite, many of which are 2 inches thick and 1 to 1½ feet in diameter. A large proportion of these muscovite crystals, however, show evidences of strain and contain considerable iron, so that they will probably not prove of economic value for sheet mica.

Magnetite is a widely distributed constituent, and in some places forms over one-third of the pegmatite mass, which in consequence becomes a lean iron ore. Magnetite occurs in crystals which solidified prior to the other constituents of the pegmatite (Pls. VIII, *B*; X, *A*; fig. 16), or in irregular aggregates which solidified practically at the same time as quartz and orthoclase (Pl. X, *B*). The crystals, which are octahedrons or octahedrons modified by the faces of the cube, reach a maximum diameter of 4 inches, and some of the aggregates are 6 inches across. Although magnetite is in general associated with biotite and less commonly with muscovite, it is in some places the only ferromagnesian mineral of the pegmatite, and locally it occurs in pegmatitic quartz dikes. Magnetite protrudes on weathering, the corners of the crystals being somewhat rounded by solution. Magnetite concentrated by the disinte-

[a] Spurr, J. E., Am. Jour. Sci., 4th ser., vol. 10, 1900, p. 351.

gration of the pegmatite is said to be effective sling-shot ammunition for the boys of Idaho Springs. A sample of the magnetite was partially analyzed by Waldemar T. Schaller, who found in it 2.07 per cent of titanic acid and no manganese.

Southeast of benchmark 9722, on the road which crosses the ridge between Trail Creek and Spring Gulch southwest of Freeland, Mr. Spurr collected specimens of magnetite pegmatite and associated magnetite-bearing alaskite. On microscopic examination these proved of great theoretic interest. The following description is based on Mr. Spurr's notes: A portion of one thin section is an allotriomorphic granular alaskite composed of quartz, fresh microcline, and aggregates of fine sericite with a little quartz. Other thin sections show that without much doubt the sericite and quartz form a pseudomorph after an acidic soda-lime feldspar, probably oligoclase. An octahedron of magnetite is included in the quartz. In one direction the alaskite becomes more quartzose until 90 per cent is quartz, with some fresh microcline, muscovite, and magnetite in crystals. Movement has occurred in this quartz, producing fractures, and following these are stringers or broad lenses of magnetite, with intercrystallized and contemporaneous biotite and muscovite. Many of the magnetite lenses and the semidetached offshoots show crystal boundaries, and the magnetite crystals clustered around the lenses and those isolated in the alaskite near by are identical.

The events in the genesis of this rock were, first, the crystallization of oligoclase; second, the alteration of oligoclase to muscovite and quartz and the solidification of microcline and quartz, the quartz deposition clearly outlasting that of microcline; third, the fracturing of the rigid alaskite; and fourth, the deposition of magnetite, biotite, and muscovite in the fractures, and of magnetite in crystals, visible channels of access being absent, throughout the rock. In this rock, therefore, magnetite is one of the last minerals to solidify; and, moreover, in the inclosure of one mineral by another, the criterion most often used to show that magnetite is one of the first minerals to crystallize from a magma, fails. The presence of magnetite, then, in idiomorphic crystals in other constituents of a rock does not always indicate that it separated from the magma prior to the consolidation of the inclosing minerals. A second thin section from this locality shows similar magnetite lenses and crystals in quartz, associated with which are biotite, muscovite, and zircon in large crystals. Zircon is practically contemporaneous with pegmatitic magnetite, and with quartz and magnetite was one of the last minerals to crystallize. How far the zircon of the rocks of the area under discussion is of this late generation can not be stated. (See p. 183.)

Black tourmaline is widely distributed, but nowhere abundant. It occurs either in crystals embedded in quartz or orthoclase, in micropegmatitic intergrowths with quartz and feldspar, in feldspar metasomatically replacing it, or in felts along cracks in the pegmatite. Hence while tourmaline usually solidified prior to quartz and feldspar it sometimes solidified contemporaneously with them, and more rarely after them or replaced feldspar. Microscopic examination in the latter case shows that muscovite simultaneously replaced feldspar, sericite shreds wreathing the tourmaline grains, and the presence of contemporaneous fluorite in irregular tiny areas elongated along a plane further indicates that magmatic gases were the agents of this alteration. The ferromagnesian mineral commonly associated with tourmaline is muscovite, and both of these minerals from other localities as a rule contain some fluorine.

Small crystals of red garnet are locally very abundant in the more siliceous pegmatites, and the association of this mineral with siliceous granite magmas in the Georgetown quadrangle appears to be constant. Crystals of black glassy allanite up to 3 inches in length are particularly well developed at the head of Maximilian Gulch. This mineral is confined to magnetite pegmatite and biotite-magnetite pegmatite cutting quartz monzonite, a restriction of some interest, since the monzonite contains allanite as an original constituent. At several localities pegmatite in hornblende gneiss and quartz diorite carry hornblende crystals. About 2.1 miles south of Mount Evans greenish-gray columnar aggregates of scapolite 10 inches in length occur in biotite pegmatite. The microscope shows that the scapolite, which is without question an original constituent of the pegmatite, includes apatite, allanite, and magnetite crystals. Scapolite occurs in volcanic rocks on Mount Somma,[a] but to the writer's knowledge has not been previously reported from pegmatite. One mile southwest of Naylor Lake irregular masses of green apatite, containing manganese (probably mangan-apatite), are a constituent of muscovite pegmatite. Both apatite and zircon are abundant microscopic constituents of the granite. Specimens of beryl from Saxon Mountain in the possession of J. S. Randall, of Georgetown, probably come from pegmatitic masses.

The individuals of the coarsest pegmatites reach a diameter of 1 foot or more. Such rocks, by loss of ferromagnesian minerals and by the simultaneous crystallization of quartz and feldspar, pass into graphic granite, the individuals of which range in diameter in cross section from a fraction of an inch to 1 inch. On the other hand, granular pegmatites grade along their strike into rudely banded dikes, quartz being commonly segregated in the center (fig. 17). Miarolitic cavities in the pegmatite are very rare. Here and there the various textures of the pegmatites and the granular texture of the granite grade into one another in a single outcrop 100 feet in diameter, and in consequence the temperature and pressure which in some places determined the production of one texture could have varied little from those which produced others.

Although typically massive, the pegmatites are locally mashed into gneisses, partly by granulation and partly by recrystallization. Quartz-magnetite pegmatite was particularly subject to recrystallization, producing a quartz-magnetite gneiss in which eyes and thin bands of magnetite lie in a mosaic of elongated quartz lenses (Pl. X, *B*). The larger magnetite individuals are much less deformed than the smaller. Futterer[b] in particular has emphasized the ease with which quartz is recrystallized, and in many of the other schists and gneisses of the Georgetown quadrangle magnetite appears to be one of the more readily recrystallized minerals. The pseudomorphous gneissic structure locally present in pegmatite surrounding gneiss is described in another place (p. 90).

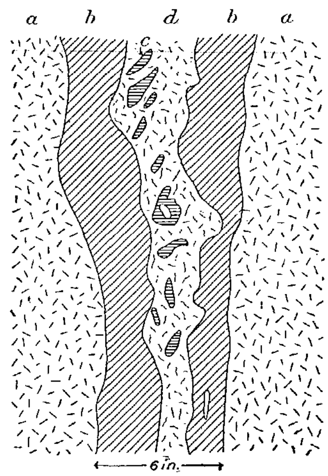


FIG. 17.—Banded pegmatite dike. South side of Clear Creek, one-half mile above Georgetown. *a*, Silver Plume granite; *b*, feldspar; *c*, biotite; *d*, quartz.

CHARACTER OF THE PEGMATITIC MAGMAS.

The magmas in general appear to have varied from a comparatively dry form, from which the granites solidified, through molten masses rich in water from which some of the pegmatites solidified, to a body so saturated with water that the banded quartz veins deposited by it resemble water-deposited veins. The extreme fluidity of the magma which deposited the pegmatite is indicated by a number of the characteristics of that rock. The pegmatitic magma or fluid sought out the smallest cracks and crevices and deposited its material therein, and the presence of pegmatite in small masses in nearly every outcrop in the quadrangle indicates that the older rock masses were thoroughly saturated with the pegmatitic material. That the process was one of saturation rather than of ordinary igneous injection, is shown by the presence, particularly in the biotite-sillimanite schist of the Idaho Springs formation, of isolated lenticular "eyes" of pegmatite (see p. 38) similar to the rock of the larger pegmatite masses (fig. 3, p. 39). The constituents of these "eyes" are absolutely uncrushed and can not be considered segments of a sheared pegmatite dike. The pegmatites further absorbed a considerable quantity of this schist and from the center of the larger inclusions gradations occur, in certain places, from pure schist to schist containing thin bands of pegmatite along its folia, thence to pegmatite, in which only a few scroll-like figures of darker pegmatite faintly suggest the crenulations of the almost totally absorbed schist, and lastly to pure pegmatite, in which a fair parting is here and there retained, indicating that the structure of the schist is partially preserved by metasomatic replacement, so that the pegmatite parting may be considered a pseudomorph of that of the schist.

[a] Dana, J. D., System of Mineralogy, New York, 1896, p. 467.
[b] Futterer, Karl, Die "Ganggranite" von Grosssachsen und die Quartzporphyre von Thal im Thuringerwald, Heidelberg, 1890, pp. 27–47.

A further proof of the extreme fluidity of the pegmatite magma is afforded by the influence on the mineral composition of the pegmatite exerted by the rock in which the pegmatite was injected. Biotite is the characteristic ferromagnesian mineral of pegmatites which inject granites older than themselves, the quartz monzonite gneiss, the quartz diorite, and the hornblende gneiss, although in many places hornblende is the typical dark mineral of pegmatites in the last two formations. Muscovite is the typical mineral of pegmatite dikes in the Idaho Springs formation, which contains 98 per cent of the occurrences of muscovite pegmatite. The pegmatite dikes in quartz monzonite areas are characteristically without ferromagnesian minerals and many of them contain, instead of an alkali feldspar, a soda-lime feldspar. Furthermore, the presence of allanite in pegmatite cutting quartz monzonite which has allanite as an accessory is perhaps significant. Magnetite was evidently an original constituent of the pegmatite magma, since it alone of the ferromagnesian constituents of the pegmatites is not influenced by the rock intruded. In areas of unusually complex injection, where the Idaho Springs formation and the granular igneous rocks are of approximately equal areal extent, both biotite and muscovite are associated with one another at numerous localities. Where the pegmatite passes from a fairly large area of granite to an area of the Idaho Springs formation, the substitution of muscovite in place of biotite is as a rule coextensive with the boundaries of the two formations. Where, on the other hand, the pegmatite has traversed a single formation for a long distance and thence passes to a second formation, there is a distinct "lag" in the introduction of the mineral characteristic of the pegmatite in the second formation. This is well seen on the north side of the quartz monzonite batholith, which passes beneath the schist at a low angle (fig. 18). Here the quartz-feldspar pegmatite extends several hundred yards into the biotite-sillimanite schist of the Idaho Springs formation, before muscovite, the characteristic mineral of pegmatites in that formation, is present.

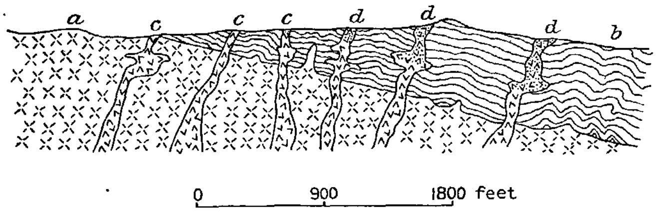


FIG. 18.—Diagram illustrating the lag in the introduction of muscovite into the quartz-feldspar pegmatite which is characteristic of the quartz monzonite-pegmatite on entering the Idaho Springs formation. *a*, Quartz monzonite; *b*, Idaho Springs formation; *c*, pegmatite containing quartz and feldspar; *d*, pegmatite containing muscovite. The rock intruded has a direct influence on the mineral composition of the pegmatite. A short distance from the contact of the Idaho Springs schist formation the pegmatite, which has schist for both walls, characteristically contains muscovite, which is lacking where the wall rocks are of quartz monzonite.

A chemical discussion of these observations is inexpedient, since the composition of the pegmatitic magma is unknown. It is indeed probable that the pegmatitic substances left the cooling mass of granite at widely varying times and that at the period of their origin they varied in chemical composition. Field evidence, however, indicates that the pegmatitic fluid abstracted prior to its solidification sufficient material from the inclosing rocks to modify in considerable degree the chemical composition of the pegmatite. In alumina-rich schists of the Idaho Springs formation a portion of the feldspar molecules of the magma were changed to muscovite by the addition of alumina from the schists. The lag already mentioned indicates that the change in composition did not occur immediately after the pegmatitic magma entered a formation, but only after it had penetrated for some distance.

GRANITES AND GRANITE PORPHYRY.

The granites associated with the latest pegmatites are massive, fine to medium-grained, granular rocks, which in the main contains the same ferromagnesian minerals as the immediately associated pegmatite. Although the granites intergrade, not only with pegmatite but with one another, certain types are rather well defined.

In the northern part of the quadrangle a white, medium-grained, siliceous muscovite granite, which in many places has pink garnet as an abundant accessory, grades into muscovite pegmatite. Biotite is here and there subordinately present, and such a rock on Ute Creek contains tabular feldspar phenocrysts 4 inches long. North of Georgetown the granitic rock is a gray muscovite alaskite in which quartz predominates over feldspar. In the central or southern parts of the quadrangle a pink or pinkish-gray, fine-grained biotite granite or biotite-magnetite granite predominates. A similar granite widely distributed in the southeast corner of the quadrangle is medium grained, and weathered surfaces are porous by the almost complete removal of biotite.

Under the microscope the texture of these granites is seen to be allotriomorphic granular. The order of crystallization is normal, except that in some thin sections titanite in the pink biotite granite lies in irregular grains between quartz and feldspar and therefore separated simultaneously with them. The accessories solidified in the following order: Zircon, apatite, magnetite, and titanite. Microcline, as a rule with microperthitic bands, is the predominant constituent of most of the granites. It is in the main original, but locally it is a product of recrystallization after the solidification of the granite, as it is in the gneissoid granite. (See p. 50.) Orthoclase, only rarely with microperthitic bands of albite or oligoclase-albite, and an acidic plagioclase (chiefly oligoclase-albite) are commonly also present. Sericite and kaolin partially replace feldspar, the former occurring locally in large secondary muscovite plates. Quartz, which occurs in irregular areas, also forms micropegmatitic intergrowths with the three species of feldspars, and is further characterized by abundant opaque threadlike inclusions. Fluid inclusions, with or without a tiny bubble, are very abundant. Biotite is an essential constituent of the pink biotite granite mentioned above, and is rare or absent in the other granites. It is in general partially or completely altered to chlorite, with the simultaneous separation of magnetite and either rutile or anatase. Muscovite or epidote is more rarely associated with chlorite. Original muscovite is more widely distributed in these granites than in any others of the quadrangle. In a single thin section blades of sillimanite are inclosed in muscovite plates, as in the gneissoid granite (see p. 50), and from the massive character of the granite sillimanite may well be an original constituent. Zircon, magnetite (some of it titaniferous), and apatite are common and abundant accessory minerals. Garnet is confined to the alaskitic muscovite granite and titanite and allanite to the pink biotite granite.

Fluorite occurs in several thin sections of biotite granite of the series south of Meridian Hill. It is colorless or spotted with irregular purple dots, and occurs as wedges and irregular masses between the essential constituents and as irregular masses in feldspar. Quartz in contact with fluorite is generally rounded, as if the irregular protuberances characteristic of quartz in contact with feldspar had been eaten away by the fluorite. Feldspar has an interlocking contact with fluorite, as if the latter mineral had partially replaced the former, a process that has certainly taken place in the small isolated areas of fluorite in feldspar. As in a few places miarolitic cavities are present in the pegmatite into which the granite grades, and as many of the fluid inclusions in quartz are full, these granites probably solidified under comparatively low pressure, and it is probable that minute cavities existed in them after solidification. It is believed that fluorite, brought in by pneumatolitic agencies, partially filled such tiny interstices between the essential constituents and partially replaced feldspar. In the vicinity of Silver Plume fluorite is clearly deposited in veins by aqueous solutions, but mineralized veins are not known to occur within a radius of 10 miles of the fluorite-bearing granite. The constituents of the granite have been deformed and in places fractured by mass mechanical processes. Here and there undulose extinction in quartz is highly developed, the feldspars are fractured, and the biotite plates and the plagioclase twinning laminæ are bent.

At several points south of Meridian Hill pegmatite and the associated granite grade into pink or grayish-pink granite porphyry. In the fine-grained groundmass, predominantly of feldspar and quartz, are many pink feldspar phenocrysts, with a maximum length of one-half inch; some rounded, slightly smoky quartz phenocrysts, one-fourth inch in diameter, and small phenocrystic areas of either biotite, magnetite, or hornblende. Since the granite porphyry occurs as irregular masses grading into nonporphyritic granite or pegmatite, the phenocrysts doubtless formed in place and are not intratelluric. Under the microscope the groundmass appears as a fine-grained, micrograntic aggregate of microcline and quartz, with orthoclase and magnetite in some thin sections and biotite in others. Biotite, on the one hand, and orthoclase and magnetite, on the other, are clearly complementary. Quartz and orthoclase or microcline locally form micropegmatitic intergrowths. The feldspar phenocrysts, of microcline with narrow microperthitic bands, have interlocking borders with the constituents of the groundmass and are characterized by many micropoikilitic inclusions of the groundmass constituents. The less perfectly bounded quartz phenocrysts are similarly characterized. Neither biotite nor hornblende forms good crystals, the latter in particular commonly occurring as skeleton aggregates of small hornblende areas, similarly oriented, and in many places connected by tiny hornblende stringers. Titanite, magnetite, zircon, and apatite are also present. Since small bodies of groundmass lie between the hornblende areas, it is evident that these phenocrysts solidified at approximately the same time as the groundmass, and it is probable that none of the phenocrysts crystallized much before the components of the groundmass. The occurrence of fluorite in granite porphyry is similar to that already described in granite.

SIMILARITY OF THE PRE-CAMBRIAN GRANITES.

Although no chemical analyses of the rocks of the Georgetown quadrangle have been made, microscopic examination shows a marked mineralogical similarity in the granites, the intrusions of which were separated in every case by considerable time intervals and in one case by the intrusion of more basic rocks. The granites are characteristically biotite granites in which microcline, undoubtedly in some places a product of recrystallization and in other of deformation, is as a rule the predominant feldspar. Orthoclase in turn predominates over oligoclase or oligoclase albite. Microcline throughout the series is characterized by microperthitic bands which are less common in orthoclase. Micropegmatitic intergrowths of quartz and orthoclase are widespread, the simultaneous separation of the two being further indicated by the rarity with which orthoclase forms crystal faces against the quartz. The presence in quartz of abundant threadlike inclusions of undetermined nature is also characteristic. Biotite appears to contain titanium, since rutile or some other titanium mineral is a by-product of its alteration. Original muscovite, except in certain of the pegmatitic granites, is present in negligible amounts. Of the accessory minerals, apatite, zircon, and magnetite are constantly and rather abundantly present. The granites of the Georgetown quadrangle present an interesting example of the repeated injection of a granitic magma or magmas of fairly constant composition. Mathews[a] emphasized the close chemical and mineralogical similarity of the granites of the Pikes Peak quadrangle, which lies at the south end of the Colorado Range. The granites of this region and those of the Georgetown quadrangle possess many characteristics in common and in some of the intrusions were probably contemporaneous.

CARBONIFEROUS (?) SANDSTONE.

Residual bowlders of silicified sandstone and quartzite occur at three points, namely, 1 mile S. 60° W. of the junction of Cascade and Chicago creeks (altitude 10,100 feet); on Cascade Creek 0.1 mile west of bench mark 9592 (altitude 9,650 feet); and between West Chicago Creek road and the road leading toward Griffith Mountain (altitude 9,200 feet). The residuals on Cascade Creek are so abundant that the original exposure of the sandstone could not have been much above the present surface. The medium-grained, well-silicified sandstone and quartzite is yellowish brown, pink, red, or purple in color. The semiporous character of certain bowlders indicates that some lime carbonate as cement may have been associated with silica. Well-rounded pebbles of quartz monzonite, hornblende gneiss, and pegmatite are embedded here and there in the finer matrix. Under the microscope the silicified sandstone proves to be composed of well-rounded grains of quartz with one or more grains of plagioclase and rounded rock fragments in most of the thin sections. The quartz, which contains zircon granules, was derived partly from the gneisses and partly from the plutonic rocks of the pre-Cambrian formations.

[a] Mathews, E. B., Jour. Geology, vol. 8, 1900, pp. 214-240.

Quartz in optical continuity with the rounded grains, from which it is separated by a film of limonite, is the chief cement, although a little hematite and chlorite also occur.

The well-sorted character of the sandstone indicates lacustrine or marine origin, while from the thorough cementation and the almost complete removal by erosion of what was once perhaps an extensive formation it may be inferred that the rock is of considerable age. It is, however, much younger than the youngest pre-Cambrian pegmatite, since before the deposition of the pebbles in the sandstone the pegmatite must have cooled beneath a considerable cap of overlying rock, which was removed by erosion prior to the depression of the land beneath the water in which the sand was deposited. Five miles south of the quadrangle, on North Fork of the South Platte about 1 mile above Shawnee, a lithologically similar sandstone rests unconformably upon the Idaho Springs formation at an elevation of approximately 8,200 feet. Similar sandstone is exposed on the north bank of the same stream at Pine post-office, 15 miles south of east of the southeast corner of the quadrangle. This sandstone belt strikes N. 60° W. and dips 70° to 80° SW., and is probably a block dropped by parallel faults into the Rosalie (pre-Cambrian) granite. The sandstone, which includes small pebbles of the Rosalie granite, is similar to that of the residuals in the Georgetown quadrangle, although the red and white coloring matter is somewhat more unevenly distributed. Lithologically this rock is very like the Fountain sandstone (Carboniferous) of the foothills of the Colorado Range. This portion of the range was at some time covered by the sea, which extended over the whole or a part of the Georgetown quadrangle, and if the above correlation be correct the submergence was in late Carboniferous time, although a different age is quite possible.

INTRUSIVE PORPHYRIES.

INTRODUCTION.

The intrusive porphyries comprise a variety of rocks, including alaskite porphyry, granite porphyry, quartz monzonite porphyry, dacite, alkali syenite porphyry, bostonite, biotite latite, and alaskitic quartz monzonite porphyry. Notwithstanding their rather wide mineralogical range, these rocks have many common characteristics. All are younger than the pre-Cambrian pegmatite and most of them are older than the important ore deposits. All are massive and have been subjected to practically no regional mashing. They are confined to the northern portion of the quadrangle.

DISTRIBUTION IN COLORADO.

A belt of late Cretaceous intrusive porphyries at least 95 miles long extends from Boulder to Aspen and Crested Butte across the Colorado, Park, and Sawatch ranges. It courses from northeast to southwest and broadens to the southwest, being but 10 miles wide at Boulder and at least 75 miles wide near its west end. West of longitude 106° 30′ the northern and southern limits of the belt have not as yet been definitely located, although probably the map (Pl. XI), which has been compiled from all available data, is approximately correct.

These intrusive porphyries of siliceous or intermediate composition bear a general resemblance to one another and in a broad way are probably contemporaneous. In sedimentary rocks they characteristically occur as sheets; in the pre-Cambrian complex, as dikes. Concerning their form Emmons[a] says:

> Normal dikes in the sedimentary strata were rarely observed, and wherever the sheets cross the strata transversely it is usually at a very low angle. In the Archean formations, on the other hand, the older rocks [the intrusive porphyries] were almost invariably found in the form of narrow and rather irregular dikes as a rule not over 50 feet in thickness, the principal eruptions being two large bodies of diorite whose outlines were not very accurately determined.
>
> The Archean exposures studied in this region were once covered by portions of the same sedimentary series in which these intrusive sheets are now found. It may therefore be assumed that the form of the channels through which the fused masses were forced up into the overlying beds is fairly represented by the average outline of these dikes. According to this reasoning it is evident that the channels in the Archean were extremely small as compared with

[a] Emmons, S. F., Mon. U. S. Geol. Survey, vol. 12, 1886, p. 296.

the extent of the sheets themselves, and were rather in the form of the narrow fissure, which has been supposed to be the source of so-called massive eruptions, than of the rounded "necks," which have sometimes been observed as the actual vents of volcanic eruptions.

Emmons[a] notes the same conditions in the southwestern portion of Summit County, and Fenneman[b] found sheets to be characteristic of the sedimentary rocks of the foothills in Boulder County.

Within this porphyry belt are situated many of the most important mining camps in Colorado, including Jamestown, Sugarloaf, Sunset, Gold Hill, Sunshine, Ward, Nederland, and Caribou, in Boulder County; Central City, Blackhawk, Russell Gulch, and Nevadaville, in Gilpin County; Idaho Springs, Freeland, Lamartine, Empire, Alice, Yankee, Lawson, Georgetown, and Silver Plume, in Clear Creek County; Argentine, Montezuma, Breckenridge, Kokomo, and Robinson, in Summit County; Fairplay and the camps northwest of it, in Park County; Leadville, in Lake County; a number of comparatively unimportant camps in Chaffee County, and Aspen and less important camps in Pitkin County. The close association of the ore deposits and these igneous rocks appears not only from the economic portion of this paper, by Messrs. Spurr and Garrey, but also from the reports on Leadville[c] and the Tenmile district[a] by Emmons and on Aspen[d] by Spurr.

In commenting on the ore deposits of the headwaters of Eagle River, Emmons says:[e] "In this [Summit] county there is a marked connection between the prevalence of eruptive rocks of secondary or Mesozoic age and the richness and magnitude of the ore deposits." He further states[f] that the ore bodies at the head of Mosquito Gulch, in Park County, are in Paleozoic limestones in contact with sheets of white porphyry. "Southward the masses of intrusive porphyry diminish in extent, as do also the number of developed mineral deposits." Concerning the ore bodies of Boulder County, Foster[g] states that there is a close connection between the ore deposits and dikes at Gold Hill, the eruptive rock closely resembling the Elvan [quartz porphyry or granite porphyry] of Cornwall." Palmer[h] says of the dike rocks in the vicinity of Mount Sugarloaf, which he calls porphyries and porphyrites: "They are probably concerned to a large degree with the mineralization of the county [Boulder]." The ore deposits of Gilpin County have been described by Rickard,[i] who remarks: "The andesite dikes appear to have a very important influence on the vein system of this district." In short, the intrusive porphyries seem throughout this belt to have a direct connection with the ore bodies, whether they are considered as the source either of the ore or of the waters or gases which deposited the ore, or whether their influence is purely physical.

The intrusive porphyries in the sedimentary rocks of the foothills near Boulder have been mapped and described by Fenneman.[j] He describes the rock as having a "felsitic groundmass" containing "phenocrysts of quartz, feldspar, and mica." In the spring of 1905, in company with Prof. R. D. George, of Colorado University, the writer examined these sheets and found them lithologically similar to the alaskite porphyry and granite porphyry of the Georgetown quadrangle. The intrusive porphyries of the pre-Cambrian complex of Boulder County have been mapped and described by Marvine[k] and Van Diest.[l] These maps show that the dikes trend in general parallel to the belt of the intrusive porphyries, that is, somewhat north of east. The porphyries of Boulder County have been described by Silliman,[m] Smith,[n] Foster,[o]

[a] Emmons, S. F., Geologic Atlas U. S., folio 48, U. S. Geol. Survey, 1898.
[b] Fenneman, N. M., Bull. U. S. Geol. Survey No. 265, 1905, p. 36.
[c] Emmons, S. F., Mon. U. S. Geol. Survey, vol. 12, 1886, pp. 541, 569-584.
[d] Spurr, J. E., Mon. U. S. Geol. Survey, vol. 31, 1898, pp. 235-236.
[e] Emmons, S. F., Tenth Census, vol. 13, 1885, p. 72.
[f] Idem, p. 75.
[g] Foster, E. Le Neve, Rept. State Geologist of Colorado for 1883-84, 1885, pp. 21-22.
[h] Palmer, Chas. S. Proc. Colorado Sci. Soc., vol. 3, 1890, p. 233.
[i] Rickard, Forbes, Trans. Am. Inst. Min. Eng., vol. 28, 1899, p. 112.
[j] Fenneman, N. M., Bull. U. S. Geol. Survey No. 265, 1905, Pl. II, pp. 36-40.
[k] Marvine, A. R., Am. Jour. Sci., 3d ser., vol. 8, 1874, pp. 29-33.
[l] Van Diest, P. H., Proc. Colorado Sci. Soc., vol. 2, 1886, p. 51.
[m] Silliman, B., Am. Jour. Sci., 3d ser., vol. 8, 1874, p. 26.
[n] Smith, J. Alden, Rept. Colorado Geol. Survey, 1879-80, pp. 19-20.
[o] Foster, E. Le Neve, Rept. State Geologist of Colorado for 1883-84, 1885, pp. 21-22.

Emmons,[a] Van Diest,[b] Palmer,[c] Farish,[d] Blake,[e] Hogarty,[f] and Breed.[g] Although these men have styled the rocks by various names, it is evident that with a single exception they are all porphyries of siliceous or intermediate composition comparable with those of the Georgetown quadrangle, alaskite porphyry, granite porphyry, quartz monzonite porphyry, dacites, and siliceous andesites being most widely distributed. The exception consists of the small intrusive masses of diabase at Sugarloaf described by Emmons.[a]

The intrusive porphyries along a portion of the southern border of Gilpin County were examined during the course of the field work for this report and were found to be similar in every way to those of the Georgetown quadrangle. While the dikes are especially clustered in the vicinity of Central City and the other mining camps of Gilpin County, the writer also observed dikes along the Denver, Northwestern and Pacific Railway west of Rollinsville. Maps of Central City and vicinity compiled by Endlich[h] and by Underhill[i] show that the majority of the dikes strike from northeast to east-northeast. Underhill[j] states that they "vary from the composition of andesite to that of trachyte, but in the area specially studied they are of intermediate composition and may be called latite porphyry." From his descriptions it is probable that granite porphyry[k] and quartz monzonite porphyry also occur. Rickard[l] states that a Gilpin County porphyry was determined by Professor Judd, of the Royal School of Mines, to be a dacite.

The boundaries of the belt in Clear Creek County were traced during the field work incident to the present report.

Our knowledge of the intrusive porphyries of Summit County is due largely to Emmons, who says[m] that on the upper part of Blue River there is a "considerable development of secondary eruptive rocks." The Director of the Mint states that in the Union district[n] northeast of Breckenridge and on Negro Hill[o] east of the same town there is porphyry. The intrusive porphyries of southwestern Summit County, mapped and described by Emmons,[p] include three types of diorite porphyry which have many features in common with those of Leadville, and facies of which in turn are similar to the quartz monzonite porphyry of the Georgetown quadrangle. Mr. Spurr[q] found no intrusive porphyries at Argentine and that they exist at Montezuma is by no means certain, although the distribution of the porphyry to the south and the character of the Montezuma ore deposits indicate that they probably occur there.

The country around the headwaters of Middle Fork of the South Platte in Park County has been mapped geologically by Emmons[r] and the intrusive porphyries have been described petrographically by Cross.[s] In another place Emmons[t] says: "Southward [from Mosquito Gulch] the masses of intrusive porphyry diminish in extent, as do also the number of developed mineral deposits." Peale[u] states that "phonolitic trachyte occurs near the headwaters of Michigan Creek," a tributary of Tarryall Creek, and this rock he compares to the intrusive rock of Mount Silverheels, which Emmons considers one of the late Cretaceous intrusives.

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[a] Emmons S. F., Tenth Census, vol. 13, 1885, p. 65.
[b] Van Diest, P. H., Proc. Colorado Sci. Soc., vol. 2, 1886, pp. 50–55.
[c] Palmer, C. S., Proc. Colorado Sci. Soc., vol. 3, 1890, pp. 233–234; vol. 5, 1898, pp. 159–164.
[d] Farish, J. B., Trans. Am. Inst. Min. Eng., vol. 19, 1891, p. 547.
[e] Blake, J. C., Proc. Colorado Sci. Soc., vol. 7, 1901, pp. 1–16.
[f] Hogarty, Barry, Proc. Colorado Sci. Soc., vol. 6, 1902, pp. 173–185.
[g] Breed, R. S., Proc. Colorado Sci. Soc., vol. 7, 1902, pp. 216–230.
[h] Endlich, F. M., Seventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1874, p. 280.
[i] Underhill, James, Proc. Colorado Sci. Soc., vol. 8, 1906, pp. 118–121.
[j] Idem, p. 119.
[k] Idem, p. 120.
[l] Rickard, Forbes, Trans. Am. Inst. Min. Eng., vol. 28, 1899, p. 111.
[m] Emmons, S. F., Tenth Census, vol. 13, 1885, p. 72.
[n] Rept. Director of the Mint on Production of Precious Metals in U. S., 1882, p. 557.
[o] Idem, 1883, p. 429.
[p] Emmons, S. F., Geologic Atlas U. S., folio 48, U. S. Geol. Survey, 1898.
[q] Oral communication.
[r] Emmons, S. F., Mon. U. S. Geol. Survey, vol. 12, 1886, atlas sheet 6.
[s] Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, pp. 316–358.
[t] Emmons, S. F., Tenth Census, vol. 13, 1885, p. 75.
[u] Peale, A. C., Seventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1873, p. 215.

Peale also mentions similar rocks at the head of Trout and Fourmile creeks[a] and near Fairplay.[b] It is evident that the distribution of these porphyries in Park County is approximately as shown on the map (Pl. XI).

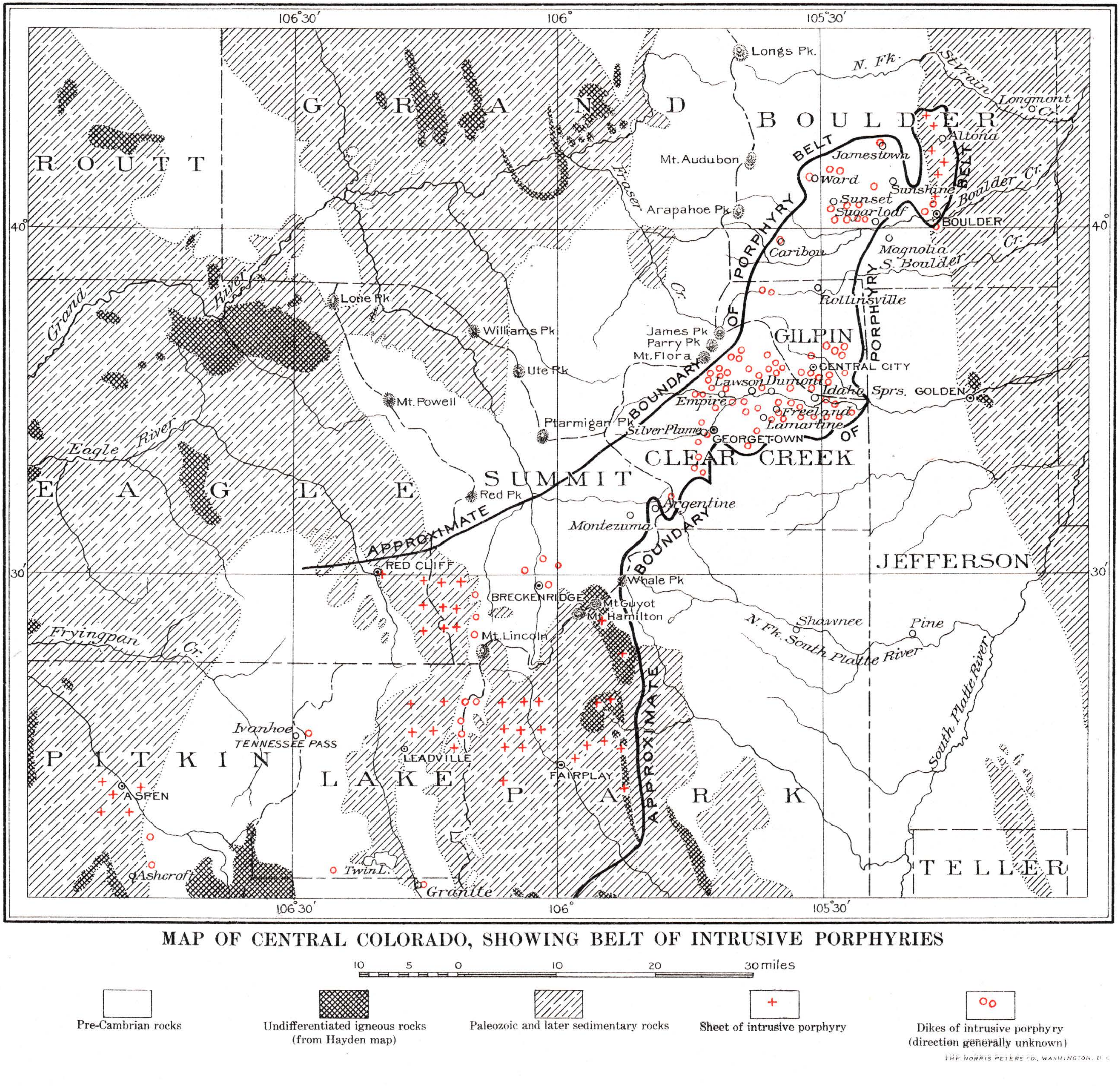
Our information concerning the intrusive porphyries of Chaffee County is fragmentary, although it is certain that practically the whole county is to be included in the belt. Foster remarks:[c] "The principal mining districts are in metamorphosed and granitic rocks through which dikes of porphyritic and feldspathic rocks are frequently found; limestone is also found in some parts of the county." Emmons[d] says concerning Chaffee County: "Its mountain slopes are composed of Archean rocks, mainly granite, traversed by porphyry dikes." Dikes of porphyry in the vicinity of Granite are mentioned by Emmons;[e] ledges of porphyry on Clear and Pine creeks by the Director of the Mint,[f] and dikes of quartz porphyry in the Chalk Creek mining district by Emmons.[d] The Director of the Mint[g] mentions porphyry at Summit, and Foster[h] describes "vertical sheets" of white porphyry at Monarch, in the southwestern portion of the county. Cross[i] says: "Dikes of a dense white quartz porphyry much like the Leadville 'white porphyry' cut the schists at several places opposite Salida and the head of Bear Creek, in the Sangre de Cristo Mountains."

The intrusive porphyries of Lake County in the vicinity of Leadville have been mapped and described by Emmons[j] and studied petrographically by Cross.[k] The rocks, like those characteristic of other portions of the porphyry belt, are siliceous and intermediate igneous rocks, including granite porphyry and diorite porphyry. Comparison with the rocks of the Georgetown quadrangle establishes the approximate identity of Cross's "white porphyry" with the alaskite porphyry of this report, and of the Lincoln porphyry with the quartz monzonite porphyry. Hayden[l] mentions the presence of dikes of "trachyte" about 2 miles above the falls of Lake Creek near Upper Twin Lake, and Peale[m] describes dikes of volcanic rock in granite on Tennessee Pass. It is probable that all of Lake County should be included in the porphyry belt.

The Tenmile quadrangle,[n] an area including the southwestern portion of Summit County and extending into the southeast corner of Eagle County, contains both sheets and dikes of intrusive porphyries. Emmons,[o] in describing the mines at Red Cliff, states that the lower Carboniferous or "blue" limestone is cut by an eruptive sheet of quartz porphyry. From the Hayden reports it is evident that the porphyry belt includes only the southern portion of Eagle County.

Spurr[p] divided the late Cretaceous or early Tertiary eruptive rocks of Aspen into quartz porphyry and diorite porphyry. He compares the former to the white porphyry of Leadville, and its finer-grained facies are practically identical with the alaskite porphyry of the Georgetown quadrangle. The diorite porphyry, on the other hand, has the mineralogical composition of the quartz monzonite porphyry of this report. Foster[q] states that the ore deposits at Ashcroft are in granite cut by "eruptive rocks." It is probable that eastern Pitkin County is largely within the porphyry belt.

[a] Peale, A. C., Seventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1873, p. 220.
[b] Idem, p. 303.
[c] Foster, E. Le Neve, Rept. State Geologist of Colorado for 1883-84, 1885, p. 30.
[d] Emmons, S. F., Tenth Census, vol. 13, 1885, p. 79.
[e] Emmons, S. F., Geological Guide Book to the Rocky Mountains, 1894, p. 423.
[f] Rept. Director of the Mint for 1884, 1885, p. 408.
[g] Rept. Director of the Mint for 1901, 1902, p. 107.
[h] Foster, E. Le Neve, Rept. State Geologist of Colorado for 1883-84, 1885, pp. 30-32.
[i] Cross, Whitman, Proc. Colorado Sci. Soc., vol. 4, 1893, p. 289.
[j] Emmons, S. F., Mon. U. S. Geol. Survey, vol. 12, 1886, atlas sheets 13, 14, pp. 74-86.
[k] Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, pp. 316-358.
[l] Hayden, F. V., Seventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1874, p. 54.
[m] Peale, A. C., Seventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1874, p. 242.
[n] Emmons, S. F., Geologic Atlas U. S., folio 48, U. S. Geol. Survey, 1898.
[o] Emmons, S. F., Geological Guide-Book to the Rocky Mountains, 1894, p. 416.
[p] Spurr, J. E., Mon. U. S. Geol. Survey, vol. 31, 1898, pp. 45-53.
[q] Foster, E. Le Neve, Rept. State Geologist of Colorado for 1883-84, 1885, p. 53.



MAP OF CENTRAL COLORADO, SHOWING BELT OF INTRUSIVE PORPHYRIES

THE NORRIS PETERS CO., WASHINGTON, D. C.

AGE.

In the Georgetown quadrangle the only determination of the age of the porphyries that can be made is that they are younger than the pre-Cambrian rocks, which they cut, and mainly older than the important ore deposits. In the west end of the porphyry belt already described, however, Emmons [a] found data indicating that the granite and diorite porphyries of Leadville were intruded in late Cretaceous time. He assigns a similar age to the intrusive porphyries of southwestern Summit County.[b] Spurr[c] believed the intrusive porphyries of Aspen to be contemporaneous with those of Leadville.

The sheets in the vicinity of Boulder, 23 miles from Idaho Springs, were examined by Prof. R. D. George, of Colorado University, and the writer. These sheets, which are petrographically similar to the alaskite porphyry and granite porphyry of the Georgetown quadrangle, cut respectively the Niobrara and Pierre (Cretaceous) and the "Red Beds." These dikes at Boulder are an extension of the belt of porphyries in this quadrangle, and the later dikes are in consequence probably of late Cretaceous age or younger, a conclusion in accord with the views of Fenneman.[d]

Andesitic pebbles with glassy groundmass in the late Mesozoic Denver formation of the Denver Basin were derived from flows that Cross[e] believes to have covered considerable areas in the Colorado Range during the deposition of that formation, which though post-Laramie is considered still probably Cretaceous. As Cross states, these andesitic pebbles have affinities with dikes near Empire, to the north of the Georgetown quadrangle. Other pebbles are rather similar to the dacite and biotite latite described elsewhere in this paper (pp. 75, 81).

DISTRIBUTION IN THE GEORGETOWN QUADRANGLE.

The Georgetown quadrangle lies on the southern edge of the belt of intrusive dikes, sheets, and stocks already described. Within the quadrangle masses of porphyry are confined to an area north of the divide between Leavenworth Creek and the Naylor Lake drainage, northeast of West Chicago Creek and north of a line connecting the junction of East and West Chicago creeks and a point 0.7 mile north of Chief Mountain. The porphyry is coextensive with the region in which active mining is carried on in the quadrangle.

Within the area specified the porphyry masses are unevenly distributed. Dikes are particularly abundant northeast of a line running from the 9,500-foot contour on Soda Creek northwestward through Alps Mountain to the north border of the quadrangle. Within this area, in turn, dikes are concentrated on the northwest side of Chicago Creek from the mouth of Spring Gulch to Eclipse Gulch. A group of dikes centers around the west end of Silver Plume, a second group 1 mile up Leavenworth Creek, a third at the mouth of Silver Creek, and a fourth on Lincoln Mountain. Active mining operations are carried on at each of these localities.

Dikes are particularly abundant in the biotite-sillimanite schist of the Idaho Springs formation, partly perhaps because of the coincident location of schist areas and the centers of profound igneous intrusion, but largely because of the numerous planes of weakness offered to injection by the highly developed schistosity of the schist. Many adjacent masses are of a similar variety of porphyry, but each rock has a rather well-defined distribution. (See p. 39.)

FORMS OF INTRUSION.

The intrusive porphyries occur as a rule in dikes and more rarely in sheets and stocks. The dikes are typically rather short, narrow, and simple. They vary in length from 50 feet to over 1½ miles, with 1,000 feet as an average. Dikes in the pre-Cambrian plutonic rocks are on

[a] Emmons, S. F., Mon. U. S. Geol. Survey, vol. 12, 1886, p. 294.
[b] Emmons, S. F., Geologic Atlas U. S., folio 48, U. S. Geol. Survey, 1898.
[c] Spurr, J. E., Mon. U. S. Geol. Survey, vol. 31, 1898, p. 53.
[d] Fenneman, N. M., Bull. U. S. Geol. Survey No. 265, 1905, pp. 35-40.
[e] Cross, Whitman, Mon. U. S. Geol. Survey, vol. 27, 1896, pp. 34, 202.

the whole shorter than those in schists and gneisses. In some places, where a dike dies out, a second and even a third segment of similar porphyry is encountered along its strike (fig. 19). (See p. 67.) On the north side of Silver Creek, 0.3 mile above its junction with Clear Creek, two small porphyry dikes intrude the hornblende-augite gneiss and the biotite-sillimanite schist of the Idaho Springs formation at the bottom of the canyon. Ten feet above the stream these dikes pinch out and are replaced by a shear zone in the older rocks (fig. 20). Further, many dikes of porphyry encountered in the mines can not be found on the surface, and in consequence it is probable that dikes are more numerous at considerable depths. The dikes vary in width from a fraction of an inch to 500 feet, although a width of 50 feet is exceptional and 35 feet is the average. Short dikes are as wide as long ones, and in consequence the width of a dike is not a function of its length. Abrupt variations in width occur in places, but the dike width is in general rather constant.

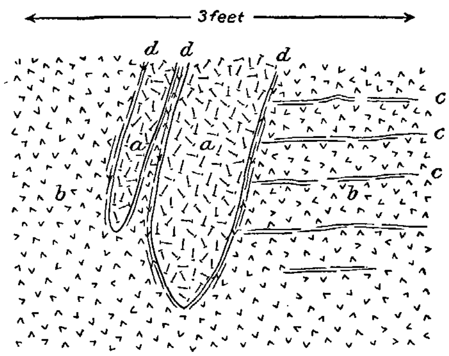


FIG. 19.—Porphyry dikes dying out with depth. *a*, Porphyry; *b*, pegmatite; *c*, inclusions of schist of Idaho Springs formation; *d*, sheared pegmatite. Spring Gulch, 6 miles north of mouth, Central City quadrangle.

The average strike of the porphyry dikes is slightly north of east and south of west, practically parallel to the average strike of the regional schistosity. Dikes striking N. 40° to 80° E. are particularly abundant. In schist neighboring dikes are in the main parallel, a feature not characteristic of dikes in the pre-Cambrian plutonic rocks. As a rule the dikes are straight, although some are gently curved and others sharply change their direction. Some dikes intruded in schist have a sinuous course that is in many places due to changes in the schistosity of the older rocks, along the planes of which the dikes were intruded. Sharp bends may accompany the passage of a dike from one structure of the older rock to another, as from a plane of schistosity to a joint, or from one set of joints to another. Although the dikes are as a rule simple, minor parallel injections and apophyses are by no means uncommon. The dikes were intruded along planes of weakness in the pre-Cambrian rocks, such as joints, faults, and schistosity planes. The preponderating occurrence of porphyry dikes in schist and the control of the dike direction by the schistosity of the intruded rock are indicated by the coincidence of the strike of the dikes with the average schistosity. Dikes across the strike of schistosity are exceptional, whereas dikes parallel to the strike of the gneiss, but of different dip, are more common. In the igneous rocks many of the dikes occupy joints and faults and, like these structures, are variable in direction over small areas.

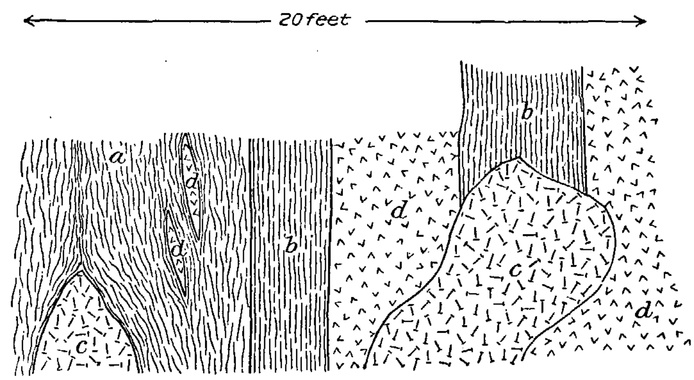


FIG. 20.—Porphyry dikes dying out before reaching surface. *a*, Biotite-sillimanite schist of Idaho Springs formation; *b*, hornblende-diopside gneiss of Idaho Springs formation; *c*, alaskite porphyry; *d*, pegmatite. One-third mile west of mouth of Silver Creek, near Georgetown.

Where the porphyry was intruded along flat gneissic or schistose planes, sheets occur. On Barbour Fork of Soda Creek, 1 mile above its mouth, such a sheet has been cut by erosion into a number of small bodies.

Stocks are few in number. Radiating dikes, characteristic of many stocks in other regions, are not connected with those of the Georgetown quadrangle, and in the vicinity of stocks dikes are not particularly abundant. On the west bank of Chicago Creek 0.2 mile northeast of the mouth of King Solomon Gulch erosion has exposed the western half of a stock of bostonite porphyry 115 feet long, which extends 20 feet above the stream bed. The schistosity of the biotite-sillimanite schist bows around this mass. Porphyry is not exposed on the east bank of the creek, and it is evident that the mass never connected with a surface flow, since it has been uncovered only by recent erosion.

There is no evidence within the quadrangle that the porphyries were ever connected with surface flows, although from the abundant débris of effusive rocks in the Denver formation in the Denver Basin it is probable, as Cross states,[a] that the Colorado Range was largely covered by lava flows about the time when these rocks were intruded. From the fact, however, that some dikes and stocks have reached the present surface only through recent erosion, it is probable that a considerable number of dikes now exposed did not at the time of their intrusion reach the surface and form flows.

QUARTZ MONZONITE PORPHYRY AND ASSOCIATED QUARTZ MONZONITE.

DEFINITION.

A rock of porphyritic habit with the composition of a quartz monzonite (see pp. 51–54) is called quartz monzonite porphyry.

DISTRIBUTION AND OCCURRENCE.

A few dikes of quartz monzonite porphyry occur south of Silver Plume and Idaho Springs and 2 miles northeast of Columbia Mountain. A stock on Lincoln Mountain, approximately 1 mile in diameter, is also composed predominantly of this porphyry, which apparently grades into a granular rock, quartz monzonite, although a lack of exposures renders proof of this impossible.

PETROGRAPHY.

The abundant medium-sized phenocrysts of this rock equal or exceed in bulk the finely crystalline gray groundmass. Of the phenocrysts the considerably predominating feldspars are stout lath-shaped plagioclases and fewer tabular orthoclases. Hexagonal plates of black mica, locally resorbed, are visible in most exposures, and some outcrops show dark hornblende columns or rounded quartz individuals. Octahedrons of iron ore and wedges of titanite are here and there noted by the naked eye. The more altered facies are yellowish white in color, the feldspars being changed to a soft, white greasy substance and black mica to a silvery white variety, and hornblende being in many places completely removed.

Under the microscope the groundmass proves to be in general micropoikilitic; in some portions spongy irregular areas of quartz contain tiny oligoclase laths and orthoclase tablets, and in others orthoclase similarly contains plagioclase laths. Rarely the groundmass has a hypidiomorphic, microgranitic texture in which plagioclase laths lie between irregular grains of orthoclase and less quartz.

The phenocrysts, named in the order of their abundance, are plagioclase, biotite, and orthoclase, and hornblende and quartz, if present. Plagioclase, which varies from oligoclase to andesine, occurs in stocky laths that where large are as a rule compound and where small are simple. The most characteristic feature of orthoclase is the excellent zonal growth commonly present. Several uncracked orthoclase phenocrysts inclose fractured crystals of plagioclase, and these cracks appear to be of intratelluric origin and older than the solidification of the orthoclase host. The feldspars are more or less altered to kaolin or sericite, quartz, and calcite. Biotite plates, many of them considerably eaten by the magma, are in general altered to chlorite, muscovite, calcite, and rutile or an ill-defined leucoxene-like substance. The biotite plates were in some places bent prior to the final solidification of the magma. Sparse phenocrysts of a brown hornblende, zonally grown, are present in a few thin sections, and green hornblende, either fresh or partially or wholly altered to epidote, is rather abundant in another. Although hornblende thus varies in color, the rocks are identical except for the association of titanite with the green hornblende. Mosaics of calcite and magnetite or limonite, its decomposition product, possess typical hornblende outlines in still other thin sections.

[a] Cross, Whitman, Mon. U. S. Geol. Survey, vol. 27, 1896, pp. 34, 202.

Quartz where present occurs as rounded grains or in ragged individuals deeply embayed by magmatic corrosion. Prior to the solidification of the groundmass the quartz phenocrysts were strained and either undulatory extinction or fractures were developed in them. During the solidification of the groundmass the older quartz of the phenocrysts controlled the crystal orientation of the younger quartz of the groundmass, which joined itself to the older quartz in optical continuity. The perfection of the orientation is beautifully shown in some specimens. A sharp line, coextensive with the older quartz individuals, separates the areas of differently oriented younger quartz. In consequence of this process an aureole of groundmass around the phenocrysts is unusually siliceous. Short columns of apatite and crystals and grains of magnetite, in part magmatically resorbed, are constant accessories which are locally included in the phenocrysts. Some of the magnetite is probably titaniferous. Titanite, commonly twinned, much of it polysynthetically, is an abundant accessory in about one-half of the thin sections and here and there is as large as any of the phenocrysts. It is rarely fresh and in some places is pseudomorphed by calcite, rutile, and chalcedony. Zircon, in tiny crystals, in one specimen inclosed in apatite, is present in several thin sections.

Thin sections cut from the contact of the biotite-sillimanite schist and this porphyry show that the older quartz of the schist controlled the orientation of the quartz of the porphyry during its consolidation. In consequence many small grains of the porphyry groundmass are in optical orientation with a single older and larger quartz grain. This phenomenon, analogous to the quartz aureole around the embayed phenocrysts, is also comparable to the secondary enlargement of quartz grains in quartzites, although in the former case the younger quartz solidified from magmatic and in the latter from aqueous solutions.

The quartz monzonite associated with the porphyry is a fine-grained granular rock of brownish-gray color, composed predominantly of feldspar individuals with tiny interstitial areas or columns of a black mineral. The rather smooth weathered surface, on which some colorless quartz is visible, is white flecked with black. Cutting the granular rock with rather sharp borders are dikes 1 inch thick, which in the field appear to be aplitic.

The microscope shows that the texture of the monzonite is allotriomorphic and rather uneven grained. The feldspars, orthoclase and oligoclase, greatly predominate over augite, hornblende, and quartz. Orthoclase slightly predominates over plagioclase and occurs in rudely tabular and irregular masses, many of which are twinned according to the Carlsbad law. Associated with it is apparently some anorthoclase. Oligoclase forms elongated tabular masses, which in many places exhibit zonal growth. Some feldspar individuals are slightly altered to kaolin and sericite. Augite occurs in grains and rude prisms which are twinned parallel to 100. Hornblende, green or brown, is closely associated or intergrown with augite. Quartz occurs in wedgelike forms between the other constituents. The accessory minerals include biotite, titaniferous magnetite or ilmenite, titanite, apatite, and zircon. The composition of this rock is such that it might well be a granular facies of the quartz monzonite porphyry.

The aplitic rock one-eighth inch from the monzonite is a fine-grained allotriomorphic mosaic of granitic composition formed of quartz and orthoclase with a little oligoclase. Magnetite, titanite, and zircon are present as sparse accessory minerals. Toward the monzonite orthoclase gradually increases in granularity and incloses the quartz micropoikilitically. This zone grades along a rather indefinite plane into one in which quartz ramifies micropegmatitically through orthoclase, and these quartz tabules extend well into the monzonite, which gradually takes on hornblende and augite and grains of plagioclase. It appears that the aplite and the monzonite in part were contemporaneous. The monzonite appears to have solidified except on certain planes along which the residual magma collected or into which residual magma was intruded. This residuum of the magma was rich in quartz and orthoclase and poor in plagioclase and ferromagnesian minerals. Solidification started from the monzonite, then apparently continued without interruption until both the monzonite and the aplitic rock were consolidated.

DACITE.

DEFINITION.

By the term dacite is meant a porphyritic igneous rock composed of soda-lime feldspar and quartz and containing in many places one or more of the minerals biotite, hornblende, and augite. It is in consequence the porphyritic equivalent of quartz diorite and occurs either as dikes, sheets, or flows.

DISTRIBUTION AND OCCURRENCE.

Dacite forms an east-west dike 50 feet wide and 0.4 mile long, located 0.4 mile south of Georgetown. The dike is practically vertical and has a very irregular contact with the pre-Cambrian rocks on the walls of the canyon of South Clear Creek (fig. 21). Large and irregular fragments of the pre-Cambrian rocks are included in the dacite near its borders, while the inclusions near the center of the dike are small and round, indicating resorption by the dacitic magma. The dacite shows wavy flow lines near its contact with the pre-Cambrian rocks, and there the phenocrysts have common flow orientation. Near the border of the dike hexagonal fractures at right angles to the border were produced during the solidification of the rock. The dike is also traversed by many joints of later origin. The dacite, while apparently poorer in alkali feldspar than the quartz monzonite porphyry, may well be a variant of that magma.

PETROGRAPHY.

The dacite is bluish gray, dense, and aphanitic, and has a conchoidal fracture. In the groundmass are abundant small laths of feldspar, columns of black hornblende, and tiny rounded grains of black quartz.

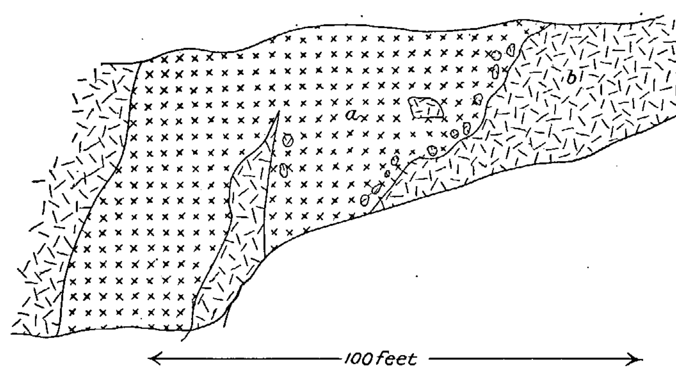


FIG. 21.—Dacite dike (*a*), showing inclusions of Silver Plume granite (*b*). East of South Clear Creek canyon, one-half mile south of Georgetown.

Under the microscope the groundmass is seen to be either felsitic or pilotaxitic. Feldspars are the most abundant phenocrysts, but they are too much replaced by sericite, calcite, and kaolin to determine their exact composition, although from their lath-like shape they are without doubt largely plagioclase. A single phenocryst-like area of microcline is present in one thin section, but this is probably a tiny fragment torn from the older rocks. Much corroded quartz occurs in every thin section examined. Green hornblende has a narrow rim of magnetite. It is partially altered to epidote, zoisite, chlorite, and calcite, or is pseudomorphed by serpentine and calcite or by chlorite, serpentine, and calcite. Biotite, titaniferous magnetite, and apatite are accessory minerals.

GRANITE PORPHYRY.

DISTRIBUTION AND OCCURRENCE.

Intrusive bodies of granite porphyry and the associated rhyolite and aporhyolite occur in three areas in the northwest corner of the quadrangle. One of these, a stock 0.3 mile in diameter, is situated $1\frac{1}{2}$ miles east of south of Paines Mountain and is the most southerly porphyry mass in the quadrangle; a second is on Pendleton Mountain near the mouth of Leavenworth Creek, where there are a number of dikes; and a third is in the vicinity of Lincoln Mountain, where a number of dikes also occur.

PETROGRAPHY.

The granite porphyry when fresh is gray and in general has a dense and aphanitic, although rarely finely granular groundmass. The medium-sized to rather large phenocrysts are very abundant and equal or surpass the groundmass in bulk. Of the phenocrysts feldspar is more abundant than biotite, which in turn predominates over quartz. Few of the feldspar phenocrysts are over one-fourth inch long and as a rule they are considerably altered. Rounded grains or crystals of slightly to deeply smoky quartz are commonly somewhat larger than the feldspar phenocrysts. Black hexagonal plates of biotite, here and there rounded by magmatic corrosion, are abundant, although in the main less than 0.1 inch in diameter.

The weathered specimens are chalky, pitted by feldspar casts, roughened by the protusion of quartz phenocrysts, and heavily stained by reddish or brownish iron oxides. The biotite phenocrysts are altered to muscovite.

Microscopic examination shows that the groundmass of the granite porphyry is allotriomorphic and microgranitic, quartz and orthoclase grains in equal bulk forming a fine-grained mosaic. In places laths of plagioclase occur with the quartz and orthoclase grains. The feldspars of the groundmass are considerably altered to sericite, kaolin, chalcedony, and calcite, and flocculent stains of limonite are almost constantly present.

Orthoclase, the predominant phenocryst, occurs as simple crystals and Carlsbad twins. Plagioclase, mostly oligoclase but in part oligoclase-albite, is more commonly in compound intergrowths than orthoclase. Pericline twins are usual; Carlsbad twins are less common and in places zonal growth is slightly developed. Both orthoclase and plagioclase phenocrysts are much altered; in some thin sections they are pseudomorphed by sericite and in others by chalcedony and calcite. Kaolin is a less common alteration product. Quartz phenocrysts are in general magmatically corroded. Fluid inclusions are present in many specimens. During the final solidification of the rock the quartz was fractured and an undulatory extinction developed in some phenocrysts. The quartz phenocrysts control the orientation of a thin band of the quartz grains of the groundmass which are in optical continuity with it, and further drew from the surrounding magma an unusually large amount of siliceous matter, in consequence of which the groundmass around the phenocrysts is more acidic than that at a distance from them.

Biotite phenocrysts are either hexagonal plates or rounded areas, deeply embayed by magmatic corrosion, which inclose irregular masses of groundmass. In many places biotite was bent prior to the final solidification of the mass. Biotite is in general pseudomorphed by muscovite accompanied by rutile, limonite, and locally calcite, and is unaltered only where calcite and chalcedony unaccompanied by sericite are the alteration products of the feldspars.

Hexagonal columns and rounded grains of apatite, the largest of which are 0.25 mm. long, are constantly present, and are in some places rather abundant. Zircon in small crystals is also a constant accessory mineral, while magnetite crystals and rounded grains, magmatically absorbed, are less commonly present. The magnetite is probably somewhat titaniferous.

Rhyolites and aporhyolites are closely associated with granite porphyry and in places grade into them. In the Marshall tunnel of the Colorado Central mine the greater portion of the main dike is greenish-gray granite porphyry, but the border facies is a glass of black, greenish-gray, or rich yellowish-brown color. The rhyolite grades rather sharply into the granite porphyry and occurs in lenses from 10 to 100 feet long and from 1 inch to 4 feet wide. Locally it shows well-developed cooling joints, closely spaced, at right angles to the dike. The groundmass of this rock is a fresh colorless glass, in which the gas cavities are arranged in flow lines. In other rhyolites of the series the groundmass is devitrified and is composed of a mosaic of irregular or more or less perfectly hexagonal units with shadowy extinction. Glass inclusions replace the fluid inclusions of the quartz of the granite porphyry, and in a single thin section the orthoclase phenocrysts possess the sanidine parting. Quartz in one thin section shows a rather distinct cleavage parallel to a pyramid. A tabular crystal of orthoclase is surrounded by a crown of irregular orthoclase individuals of different orientation. In each orthoclase individual are micrographic characters and ramifying tubelets of quartz which in a single individual are of common orientation. Similar micrographic phenocrysts in rhyolite have been described by Iddings from the Yellowstone National Park[a] and from Eureka, Nev.[b] In the aporhyolite from a dike on the Pendleton Mountain ridges several microcline phenocrysts are associated with those of orthoclase.

ALASKITE PORPHYRY (FERROMAGNESIAN-POOR GRANITE PORPHYRY).

DEFINITION.

Alaskite porphyry is a porphyritic holocrystalline rock composed essentially of quartz and orthoclase, being the porphyritic equivalent of alaskite, a type of siliceous granitoid rocks first differentiated by Spurr.[c]

DISTRIBUTION AND OCCURRENCE.

Alaskite porphyry occurs as dikes in the vicinity of Silver Plume and on either side of Clear Creek north of Georgetown. Two stocks, the largest of which is approximately 0.3 mile in diameter, outcrop on the south side of Leavenworth Creek near the west border of the quadrangle.

PETROGRAPHY.

The alaskite porphyry when fresh is dull white or light gray, with dense, aphanitic, rarely flinty groundmass. The large phenocrysts are scarce to fairly abundant, but are uniformly very subordinate to the groundmass in bulk. Of these, feldspars predominate over quartz, which in turn predominates over muscovite and much altered biotite, locally present. The last three minerals are absent in some of the rock. The orthoclase and plagioclase phenocrysts, which range in length from one-sixteenth to three-eighths of an inch, are in the main opaque through alteration. Quartz of like size forms light-gray transparent phenocrysts with dulled vitreous surfaces. Muscovite, present in some specimens, occurs in hexagonal plates or areas rounded by resorption which range from one-sixteenth to one-fourth inch in diameter. The muscovite is generally silvery white or gray in color, but some of it is almost black, and resembles biotite in the hand specimen. Ill-defined, much-altered biotite phenocrysts are also present here and there.

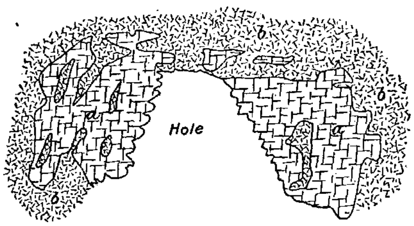


FIG. 22.—Sketch showing intense magmatic corrosion of an orthoclase phenocryst (a) in alaskite prophyry (b). ×20.

Messrs. Spurr and Garrey report that in the Baltimore tunnel flow banding and consequently ready parting is well developed in an alaskite porphyry. Discontinuous wavy bands of green, gray, brown, and white rock, varying in texture from dense to semivitreous, open, curve, and close around the quartz, feldspar, and biotite phenocrysts.

The weathered surface of the alaskite porphyry is as a rule slightly glazed, pitted by the removal of the feldspar phenocrysts, and roughened by the protrusion of the quartz phenocrysts. On advanced alteration the rock is reduced to a chalky mass. Limonite stains on joint surfaces are apparently derived from the surrounding formations. Dendrites of manganese dioxide also occur along joints and in some places penetrate the rock near them.

As seen under the microscope the groundmass is in the main allotriomorphic and micrograniltic, being composed of a mosaic of orthoclase and quartz grains which vary in diameter from 0.02 to 0.05 mm. Sericite is a constant and in some places a very abundant alteration product of the feldspar grains; calcite and chalcedony are less constantly present.

Orthoclase phenocrysts are here and there intensely corroded magmatically (fig. 22), detached areas of orthoclase lying in the groundmass and islands of groundmass being inclosed in orthoclase. During the flow of the magma prior to solidification some of the phenocrysts were broken and cracks and undulose extinction locally present were probably produced at

[a] Iddings, J. P., Seventh Ann. Rept. U. S. Geol. Survey, 1888, pp. 274-276.
[b] Mon. U. S. Geol. Survey, vol. 20, 1892, p. 375.
[c] Spurr, J. E., Am. Geologist, vol. 25, 1900, p. 229.

the same time. Plagioclase (albite-oligoclase) forms short lath-shaped phenocrysts which are less abundant than those of orthoclase. The feldspar phenocrysts are in many places wholly and everwhere partially sericitized. Much of the sericite is accompanied by chalcedony and some chalcedony pseudomorphs of feldspar are present.

Quartz phenocrysts, many of which are intensely corroded, are as a rule formed of a single grain of quartz, although some of them consist of an aggregate of several grains diversely oriented. Partially filled fluid inclusions are locally present. A narrow aureole of the quartz of the groundmass is ordinarily in optical continuity with the quartz phenocrysts. During the flow prior to the final solidification of the magma the quartz phenocrysts suffered the same deformation as the orthoclase.

The rarity of muscovite in granite porphyries makes its presence as an original phenocryst in a number of the rocks of considerable interest. Hexagonal plates with good crystal boundaries are rare, but ellipsoidal areas rounded by magmatic corrosion are characteristic. Some of the plates were slightly bent prior to the final solidification of the magma. In a few slides small pseudomorphs of muscovite and limonite, with or without rutile, occur, and these are evidently much-altered biotite phenocrysts. Zircon granules, locally inclosed in the phenocrysts are present in the majority of the slides.

BOSTONITE AND BOSTONITE PORPHYRY.

DEFINITION.

Bostonite is a light-colored holocrystalline rock of trachytic texture which is composed essentially of sodium-rich feldspars and is characteristically poor in ferromagnesian minerals. If such a rock contains phenocrysts, it is called a bostonite porphyry.

DISTRIBUTION AND GENERAL STRUCTURE

Bostonite and bostonite porphyry form numerous dikes in the northern part of the quadrangle east of Saxon Mountain. It is the most widely distributed of the intrusive porphyries, and it forms the longest and most persistent dikes. A small stock already mentioned (see p. 72) occurs on Chicago Creek 0.2 mile northeast of the mouth of King Solomon Gulch. Bostonite rarely contains inclusions of older rock.

PETROGRAPHY.

The bostonite is, when fresh, a lilac or pinkish-gray, dense, finely granular rock, which to the naked eye appears to be composed wholly of feldspar laths. A number of the dikes near the mouth of Little Bear Creek are of this phenocryst-lacking variety. From bostonite this rock grades into bostonite porphyry, in which the phenocrysts in some specimens are equal in volume to the groundmass. The phenocrysts, chiefly alkali feldspar and plagioclase, are in some places accompanied by pyroxene pseudomorphs. The feldspars are in general much altered, the alkali feldspars having compound tabular or rhombic forms and the plagioclase being lath-shaped. They range in size from tiny crystals to those 1 inch in diameter. In the alkali feldspars weathering brings out a zonal growth. In many bostonite porphyries the feldspar phenocrysts are small or absent within 4 inches of the border of the dikes. The smaller size is in part due to the growth of the phenocrysts near the center of the dikes, where cooling was slower than on the borders, by addition of feldspar from the groundmass. (See pp. 94–95.) The lack of phenocrysts is, however, not easily explained, for they are plainly of intratelluric origin, as is shown by the fact that in some places both pyroxene and feldspar phenocrysts have an orientation on the border of the dike parallel to its extension. Pseudomorphs resemble in form pyroxene and vary in length from one-fourth to 1 inch. Penetration twins, in which the individuals join one another at an angle of about 60°, are common. These columns are a light to blackish green, slightly fibrous substance resembling serpentine.

Under the microscope bostonite proves to have a coarse or fine trachytic or trachytoid texture. Anorthoclase laths which vary in length from 0.1 to 1.25 mm. have in the trachytic groundmass a highly developed flow arrangement. Between the anorthoclase crystals lie wedges and irregular equidimensional masses of orthoclase and quartz, locally with magnetite, and each of these minerals clearly solidified after the anorthoclase laths. Some of the wedges, particularly quartz, have common orientation over considerable areas, in which case the texture is both trachytic and ophitic. The irregular masses of quartz and orthoclase, on the other hand, micropoikilitically inclose anorthoclase laths, the texture being trachytic and micropoikilitic. In the trachytoid structure flow orientation of the anorthoclase laths is poorly developed, and they penetrate one another, many of them forming six-armed crosses. Here and there pyrite metasomatically replaces the feldspars.

The textures of the bostonite porphyry are those of the bostonites, except that quartz, micropoikilitically inclosing anorthoclase and orthoclase, is in many places particularly prominent in the center of areas of groundmass between the phenocrysts. The orthoclase laths are dammed against the phenocrysts and then sweep around them in flowing curves. The predominant phenocrysts are orthoclase, which where small are simple crystals and where large are, as a rule, complex. The borders are in general slightly roughened by the addition of orthoclase from the groundmass in similar optical orientation. In some places a few anorthoclase laths are inclosed in this younger border. Anorthoclase and oligoclase phenocrysts are also sparingly present. The feldspar phenocrysts are rounded by magmatic corrosion, and rarely areas of groundmass are included in the phenocrysts.

Prior to solidification of the groundmass some of the feldspar phenocrysts were broken or cracked and an undulose extinction developed in them. Locally feldspar is completely altered to kaolin and to sericite, which is very commonly accompanied by quartz or chalcedony and only rarely by calcite. The forms resembling pyroxene are composed of either serpentine or talc, with or without quartz, magnetite, orthoclase, epidote, and zoisite. A leucoxene-like substance is also present in some specimens, indicating that the pyroxene was titaniferous or that magnetite, which in some places rimmed it, contained some titanium. A few sparse titaniferous magnetite cubes are of intratelluric origin, as are also stocky columns of apatite, which are confined to the porphyritic bostonites. Pseudomorphs of titanite occur only in the pyroxene-bearing varieties. These are composed of chalcedony or quartz with a rather indefinite leucoxene-like material that in a single thin section is certainly rutile. Small crystals of zircon have been observed in a single thin section. Fluorite occurs in bostonite dikes 0.2 mile S. 15° E. of the mouth of Little Bear Creek, 1.5 miles east of Freeland, and at other places. In thin sections from the Freeland locality it is very abundant in wedges between the other constituents of the groundmass and in irregular patches replacing feldspar. The latter occurrence is certainly of secondary origin, but the former has every appearance of being original, although the scanty occurrence of this mineral in the series is rather against this view. The purple coloring is either in dots or in bands roughly parallel to the boundary of the areas.

By various processes of alteration the bostonite and bostonite porphyry undergo a variety of color changes, usually accompanied by loss of density. Through sericitization the rock becomes a greenish white; through calcitization and kaolinization it bleaches; and through the hydration of its iron content and the introduction from without of iron oxides it takes on various shades of yellow, pink, red, and purple. Black stains of manganese dioxide occur particularly on the feldspar phenocrysts, a phenomenon also noted in the alaskitic quartz monzonite porphyry. In many places weathered surfaces of the bostonite porphyry are porous through the removal of the phenocrysts.

ALASKITIC QUARTZ MONZONITE PORPHYRY (FERROMAGNESIAN-POOR QUARTZ MONZONITE PORPHYRY).

DEFINITION.

Where biotite, amphibole, and pyroxene are only sparingly present in a quartz monzonite porphyry (see pp. 73–74) the rock may be called an alaskitic quartz monzonite porphyry.

DISTRIBUTION AND OCCURRENCE.

This rock occurs in dikes which are confined to the northeastern portion of the quadrangle and are particularly abundant near Freeland, on the tributaries of Soda Creek, and south of Alps Mountain. The dikes of the latter locality have a rude east-west alignment and may well be segments of a single dike which at some distance beneath the surface are connected with one another.

PETROGRAPHY.

The alaskitic quartz monzonite porphyry is a white or light-gray rock with dense and flinty or finely granular groundmass. The more flinty facies have a conchoidal fracture. Phenocrysts of feldspar as a rule are sparse, but rarely are so abundant that they equal the groundmass in bulk. In general both orthoclase and plagioclase are altered. The phenocrysts, most of which are one-eighth of an inch long, reach a maximum length of three-eighths of an inch. Sparse quartz phenocrysts are present in the rock of some dikes. (See p. 184.)

Most of the weathered outcrops have a smooth surface pitted by the removal of the feldspar phenocrysts. Since few, if any, iron-bearing minerals are present in the rock, weathered exposures are stained only a lemon yellow by iron salts. Manganese-dioxide stains are in many places localized on the feldspar phenocrysts, probably because feldspar is favorable either physically or chemically to the precipitation of manganese dioxide from aqueous solutions. The residual bowlders are as a rule blocks sharply bounded by joints.

In the majority of thin sections examined the groundmass, composed of orthoclase, quartz, and somewhat less oligoclase, is holocrystalline. Oligoclase forms laths, orthoclase forms tablets and irregular areas, and quartz forms irregular areas, many of which are of considerable size, inclosing the other constituents poikilitically, a feature less characteristic of the irregular orthoclase areas. The groundmass in some thin sections, however, is seen to be formed of irregular or hexagonal areas of low birefringence, possessing slightly wavy extinction. This groundmass suggests a devitrified glass, and some members of the series may originally have had a glassy groundmass and, in consequence, be altered latites. Phenocrysts of orthoclase and oligoclase are in general equally abundant. The orthoclase phenocrysts, most of which are compound, possess in many specimens beautifully developed zonal growth. Oligoclase phenocrysts are in the main smaller and more commonly simple than are those of orthoclase. Twinning according to the Carlsbad and pericline laws is locally present. The feldspars of the rock vary from those that are practically fresh to others completely altered to kaolin or sericite. Chalcedony and quartz with sericite form feldspar psuedomorphs in several thin sections. Quartz where present is similar to that of the alaskite porphyry. In two thin sections small shreds of muscovite heavily stained by limonite probably represent original biotite phenocrysts. Titanite crystals reaching a maximum length of 2 mm. and showing in many places reentrant angles due to twinning are present in most thin sections. As a rule titanite is altered to rutile and chalcedony, the former mineral occurring in stocky columns and geniculated twins bordering the latter. This alteration is present in a rock otherwise so fresh that it is perhaps more logically to be considered a change which took place prior to the final solidification of the groundmass. Rather large apatite columns are present in the majority of thin sections. Magnetite, although fairly abundant in certain sections, is not characteristic of the series. Zircon is more rare.

BIOTITE LATITE.

DEFINITION.

Latite is the lava equivalent of granular monzonite. The prefix biotite indicates that biotite is the characteristic ferromagnesian mineral present.

DISTRIBUTION AND OCCURRENCE.

Biotite latite dikes are confined to the valleys of Chicago and West Chicago creeks, from King Solomon Gulch southwestward to a point 1.3 miles above the junction of the creeks. The dikes are short and from 5 to 10 feet wide, and with one probable exception have a strike approximately northeast and southwest. This, together with the linear arrangement of the dikes, suggests that they may be segments of a single dike continuous at depths beneath the surface. The latite at the junction of the Chicago creeks contains a few rounded inclusions of quartz monzonite from 4 to 6 inches in diameter.

PETROGRAPHY.

The biotite latite is a yellowish-brown or gray rock with slightly greenish or pinkish tinge. The groundmass is in general dense and aphanitic, although contact phases are locally a black glass with greenish tinge. Thin flakes of this phase, forming a band several inches wide on the northwest side of the dike at the mouth of Eclipse Gulch, are semitransparent. Rarely weathering reveals in this phase indistinct lines of flow. The groundmass predominates largely over the phenocrysts in bulk, although small phenocrysts of biotite and feldspar in equal abundance are very numerous. Most of the feldspar phenocrysts, both tabular orthoclase and short lathlike plagioclase are 0.05 inch in length, although a few reach 0.2 inch. Biotite occurs in hexagonal plates from 0.05 to 0.4 inch in diameter, 0.1 inch being the average size. As a rule the crystals, which are locally rounded and embayed by magmatic corrosion, are very thin, being composed of but a few cleavage folia.

The latite is well jointed and on weathering breaks down into small joint blocks. Dendrites of manganese dioxide and concentric rings of limonite are present here and there on joint surfaces. The weathered surface which, when unstained by iron salts, is bluish gray or greenish white in color, is rather smooth, although slightly pitted by the removal of feldspar phenocrysts. The latite readily disintegrates to a bluish-gray clayey substance.

Under the microscope the hyalopilitic groundmass, with flow structure in some thin sections and without it in others, is a clear light-brown glass, in places slightly devitrified. In it are microlites of lath-shaped plagioclase (labradorite), tabular orthoclase, and in some thin sections shredlike biotite. A thin section from the border of the dike shows chalcedony and a little chlorite filling vesicular cavities. The phenocrysts, named in the order of abundance, are orthoclase, biotite, and plagioclase, with brown hornblende in some slides. Most of the orthoclase phenocrysts are simple, but a few are complex aggregates. Some of them show slight magmatic corrosion and zonal growth is rather characteristic of both generations of orthoclase crystals. Some of the phenocrysts are twinned according to the Carlsbad law. The plagioclase phenocrysts (oligoclase) are lath-shaped and are locally twinned according to the Carlsbad law. Here and there biotite in crystals and in embayed individuals is partly or completely inclosed in the feldspars. Flexing fracture of biotite occurred prior to the final solidification of the rock. The accessory minerals present are magnetite, apatite, and zircon, abundant in the order named. All the constituents of the rock are remarkably fresh.

ALKALI SYENITE PORPHYRY.

DEFINITION.

Alkali syenite is a granular igneous rock composed essentially of an alkali feldspar or feldspars and in general either an alkali pyroxene or amphibole with or without other alkali-rich minerals. A porphyritic rock of this composition is called an alkali syenite porphyry.

DISTRIBUTION AND OCCURRENCE.

On the south side of Clear Creek, east of the mouth of Soda Creek, a small mass, presumably a stock, of alkali syenite porphyry, with a surface exposure 0.15 mile in diameter, intrudes the pre-Cambrian rocks. The alkali syenite porphyry at its contact with the pre-Cambrian rocks contains many inclusions of the Idaho Springs formation. A dike 0.2 mile long and 8 feet wide of rather similar rock occurs southeast of the main mass. It courses northwest and dips 60° NE. The mineral springs of Idaho Springs come either from this rock or from its contact with the pre-Cambrian rocks, and it is believed that the water derives its high sodium content from the sodium-rich porphyry. The heat of the water of some of the springs is perhaps genetically connected with the after effects of volcanism.

PETROGRAPHY.

The alkali syenite porphyry varies considerably in texture throughout the main mass described above. The most widely distributed facies is a light bluish-gray porphyritic rock in which the groundmass is subordinate to the abundant and rather large phenocrysts. The groundmass is made up of tiny individuals of feldspar. The most striking phenocrysts are velvet or greenish-black octagonal prisms, presumably pyroxene, and of these the largest are one-eighth inch in length. Equally striking but somewhat less abundant are brownish-black garnet crystals with metallic luster, which in some exposures are three-eighths of an inch in diameter. Less striking but more abundant than either pyroxene or garnet are glassy, whitish-gray, unstriated feldspar phenocrysts. These tabular crystals vary in length from one-eighth to five-eighths of an inch. Small wedges of clove-brown titanite and octahedrons of magnetite are also visible to the naked eye. The distribution of pyroxene and garnet is uneven throughout the mass and both may be scarce or abundant or either may be present to the almost total exclusion of the other. This type appears to grade into a rock with light greenish-gray holocrystalline groundmass in which are embedded many large pink feldspar crystals reaching a maximum length of 4 inches. On weathering the rock first bleaches and then is stained yellow, pink, brown, or purple by iron oxides. The weathered surface is smooth but pitted by the partial or complete removal of pyroxene and garnet.

As seen under the microscope, in some thin sections the micrograntic groundmass almost equals the phenocrysts in bulk, while in others it consists of small areas between the greatly predominant phenocrysts. The groundmass is composed chiefly of irregular masses of anorthoclase and some orthoclase, quartz also being present in some thin sections. The pyroxene phenocrysts are ægirite-augite, many of them being zonally built, with ægirite predominant on the border. Although some, as already mentioned, are partial crystals, others are little more than rounded grains, some of which are inclosed in anorthoclase and melanite. Twinning parallel to 100, often repeated, is common. The ægirite-augite is in general fresh, but in a single thin section is altered to serpentine and an iron ore. The garnet, a dark-brown species with faint zonal growth, is apparently melanite. Some of the larger crystals contain other phenocrysts as inclusions, and the smaller, in particular, are slightly embayed by magmatic corrosion. The anorthoclase and fewer orthoclase phenocrysts are locally twinned according to the Carlsbad law. Rarely these crystals have as centers laths of oligoclase. The feldspars are slightly altered to sericite and kaolin. Wedge-shaped crystals and irregular grains of titanite, octahedrons of magnetite, and short crystals of apatite are present as abundant accessories. In many specimens titanite is twinned, some of it polysynthetically. Very small crystals, probably zircon, and biotite shreds are present in a single slide.

Fluorite is present in irregular ramifying areas in the groundmass and in small areas flecking feldspar or ægirite-augite. Fluorite was probably introduced after the solidification of the rock, possibly by gases, and in part fills cavities between the minerals and in part replaces them. Analcite occurs in similar small areas, which are, however, more largely confined to the groundmass. Since it occurs in thin sections of very fresh rocks, it is perhaps an original mineral, although it may be of secondary origin. The small percentage of SO_3 in the chemical analysis indicates the presence of haüynite, or nosean, although neither mineral was recognized in the thin sections.

George Steiger made the following analysis of a specimen of the type rock:

Analysis of alkali syenite porphyry from south side of Clear Creek, near Soda Creek.

SiO_2	60.30	ZrO_2	0.01
Al_2O_3	18.12	CO_2	None.
Fe_2O_3	2.45	P_2O_5	.25
FeO	1.25	SO_3	.06
MgO	.28	S	None.
CaO	3.89	MnO	.12
Na_2O	5.83	BaO	.26
K_2O	5.01	SrO	Not looked for.
H_2O	.75	F	None.
H_2O+	.77		
TiO_2	.55		99.90

According to the classification of igneous rocks proposed by Cross, Iddings, Pirsson, and Washington,[a] the alkali-soda syenite is pulaskose. It is analogous to a bostonite from Burlington, described by Kemp and Marsters;[b] a pulaskite from Fourche Mountain, Arkansas, described by Washington;[c] a quartz syenite from the Highwood Mountains, Montana, described by Weed and Pirsson,[d] and a trachyte from the Rosita Hills, Colorado, described by Cross.[e] Mineralogically the quartz syenite from the Highwood Mountains is very similar to the alkali syenite porphyry, although richer in quartz and without melanite. The trachyte described by Cross from the Rosita Hills, Custer County, 115 miles from Idaho Springs, is of very similar chemical, although of widely variant mineral composition. Cross[f] considers the trachyte of Eocene or Miocene age.

QUATERNARY DEPOSITS.

GENERAL OUTLINE.

The Pleistocene history of the Georgetown quadrangle has been complex and has included the deposition of river-terrace gravels, glacial drift, and alluvium. The earliest event recognized was the deposition of the 180-foot and 55-foot terraces. Then followed the earlier glacial epoch, after which the 25-foot terrace was formed. The later period of glaciation, accompanied by the deposition of débris sheets in the nonglaciated valley heads, followed, and in comparatively recent time travertine, alluvium, landslide material, and talus have been deposited.

TERRACE GRAVELS.

In the vicinity of Idaho Springs three sets of terrace gravels, now eroded into a number of separate areas, mark three distinct stages in the downcutting of the valleys of Clear Creek and its tributary, Chicago Creek. These terraces are striking topographic features. (See Pl. XIII.) The gravels are predominantly granitic, since the pre-Cambrian schists are not resistant to stream corrasion. The gravels contain gold and were formerly actively worked, in fact, they are now being mined just east of Idaho Springs.

[a] Classification of Igneous Rocks, Chicago, 1903.
[b] Kemp, J. F., and Marsters, V. F., Bull. U. S. Geol. Survey No. 107, 1893, p. 20.
[c] Washington, H. S., Jour. Geol., vol. 9, 1901, p. 609.
[d] Weed, W. H., and Pirsson, L. V., Am. Jour. Sci., 4th ser., vol. 1, 1896, p. 295.
[e] Cross, Whitman, Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 324.
[f] Idem, p. 273.

The following table gives the elevations of the terrace surface and its bed-rock floor above Clear Creek and Idaho Springs, the average thickness of the gravel upon it, the number of remnants, and the approximate total area of each terrace deposit:

Height, thickness, and area of Pleistocene river terraces in Georgetown quadrangle.

Height of surface above Clear Creek.	Average height of bed-rock floor above Clear Creek.	Average thickness of gravel.	Number of remnants.	Total area.
Feet.	*Feet.*	*Feet.*		*Acres.*
180	160	20	4	710
55	35	20	2	175
25	20	5	4	12

There are four remnants of the 180-foot terrace, the floor of which lies from 150 to 160 feet above Clear Creek. The surface, now gently rounded by erosion, is 180 feet above the stream. The deposit consists of well-rounded pebbles, cobbles, and bowlders, the largest of which are 5 feet in diameter, with some lenses of coarse sand. The bowlders are predominantly granitic and are comparatively fresh, the few hornblende-gneiss bowlders present being considerably decomposed. Portions of the mass are stained red or reddish brown.

Since the formation of this terrace Clear Creek has sunk a canyon in solid rock 600 feet wide and at least 160 feet deep. The size of this canyon, much greater than that of any interglacial canyon, proves that this terrace is preglacial.

Two remnants of the 55-foot terrace occur on Clear Creek, and of these one extends a short distance up Chicago Creek. The bed-rock floor is from 30 to 35 feet above the creek, and the terrace surface is in most places 55 feet high. The deposit is composed of sand and bowlders, the largest of which are 4 feet in diameter. This terrace may be either interglacial or preglacial.

The bed-rock floor of the 25-foot terrace, whose remnants are confined to the lower 2.2 miles of Chicago Creek, is about 20 feet above the creek level at the southern limit of the terrace and only 15 feet at the mouth of the stream. The old channel floor is covered by 5 to 10 feet of gravel. At the cemetery, three-fourths of a mile above the mouth of Chicago Creek, the deposits consist of 3 to 5 feet of moderately coarse river gravel grading upward into a bed of brown silty sand from 2 to 5 feet thick. The valley train of the later Clear Creek glacier is 18 feet above Clear Creek, and in consequence this terrace is somewhat older than the later glacial epoch.

Less conspicuous old channels and terrace remnants occur at several elevations between the 25-foot and 180-foot terraces.

GLACIATION.

Alpine glaciers occupied the heads and upper reaches of the valleys of the Georgetown quadrangle during two distinct glacial epochs, separated by a considerable interval.

EARLIER GLACIAL EPOCH.

Glaciers.—The glaciers of the earlier glacial epoch headed in the Continental Divide to the west of the Georgetown quadrangle and flowed eastward down Clear Creek and West Fork of Clear Creek (in the Central City quadrangle, to the north) to Empire station. From this point the united glaciers extended to Dumont, where there are remnants of the terminal moraine. The presence of patches of till on Bard Creek and on South Clear Creek, opposite the mouth of Leavenworth Creek, leads to the belief that small lobes of the main glacier extended a short distance up these streams. At the west border of the Central City quadrangle the glacier extended approximately to the 11,200-foot contour. The terminal moraine at Dumont is at an altitude of 7,900 feet, showing that the upper surface of the glacier descended about 400 feet per mile. Glaciers in the earlier epoch apparently did not head from Mount Evans, since if such were the case earlier till should be found in some of the valleys extending to the east and south from that mountain. It is possible, however, that small glaciers existed, although they must have been less extensive than those of the later glacial epoch. Although the valley of South Clear Creek has steep walls 200 to 1,000 feet above the upper limit of later glacial erosion, this is believed to be due to sapping by the later glacier and the subsequent wedging off of great masses from the cliffs.

Character and material of the deposits.—The till of the earlier glacial epoch occurs in irregular remnants whose glacial topographic features have been in large part destroyed by erosion. In a broad way the distribution of these remnants suggests a glacier-like form, and at Dumont the terminal moraine, with a minor recessional moraine within, is rather clearly outlined. The deposits of the earlier epoch are well drained and without marshes and springs.

The till is a light-yellowish sandy clay with many bowlders and cobbles of a great variety of rocks. The bowlders, the larger of which are 10 feet in diameter, are angular, subangular, or less commonly rounded. Bowlders from freshly exposed till show glacial smoothing and suggestions of striæ, porphyry bowlders alone being well striated. The rarity of striations is partially due to the small development of ground-morainal till. The bowlders lying upon the surface of the till are roughened by weathering and somewhat decomposed, particularly those of hornblende gneiss. The till is oxidized to a reddish-brown color to depths varying from 3 to 15 feet.

LATER GLACIAL EPOCH.

Glaciers.—The distribution of the glaciers of the later glacial epoch has already been described (p. 33). The lowest point (elevation 8,175 feet) reached by a glacier of the second epoch is marked by the terminal moraine of the Clear Creek glacier near Empire station, three-fourths of a mile north of this quadrangle. The following table gives the length and maximum width of the glaciers, the altitude of the upper and lower limits of glaciation, the approximate maximum depth of the ice, and the approximate rate of descent of the later glaciers:

Dimensions, altitude, and slope of later glaciers in Georgetown quadrangle.

Name.	Length.	Maximum width.	Present altitude of upper limit of glaciation.	Present altitude of lower limit of glaciation.	Approximate maximum depth of ice.	Approximate rate of descent.
	Miles.	*Miles.*	*Feet.*	*Feet.*	*Feet.*	*Feet per mile.*
Lincoln Lake	1.45	0.45	12,500	10,900	400	1,100
South Fork of Deer Creek	1.80	.70	[a] 11,500	10,200	700	720
Naylor Lake	1.90	.65	[a] 12,200	11,200	700	530
West Geneva Creek	2.10	.90	[a] 10,500	9,675	600	390
Deer Creek	2.15	.40	12,000	10,675	400	620
Beartrack Creek	2.90	.55	13,200	10,250	600	1,020
Bard Creek	3.40	.70	12,100	8,925	700	930
Leavenworth Creek	4.00	.65	[a] 11,400	9,700	500	420
Bear Creek	4.90	1.30	13,400	9,250	900	850
West Chicago Creek	5.35	1.15	13,400	9,275	1,000	770
Upper East Geneva Creek	5.70	1.45	[b] 13,900	10,850	1,000	530
Duck Creek	7.10	.85	[b] 13,900	9,800	700	580
East Chicago Creek	7.15	1.30	14,100	8,900	1,200	730
Lake Fork of East Geneva Creek	7.50	1.25	14,000	9,300	1,500	630
Clear Creek	8.00	1.15	[a] 11,500	8,175	2,200	410
South Clear Creek	8.90	.60	[b] 13,900	9,650	700	480

[a] For those glaciers which headed beyond the limits of the quadrangle, the highest point of glaciation on the quadrangle border is given as the nominal head of the glacier. Although not accurate, this course is adopted for the reason that the heads of some of the glaciers have not been located.

[b] The glaciers of South Clear Creek, Duck Creek, and Upper East Geneva Creek had a common head.

From this table it is evident that greater length is, as a rule, accompanied by greater width and maximum depth of ice and a less rate of descent.

Erosional forms.—The topographic forms produced by the glaciers of the later period have already been described (p. 33). Glacial groovings and smoothings, in places partially roughened by postglacial weathering, are common. Glacial striæ, in general parallel to the length of the glacier, are particularly abundant near Silver Plume.

Character and material of the deposits.—The glacial deposits have been but little eroded, and except along Clear Creek, where stream erosion has been especially active, the continuity of the deposits has not been destroyed. Lateral moraines are strikingly developed, but terminal, recessional, and ground moraines are inconspicuous. Although the presence here and there of double lateral moraines indicates a distinct check in the shrinkage of the retreating glaciers, the rarity of recessional terminal moraines shows that such interruptions of retreat were not frequent. Kames occur to the north of the quadrangle, near Empire station.

The morainal material is a light-yellowish sandy clay containing a wide variety of subangular cobbles and bowlders and fewer of rounded form. The finer material of the ground moraine is more clayey and the bowlders are smaller and less abundant than in lateral and terminal moraines. Striated bowlders are rare. The bowlders upon the surface of the till are not weathered, and the clay is unoxidized.

The valley trains and outwash fans of coarse bowlders and sand are in most places of small development, although a valley train extends from the terminal moraine of the later Clear Creek glacier at Empire station down Clear Creek beyond Idaho Springs, and Idaho Springs itself is mainly built upon it. The gravels are auriferous and have yielded a considerable amount of placer gold. The postglacial canyon of Clear Creek, from 10 to 30 feet deep, separates this valley train into a number of disconnected areas.

Southeast of Naylor Lake and south of Duck Lake are two peculiar deposits, partially surrounded by glacial till, consisting of huge angular masses of rock, many of them 20 to 100 feet in diameter, all of material from the overhanging cliffs. The rock masses are unglaciated, although in some places patches of till are associated with them. The topography is that of a moraine, with kettle holes, hillocks, and ridges, but the material is similar to that of a landslide, and the Duck Lake deposit grades into an undoubted landslide higher up on the hill. These deposits were evidently landslides which lodged upon the decaying glacier and which, as the ice melted, took on a morainic topography. During the decline of glaciation the conditions for the formation of landslides are ideal, since cliffs are undercut and the rocks are saturated with water. It is probable that during each glacial epoch many landslides lodged upon the glaciers, but the material of all except those formed immediately prior to the final retreat of the ice became so involved with drift that it is impossible to recognize them as landslides.

RELATIVE AGES OF THE GLACIAL EPOCHS.

The two glacial epochs, as shown by the glacial deposits and erosional features, were separated from each other by a considerable interval of time. The glacial deposits of the earlier stage are deeply oxidized, and the surface bowlders are considerably decomposed; the deposits of the later epoch are unoxidized, and the surface bowlders are fresh. Where lodgment was possible the later glacial deposits are continuous, and their topographic form is preserved. The earlier glacial deposits, on the other hand, have been carved by erosion into many irregular patches that lack glacial topography. Valleys that were glaciated only in the earlier stage are rugged and set with numerous rock pinnacles; those glaciated in the later epoch are smooth and in many places striated. Douglas Mountain was covered by ice in the earlier glacial stage, but in the later it was only partly surrounded by ice. In consequence, its base is smooth, and its upper slopes are very rugged. Since the earlier glacial epoch granite bowlders have weathered out, and a considerable depth of residual soil has formed on its summit. In the Central City quadrangle, to the north, the smaller of the two small streams named Silver Creek, a tributary of Clear Creek, has cut a canyon in the earlier glacial deposits 3,000 feet long with an average depth of 100 feet and a width at the top of 250 feet. At one place the upper 85 feet is cut in glacial till and the lower 15 feet in the biotite-sillimanite schist of the Idaho Springs formation and in muscovite pegmatite. Farther downstream the canyon is sunk 150 feet in resistant pre-Cambrian rocks. The other somewhat larger stream named Silver Creek, a tributary of Fall River, has cut a trench in the later till 20 to 30 feet deep and 50 to 75 feet wide. Of like significance are the phenomena at Dumont, where Clear Creek broke through the terminal moraine of the earlier epoch, partially washed it away, and then deepened its canyon. Subsequently the canyon was partly filled by the valley train of the later Clear Creek glacier, in which a small postglacial canyon has been cut.

The extent of interglacial erosion is unknown. A portion of the inner canyon of South Clear Creek, southeast of Georgetown, is probably interglacial, since it is considerably larger than the canyon of Clear Creek southwest of Georgetown, notwithstanding the fact that the latter stream is the larger of the two.

The later glacial stage was doubtless comparatively recent and in a minor way continues to the present day, the snow fields and small glaciers of the Colorado Range, a short distance to the north, being probably remnants of the later glaciers.

Postglacial erosion of even the larger streams has not been great. Southwest of Georgetown, Clear Creek, the major stream of the quadrangle, has cut a canyon 1,000 feet long and 30 feet deep in pre-Cambrian schists and granites. The upper 200 feet of the canyon is from 10 to 50 feet wide; the lower 800 feet averages 60 feet in width.

Spurr,[a] in describing the glacial deposits of the Aspen mining district, which were probably in a broad way contemporaneous with those of the Georgetown quadrangle, considers the valley glaciers to be the shrunken remnants of the older glacier which covered a large area in the vicinity of Aspen. Although it is recognized that this interpretation may apply to the glaciers of the Front Range, it is believed that the two glacial epochs here described were separated from each other by so long a period of interglacial erosion that their treatment as two distinct stages is warranted. In the interglacial time, however, as at present, snow fields and even small glaciers may have existed.

HIGH BASIN DÉBRIS SHEETS.

The upper drainage areas of many streams which were not occupied by glaciers are covered by basin-like sheets of débris. The accompanying table gives the average elevation and the size of these débris sheets:

Elevation and area of high basin débris sheets in Georgetown quadrangle.

Situation.	Average elevation above sea level.	Approximate area.
	Feet.	*Acres.*
Basin of Silver Creek, south of Lawson and west of Lamartine	10,200	200
Head of Trail Creek	10,400	130
Highland Park	10,800	320
Head of Warren Gulch	9,600	45
Head of Soda Creek	9,500	150
South of Devils Nose	10,500	125
2½ miles north of Chicago Lakes	11,000	400
1½ miles northwest of Mount Evans	12,800	175
East of Summit Lake	12,500	700
Head of Lost Creek	10,700	350
1 mile northwest of Meridian Hill	11,100	100
½ mile east of Meridian Hill	10,700	350
1 mile southeast of Rosalie Peak	11,100	350
Head of Elk Creek	11,000	140
Average	10,850	250

The surface of these débris sheets rises gently from the center toward the head and the sides of the valley. In a broad way it is smooth, but in the minor details it is uneven and in places reminds one of landslide topography. Swampy areas and springs are not uncommon, although true glacial forms are absent. The streams have cut small canyons from 20 to 100 feet deep.

The débris sheets are composed of angular and badly weathered rock fragments, sand, and silt, all local material clearly derived from the surrounding ridges. The deposits are at a minimum 20 feet and in some places over 100 feet thick, and few rock exposures protrude from them.

Three distinct stages in the history of the headwaters of the streams are recorded by these sheets—first, the development by erosion of broad valleys from 20 to more than 100 feet below the present valleys; second, the filling of these valleys approximately to their present height by the inwashing of detritus from the surrounding ridges; and third, the incision of small canyons.

[a] Spurr, J. E., Mon. U. S. Geol. Survey, vol. 31, 1898, p. 250.

The débris sheet at the head of Silver Creek, west of Lamartine, lies behind the lateral moraine of the earlier Clear Creek glacier, showing that the erosion of the valley now filled with débris occurred in preglacial time and that the filling was deposited after the moraine was formed. The material of these débris sheets contains less clay and is probably more rapidly eroded than glacial till. The canyons, which equal in size or are slightly larger than the postglacial canyons in till, are therefore probably of postglacial age. It is probable that the wide valleys occupied by the débris sheets were cut in preglacial time and filled with débris mainly in late glacial time, and that the canyons were incised in postglacial time. While the climatic conditions were favorable to the formation of glaciers in the highest valleys, they were also particularly favorable to the existence of mud streams and sheet erosion, recently clearly discussed by Anderson,[a] in the lower valleys. Débris would accumulate in the heads of the lower valleys, since it was deposited more rapidly than it could be removed by the mountain streams.

ALLUVIUM.

The "alluvium" of the map includes a variety of postglacial stream deposits. On Clear Creek in the vicinity of Idaho Springs and on Deer and Elk creeks and the tributaries of Bear Creek the alluvium consists of flood-plain deposits of fine silt and gravel bars.

The alluvial flat north of Georgetown, through which Clear Creek meanders, is due to stream infilling behind the terminal moraine of the later Clear Creek glacier. Geneva Park was formed by the filling of a preglacial valley dammed by the lateral moraine of East Geneva Creek. Small patches of alluvium occur in all the minor stream valleys obstructed by lateral moraines, but many of these are too small to map. The larger areas of alluvium within the glacial deposits are mapped, but many small areas, partly filled lakelets and swamps, are so intricately associated with ground moraine that the scale of the map is inadequate for their delimitation. Some of the glacial lakes are rimmed by alluvium, a measure of their former greater size.

The alluvium at the head of the east branch of Lost Creek is an alluvial fan built by a streamlet, now a tributary of Indian Creek. The lakes on the border of the quadrangle northeast of Meridian Hill, popularly known as Mud Lakes, are surrounded by mud flats and talus, the former infilling by a small stream, the latter slide from the neighboring hills.

Small alluvial-fan deposits near Georgetown and Idaho Springs are also included in the alluvium. The extension of numerous alluvial fans upon the flood plain of Clear Creek partially accounts for the sinuous course of that stream. These fans rest on later glacial valley trains or on postglacial alluvium, and are hence Recent in age.

LANDSLIDES.

A number of small landslides are mapped. Their material is angular and of local origin and their surface is characteristically uneven and hummocky. Some (see p. 86) are glacial in age; others are probably postglacial and hence Recent.

TALUS.

The valley slopes are more or less covered by débris which has fallen from the slopes above. In cirques much of the postglacial talus is composed of angular blocks, 50 feet in diameter, with interspaces large enough to shelter a man. In many places the upper limit of later glaciation is marked by talus which lodges on narrow, glaciated benches or behind lateral moraines.

TRAVERTINE (CALCAREOUS SPRING DEPOSITS).

One of the springs on the east side of Soda Creek, near Idaho Springs, flows from a small dome of yellowish-white travertine 20 feet in diameter. It is said that a thickness of 0.1 to 0.2 inch of travertine is now being added to the cone annually by the spring water. Smaller areas of this substance near by mark the sites of extinct springs. The travertine is of Recent and probably in part also of Pleistocene age.

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[a] Anderson, J. J., Jour. Geol., vol. 14, 1905, pp. 91-112.

STRUCTURAL GEOLOGY.

The processes which have produced the structure of the rocks of the Georgetown quadrangle are folding, mashing that has caused schistosity, faulting, jointing, and igneous intrusion. As a result of these processes the rocks have been profoundly metamorphosed.

FOLDING.

If the theory that the Idaho Springs formation is of sedimentary origin is correct, its members, the schists, gneisses, and massive crystalline rocks, represent beds which were deposited under water in a horizontal or approximately horizontal position. At the present time the planes separating the various members of the Idaho Springs formation are, where determinable, in the main highly inclined, and it is surmised that the formation has been profoundly folded in a complex manner. The lack of any persistent horizon, recognizable over large areas, and the intense metamorphism suffered by the formation, however, make the unraveling of the structure impossible. The history of the folding of the rocks has doubtless been long and complex, beginning far back in pre-Cambrian time and continuing even after the intrusion of the porphyries, which in a few places have been slightly flexed.

SCHISTOSITY AND GNEISSIC STRUCTURE.

The earlier pre-Cambrian rocks of the Georgetown quadrangle, while deeply buried, were subjected to great stresses, and in consequence either schistosity or a gneissic structure has been developed in them. The schistosity of the biotite-sillimanite schist of the Idaho Springs formation is strikingly well developed and that of the associated biotite schist is good. The gneissic structure of the quartz schist and certain facies of the silicate rocks of the Idaho Springs formation, the hornblende gneiss, and the quartz monzonite gneiss, is also highly developed. In some places the gneissoid granite has a pronounced gneissic structure, and the later pre-Cambrian rocks are locally gneissic. The Tertiary igneous rocks, on the contrary, are massive.

Abrupt variations in the strike of parting planes and intense crenulation are characteristic of the schistose rocks, particularly of the biotite-sillimanite schist. In this rock minute crenulations are superimposed on larger crenulations, these on minor schistosity folds, and these on larger folds, and still the superimposition is much more complex. The planes of the gneissic structure are as a rule straight or gently curved; only in a very few places are they sharply crenulated.

The planes of schistosity and gneissic structure are in places horizontal or dip at small angles, but more commonly they approach a vertical position. The strike of the gneissic and schistose planes is shown by the wavy lines on the map. Prior to the intrusion of the pre-Cambrian granitoid rocks the schistosity of this portion of the Colorado Range probably had a prevailing north-south strike parallel to the present trend of the range. Even in early pre-Cambrian time the trend seems to have been along an important orogenic axis. The intrusion of the pre-Cambrian granitoid rocks has greatly disturbed the original strike of the schistosity and produced a rudely concentric schistosity around the larger igneous masses, a phenomenon well exemplified by the quartz monzonite batholith. The development of the schistosity and gneissic structure was a process, sometimes interrupted, which extended over an immense period, beginning very early and, since the youngest pre-Cambrian formations are comparatively massive, ceasing as an important process before Cambrian time. The relations of the rocks as shown by the contacts indicate that the periods of deposition of the various formations were separated by long time intervals, during which the rocks were successively subjected to dynamic forces producing schistosity or gneissic structure.

In consequence secondary structure of these two types is highly developed in the oldest rocks, which were subjected to all of the deformation, and poorly developed or lacking in the youngest rock, which has been deformed only to an unimportant degree. The Idaho Springs formation accordingly, which has been wholly recrystallized, is in a few places cut by rather massive facies of hornblende gneiss, a formation which under ordinary circumstances has also been thoroughly recrystallized. The quartz monzonite gneiss had a good gneissic structure prior to the intrusion of the gneissoid granite, which contains inclusions of this gneiss with the gneissic planes of the two rocks at right angles. Again, inclusions of gneissoid granite in quartz monzonite appear as gneissic as the more mashed facies now in place in the quadrangle. The deformation between the intrusion of the two rocks last mentioned was the last one to form gneissoid rocks over large areas, and the quartz monzonite and younger formations are, in a broad way, massive. The inclusion, however, of gneissoid quartz monzonite in Silver Plume granite and the presence of mashed fragments of this granite in massive pegmatite show that several periods of lesser differential movements followed the intrusion of the quartz monzonite.

The present direction and attitude of the schistosity is due to three processes—first, the production of the schistosity by recrystallization and mashing caused by compressive stresses; second, the modification of this structure by the intrusion of igneous bodies; and, third, faulting. In the Colorado Range the first process is predominant, although subordinate to the second in the vicinity of large intrusive bodies in the Georgetown quadrangle. The third process is of local importance only.

FAULTS.

The determination of the presence of faults in the pre-Cambrian rocks is difficult, owing to the fact that persistent, recognizable horizons are not present in the Idaho Springs formation and that the other formations, being igneous, solidified as masses of irregular shape. Faults of large throw are probably not developed in the pre-Cambrian rocks, but faults of small throw are common and, in the aggregate, important structures. The magnificent exposures in the cirque walls show no large faults, although faults displacing igneous dikes from 2 to 10 feet are common. In mine workings small faults are numerous along zones of maximum stress. Faults are more common in the massive crystalline rocks and the gneisses than in the schist members of the Idaho Springs formation, for the deformation which in the former brittle rocks produced displacement simply intensified the crenulation of the latter more flexible rocks.

During recrystallization the Idaho Springs formation and the hornblende gneiss were buried so deeply that if faulting accompanied the folding of the series it was subordinate in amount. Faulting occurred, however, prior to the intrusion of the quartz monzonite, for this rock contains inclusions of the Idaho Springs formation cut by faults the fractures of which were filled by quartz prior to the monzonite intrusion. The intrusions of all the succeeding pre-Cambrian formations were accompanied by more or less faulting.

Faulting also occurred between the solidification of the pre-Cambrian pegmatite and that of the intrusive porphyries, for the latter rocks in many localities displaced the former. The Tertiary dikes themselves have been faulted. A dike 0.35 mile above the mouth of Golden Glen Gulch is cut by a north-south fault which offsets the dike 30 feet. Shear planes in the Tertiary dikes and at their contact with the pre-Cambrian rocks are common. The latest recognized faults are those which affect the ore bodies.

JOINTS.

Although joints are well developed in the rocks of the quadrangle, their directions are not constant over considerable areas, a fact due in part to the complexity of the stresses to which the rocks have been subjected and in part to the heterogeneous character of the rock complex of the quadrangle.

The schists of the Idaho Springs formation split readily parallel to the schistosity and are cleanly cut by a set of joints, approximately at right angles to the strike of the schistosity. The other members, being more brittle, are cut by three closely spaced joint systems approximately at right angles to one another. Similar systems of joints, less highly developed, occur in the hornblende gneiss. The granites as a rule have several systems of well-developed joints, one of which is in many places closely spaced, and in consequence is a sheeting. The quartz monzonite is characterized by an approximately horizontal rift which is parallel to the gneissic structure, and this is cut by highly inclined systems of joints. The intrusive porphyries are brittle, and in consequence are cut by several systems of joints which are in places less than 1 inch apart. Sheeting parallel to the length of the dike is also characteristic.

The pre-Cambrian pegmatites and the intrusive porphyries in particular have been intruded along ancient joints, and here and there joints which cleanly cut the gneisses and older plutonic rocks stop at the border of pegmatite and porphyry dikes and are continued beyond. As these rocks are also cut by other joint systems, it is evident that joints have been produced at more than one period.

Joints do not control the major topographic forms, but where weathering and erosion are vigorous they have played an important part in shaping the minor features. This is particularly true along streams and in higher altitudes, where freezing water and changes of temperature are important agents of degradation.

IGNEOUS INTRUSION.

The most important structure of the rocks of the quadrangle is intense and complex intrusion. Many of the gneiss areas are aggregates of shattered blocks embedded in plutonic masses, which in turn are most intricately injected by later igneous rocks. Inclusions within inclusions are common. So intense is the intrusion that the rocks of the quadrangle may be considered an immense igneous breccia, exposure after exposure being encountered, concerning which it is difficult to decide whether to map it as an older rock intruded by a younger or as a younger rock containing inclusions of an older. Some idea of the complexity of the intrusion may be gained from the fact that in a distance of 1 mile south from the northern boundary of the quadrangle, on the ridge between Silver Creek and Clear Creek, six formations alternate seventy-six times, or at the rate of one alternation to 70 feet. This is exclusive of a number of minor intrusions and inclusions. The complexity of intrusion is shown to a slight degree on the map (Pl. II, in pocket), but can not be adequately depicted on a scale so small as that here used.

The forms and the dynamics of intrusion have already been briefly described in the discussion of each igneous rock. Secondary structure in the older rock controlled to a considerable extent the intrusion of the smaller igneous masses. In the more intensely mashed rocks rupture occurred readily along the planes of schistosity and of gneissic structure, and in consequence the smaller masses of igneous rocks predominantly followed these planes. In the more massive granular rocks joints and faults were important planes of weakness. In many places where a gneissoid structure and joints and faults form planes of equal weakness dikes of later rock pass from one plane of weakness to another.

Many of the various igneous intrusions were separated by long time intervals—an inference founded on the differing degree of metamorphism of the various formations and strengthened by the fact that in igneous breccias the igneous rock containing inclusions was thoroughly solidified and the two so firmly cemented one to the other prior to their mutual intrusion by a third rock that rupture and consequent intrusion occurred through the inclusion rather than around it.

BUILDING STONE.

The later pre-Cambrian granular igneous rocks, particularly the quartz monzonite and the Silver Plume and Rosalie granites, are suitable for building purposes. Care should be exercised, however, to locate quarries in areas comparatively free from inclusions of older and dikes of younger rocks. The quadrangle has not the advantage of cheap transportation rates to Denver, the natural market. A very pleasing building stone which is shipped to Denver is quarried from the Silver Plume granite at the mining camp of that name. The Rosalie granite is a strikingly beautiful rock, but can be more advantageously shipped from areas outside of the quadrangle.

GEOLOGIC HISTORY.

But a chapter here and there of the geologic history of the Georgetown quadrangle can be read from its rocks, since most of Paleozoic and Mesozoic time is blank. It may be well, however, to summarize the principal events.

Early in pre-Cambrian time the area of the quadrangle was, as recorded by the older rocks, a sea bottom, probably adjacent to a land mass, from which sand, clay, and at times pebbles were carried to the sea. From the character of the Idaho Springs formation, the deposit of this period, it is inferred that the sea was comparatively shallow, that conditions favoring the deposition of pure limestone rarely held sway, and that very likely the adjacent land was largely or in part composed of granite. After its deposition the Idaho Springs formation was deeply buried, folded, and pegmatized, and in it a parting was developed. This early pegmatization ceased before the end of the intrusion of dikes and sheets of diabase which followed. It is probable that the greater part of the intense recrystallization of the Idaho Springs formation occurred prior to the intrusion of the diabase, although the proportion is unknown. Mashing, however, succeeded the solidification of the diabase, which was changed into a hornblende gneiss. Then followed in order intrusions of quartz monzonite (quartz monzonite gneiss) and siliceous granite (gneissoid granite). These are the youngest formations to which a gneissoid structure has been imparted over large areas, and at about this time the oldest faults of which we have record were formed. Next the huge batholith of quartz monzonite cut and forced its way into the older rocks, and, probably as a later manifestation of the same intrusion, the quartz diorite and hornblendites solidified. From this time on faulting became a more important process and mashing, producing gneissoid rocks, less important. Then followed in order the intrusion of the Rosalie and Silver Plume granites and the granite-pegmatite. During the latter event the schistose and gneissic rocks were completely saturated by liquids emanating from the pegmatite magma (See Pl. XII.)

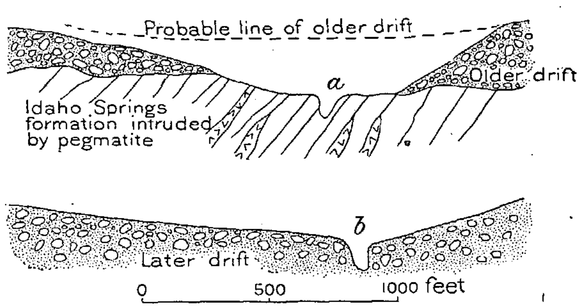
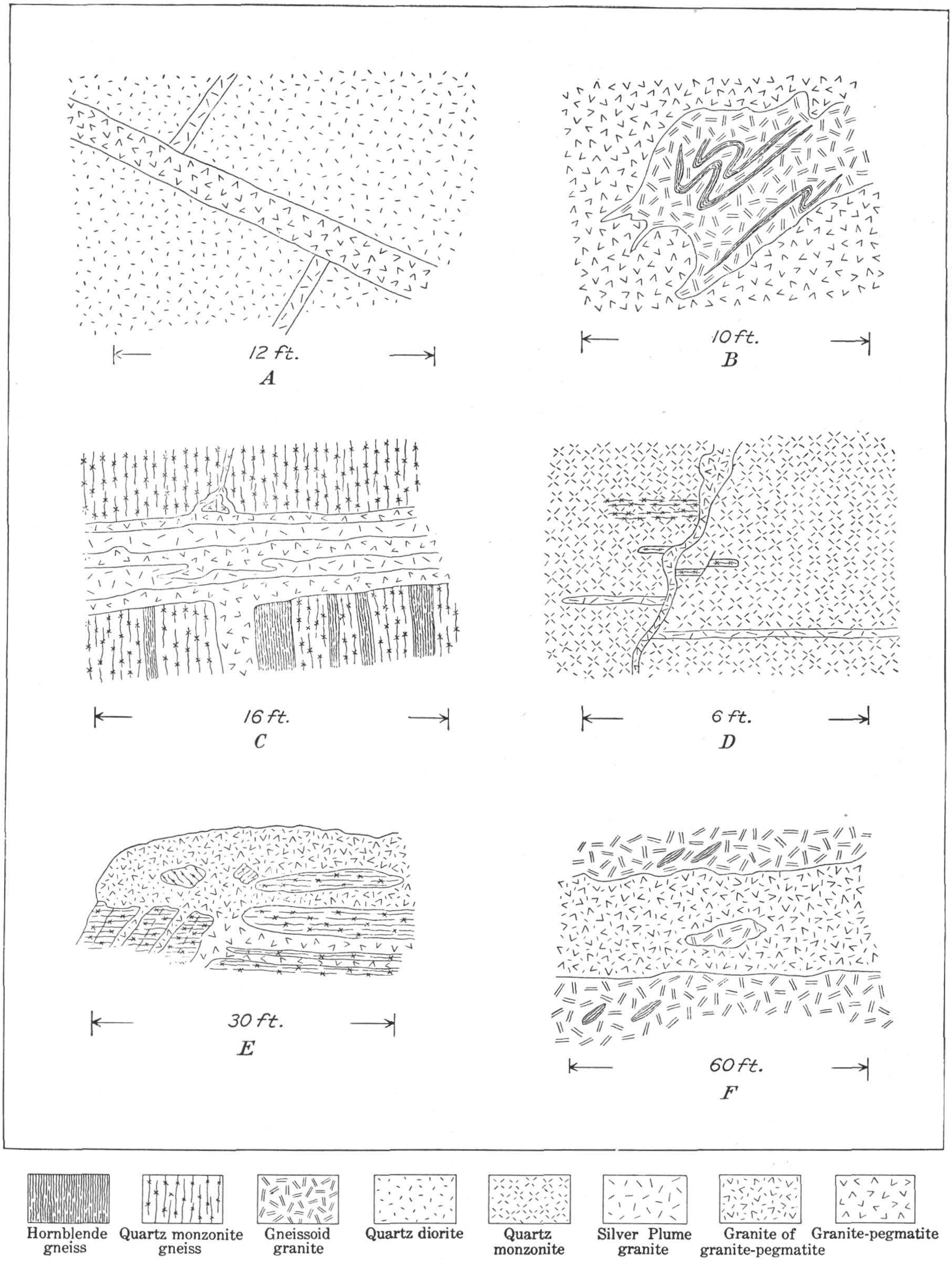


FIG. 23.—Cross sections showing erosion (*a*) of Silver Creek (a tributary of Clear Creek), sunk in the drift of the earlier glacial epoch; (*b*) of Silver Creek (a tributary of Fall River), in drift of the later glacial epoch. The streams are of equal size and hence the cross sections indicate the relative ages of the two glacial epochs.

Of the greater portion of Paleozoic history we can ascertain nothing from the quadrangle itself beyond the fact that it was probably a land mass, although from the rocks of other portions of Colorado it is inferred that it was subjected to profound erosion. It was, in fact, from the rocks of this and contiguous areas in the Colorado Range that material was derived for the Paleozoic rocks which underlie the Mesozoic sediments of the foothills. At some period after the pre-Cambrian rocks had been deeply eroded, which may provisionally be assigned to late Carboniferous time, the sea overflowed a portion at least of the Georgetown quadrangle, the supposed Carboniferous sandstone bowlders admitting of no other conclusion.

Erosion accompanied by uplift persisted throughout the Mesozoic era, but toward the end of Cretaceous time or the beginning of the Tertiary a belt stretching from Boulder on the northeast to Aspen on the southwest was broken by a vast number of fractures, and into these porphyries were intruded. As Cross[a] has shown, it is probable that surface flows which largely or completely covered this portion of the Colorado Range were connected with these or related intrusive masses. It is probable that the intrusion of some of the porphyries extended into late Tertiary time. Since the solidification of the earlier intrusions, at least, these rocks have been fractured, faulted, and slightly flexed. Erosion continued through the Tertiary period, and by Pliocene time the Georgetown quadrangle was a mature, mountainous upland, with broad valleys, and high, rounded summits. It is evident that prior to the formation of this upland the late Cretaceous or early Tertiary lava flows had been completely removed, and that the streams were working again on the pre-Cambrian complex.

[a] Cross, Whitman, Mon. U. S. Geol. Survey, vol. 27, 1896, pp. 34, 202.



SKETCHES ILLUSTRATING INTRUSIVE PHENOMENA.

A. Quartz diorite cut by dike of Silver Plume granite, which in turn is cut and faulted by a granite-pegmatite dike. Near Empire station, Central City quadrangle.
B. Shreds of hornblende gneiss included in gneissoid granite, which in turn is included in granite of granite-pegmatite series. Newhouse tunnel.
C. Quartz monzonite gneiss with parallel intrusions of hornblende gneiss cut and faulted by dike of Silver Plume granite, which in turn is complexly intruded by pegmatite. North side of Leavenworth Creek, three-fourths mile above mouth, at Atlantic tunnel.
D. Inclusions of quartz monzonite gneiss in quartz monzonite cut by a dike of Silver Plume granite, which in turn is cut and faulted by a dike of pegmatite. One-half mile south of Upper Chicago Lake.
E. Granite-pegmatite grading into granite, with intrusions of quartz monzonite gneiss. Northwest side of East Geneva Creek, 2 miles above its mouth.
F. Gneissoid granite with hornblende gneiss intrusions cut by pegmatite-granite with intrusions of gneissoid granite.

In early Pleistocene time the area was uplifted, and then carved by streams, which later were aided by glaciers of two distinct epochs (fig. 23). These and the more recent changes have, however, been already described (p. 33).

MINERALS AND TEXTURES OF METAMORPHIC AND IGNEOUS ROCKS.

It is the intention in this section to discuss briefly some of the more interesting characteristics of the metamorphic and igneous rocks of the Georgetown quadrangle.

ORIGIN OF MICROCLINE.

Microcline is a triclinic feldspar near orthoclase in habit and composition. As a rule, however, it contains somewhat more sodium than orthoclase, and when this element is prominent it is called soda microcline. In many of the granular igneous rocks it takes the place of orthoclase, and is especially characteristic of graphic granite. It occurs less abundantly in porphyritic rocks and is very rare in those with glassy groundmass.[a] In many siliceous gneisses and schists it is the predominant feldspar. Unlike orthoclase,[b] microcline has not, so far as the writers know, been found as a gangue mineral in ore-bearing veins, although its presence is to be expected, from its deposition in schists by waters analogous to those forming veins. Brush and Dana[c] report it as an alteration product of spodumene by alkali solutions.

Rosenbusch[d] states that it has not been produced artificially.

In the rocks of the Georgetown quadrangle microcline either crystallized from the magma or formed subsequent to the consolidation of the rock. As a mineral separating from the magma it occurs in most of the pre-Cambrian granular rocks and as phenocrysts in a single thin section of the late Cretaceous aporhyolite. (See p. 66.) Its occurrence in the latter rock is extraordinary.

In the gneissoid granite, the Silver Plume granite, the quartz monzonite, and the quartz monzonite gneiss much of the microcline was formed subsequent to the solidification of the magma. Its amount in these formations thus varies directly with the recrystallization which the rock has suffered. This microcline further differs from an original mineral in that its relative abundance is very uneven throughout the slide. It occurs in hooks and wedges forced into fractures of orthoclase, plagioclase, and quartz or in veinlets cutting these older minerals. Fresh microcline occupies fractures in altered orthoclase and plagioclase, and in many specimens these areas scattered in a single host are in similar optical orientation. Some sections show a narrow rim of fresh orthoclase and plagioclase against areas of fresh secondary microcline. In such places, where the adjoining mineral changes from micrcoline to quartz, orthoclase, or plagioclase, the fresh rim disappears and the feldspar is completely altered. It is evident not only that microcline is a product of recrystallization, but also that during its deposition a narrow rim of the neighboring older feldspars was regenerated. This secondary microcline was formed after the solidification of the magma, and probably in the early stages of the processes determining the formation of the gneissic structure. That its formation ceased prior to the end of these processes is indicated by the fact that plates of muscovite arranged in the gneissic planes in rare instances replace it. That it is not secondary to orthoclase through strain alone is shown by the sharp contacts with which it invariably joins the other feldspars, as well as by the remarkably and uniformly fresh condition of the microcline, in contradistinction to the altered condition of plagioclase and orthoclase. If microcline in these instances was orthoclase under strain it would naturally be more altered than orthoclase, as minerals under strain are less resistant to alteration than unstrained minerals.[e]

The microcline of the gneissoid types of quartz diorite and that of the large pink phenocrysts of the quartz monzonite gneiss are probably of similar origin. Secondary microcline in many ways resembling this type of microcline in the Georgetown quadrangle has been described

[a] Rosenbusch, H., Mikroskopische Physiographie, Stuttgart, 1892, p. 652.
[b] Spurr, J. E.; Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 229.
[c] Brush, G. J., and Dana, E. S., Am. Jour. Sci., 3d ser., vol. 20, 1880, pp. 257-285.
[d] Op. cit., p. 652.
[e] Van Hise, C. R., Mon. U. S. Geol. Survey, vol. 47, 1904, pp. 96-97.

by Bayley[a] from the gneissic granite of the Marquette Range, Michigan, and by Hall[b] from the gneisses of Minnesota.

In the Idaho Springs formation near planes of movement wavy extinction of orthoclase grades into the grating structure of microcline. Here the common explanation of the origin of microcline from orthoclase as a result of pressure appears to hold.

SECONDARY ENLARGEMENT AND RELATED PHENOMENA.

It has long been recognized by petrographers that in sedimentary rocks clastic grains retain their mineral potency and that when mineral-bearing solutions pass through the rocks each grain selects from the solutions material like itself. This new growth is added to the old grain in optical continuity, new crystal faces often being formed. The Carboniferous sandstone illustrates this process. An analogous case is that of the control of numerous tiny quartz individuals of the groundmass of the late Cretaceous quartz monzonite porphyry by large quartz areas of the biotite-sillimanite schist of the Idaho Springs formation, where these two formations are in contact. Notwithstanding the fact that the latter formation is the oldest of the pre-Cambrian rocks and the former is of late Cretaceous age, the old quartz areas were able to attach to themselves in similar optical orientation silica from the molten magma.

A related phenomenon is the control exerted by phenocrysts of porphyritic rocks on like material of the groundmass. This phase of mineral control has been lucidly presented by Haworth.[c] In consequence of the process the phenocrysts, those of quartz in particular, are surrounded by rims of tiny areas of similar material, each of which is in similar optical orientation with the phenocryst. Such mineral control is well exemplified by the quartz aureoles surrounding the quartz phenocrysts of the quartz monzonite porphyry and the alaskite porphyry, each of late Cretaceous age. In these rocks not only did the phenocrysts have the power to orient like material in continuity with themselves, but they drew from the surrounding magma considerable quantities of quartz, increasing the percentage of silica of the groundmass in their vicinity. Many of the alkali feldspar phenocrysts of the bostonite porphyry, on the other hand, are ragged through the addition of feldspar areas from the groundmass. The groundmass surrounding the phenocrysts is also enriched in feldspar, and in consequence the excess silica of the magma was concentrated as groundmass quartz in the center of areas between the feldspar phenocrysts.

ORIGIN OF THE PHENOCRYSTS.

It is not the intention here to treat in detail the much-discussed question of the origin of phenocrysts. It may be of value, however, to summarize the occurrences of phenocrysts in the rocks of the Georgetown quadrangle.

Phenocrysts clearly of much earlier origin than the groundmass characterize the intrusive porphyries. The greater age of many of these phenocrysts is conclusively proved, on the one hand, by the intense magmatic corrosion which some of them have suffered, and, on the other hand, by the magmatic alterations shown by others. As examples of magmatic corrosion, the quartz phenocrysts of the quartz monzonite porphyry and the orthoclase phenocrysts of the alaskite porphyry may be cited. Magmatic alteration is typically shown in the hornblende phenocrysts of the andesite of the Empire mining district, which are altered to aggregates of hornblende, biotite, and epidote. Since the phenocrysts of the intrusive porphyries originated, however, considerable material has been added to the old form of some of them. This is well shown by the quartz phenocrysts of the quartz monzonite porphyry and the alaskite porphyry and by the alkali-feldspar phenocrysts of the bostonite porphyry. The amount of growth of the phenocrysts of the bostonite porphyry, however, varies with their position in the dike, those near the center of the dike having received greater additions than those along its borders. This is to be expected, since the magma in the center of the dike must have cooled somewhat less rapidly than that along the edges, and in consequence the older phenocrysts had more time

[a] Bayley, W. S., Mon. U. S. Geol. Survey, vol. 28, 1895, p. 172.
[b] Hall, C. W., Bull. U. S. Geol. Survey No. 157, 1899, p. 52.
[c] Haworth, Erasmus, Missouri Geol. Survey, vol. 8, 1895, pp. 143-151.

in which to control the younger constituents of the groundmass. The almost total lack of phenocrysts near the borders of some dikes of bostonite porphyry is, however, less readily explained. The feldspar phenocrysts of the Silver Plume granite are types of phenocrysts of granular rocks which developed considerably earlier than the solidification of the rest of the rock mass. Near contacts with the older rocks these phenocrysts show a marked flow orientation parallel to the contact. This shows that prior to the solidification of the granite these phenocrysts were dragged into parallel position by the movement of the still molten magma. In the porphyritic facies of the granite-pegmatite and of the quartz monzonite gneiss some of the larger crystals clearly solidified before the groundmass, and others contemporaneously with it. In the quartz monzonite gneiss the larger crystals of augite and biotite are skeleton growths in which individuals of the groundmass are inclosed. The augite in particular occurs as small areas disconnected in the plane of observation, with similar optical orientation, and between these the groundmass mosaic lies. Similar forms characterize the biotite and hornblende of the granite porphyry of the granite-pegmatite series. In such rocks, without much question, these ferromagnesian minerals, which in the hand specimen have the appearance of phenocrysts, solidified contemporaneously with the crystallization of the constituents of the groundmass.

As phenocrysts of metamorphic origin the garnet, corundum, and tourmaline of the Idaho Springs formation and the microcline of the quartz monzonite gneiss may be cited. The tourmaline and garnet, in many places at least, have been derived from adjacent dikes of pegmatite, and have therefore been introduced from without. The corundum, on the other hand, developed during contact metamorphism of the biotite-sillimanite schist of the Idaho Springs formation, due to the intrusion of the quartz monzonite batholith. The large pink microline phenocrysts of the quartz monzonite gneiss appear to have developed after the gneissic structure was produced and are believed to have been formed by recrystallization through solutions.

MICROPEGMATITIC AND RELATED TEXTURES.

The term micropegmatite is applied to an intimate intergrowth of two minerals, such as orthoclase and quartz, which is visible only under the microscope. As a rule one of the minerals sends cylindrical arms out into the other. The texture is very common in the pre-Cambrian rocks of the Georgetown quadrangle, and as an original texture indicating simultaneous separation of the minerals from the magma it is characteristic of a rather wide range of minerals. In the quartz monzonite gneiss, the gneissoid granite, the quartz monzonite, the quartz diorite, and the Rosalie and Silver Plume granites quartz is micropegmatitically intergrown with orthoclase, microcline, and plagioclase. In the Rosalie granite and the quartz monzonite biotite and quartz form micropegmatite; and in the quartz monzonite gneiss quartz and hornblende are similarly intergrown. In quartz diorite quartz is intergrown micropegmatitically with biotite and with hornblende, plagioclase with hornblende, and orthoclase with biotite. In the granite-pegmatite tourmaline forms graphic intergrowths with both quartz and microcline. In the contemporaneous aplitic dike in the late Cretaceous quartz monzonite of Lincoln Mountain the gradation from the allotriomorphic texture through the micropoikilitic to the micropegmatitic is well seen.

The micropegmatitic texture also arises through recrystallization and in the hornblende-diopside gneiss of the Idaho Springs formation orthoclase, microcline, and plagioclase are each intergrown with quartz. In the same formation epidote and plagioclase feldspar are similarly intergrown, tubules of feldspar extending well into epidote. The epidote, which has grown at the expense of the feldspar, has attacked it very irregularly, giving rise to a typical micropegmatitic intergrowth. Identical growths were found by Williams [a] in the mica diorite of Stony Point, N. Y., and by Adams[b] in some Alaska granites.

In numerous specimens the secondary microcline of the pre-Cambrian granites (see p. 66) is similarly oriented in many small areas distributed in the older orthoclase and plagioclase hosts. In like manner single plates of secondary muscovite inclosed numerous small areas of orthoclase, which as yet has not been altered.

[a] Williams, G. H., Am. Jour. Sci., 3d ser., vol. 35, 1888, p. 445.

[b] Adams, F. D., Canadian Rec. Sci., vol. 4, 1891, p. 348.

In the hornblende-diopside gneiss of the Idaho Springs formation epidote and zoisite, epidote and garnet, epidote and hornblende, and calcite and garnet occur in large areas of one member of the couple inclosing smaller areas of the other, the smaller areas all being in similar optical orientation. This structure, a result of simultaneous solidification of the minerals of the rock, is by no means uncommon in hornblende gneisses from other areas.[a]

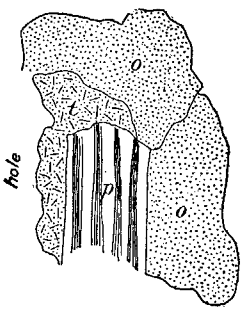


FIG. 24.—Titanite (*t*) molded upon a plagioclase crystal (*p*) and approximately contemporaneous with orthoclase (*o*). × 4. From monzonite, in the Central City quadrangle.

RELATIVE AGE OF TITANITE.

Titanite or sphene is usually held to be one of the oldest minerals of the rock in which it occurs. In the rocks of the Georgetown quadrangle it appears that this is not necessarily the case. Figs. 24 and 25 illustrate titanite that is later than plagioclase and hornblende, and approximately contemporaneous with orthoclase—hence it belongs to the later period of the rock's consolidation.

ORIGIN OF FLUORITE.

The deposition of fluorite in the Georgetown quadrangle is genetically connected with the crystallization of three formations—the pre-Cambrian granite pegmatite and the associated granite porphyries, the bostonite, and the alkali syenite porphyry of the late Cretaceous rocks. In the Empire mining district it occurs in the late Cretaceous monzonite. In the granite pegmatite it occurs in a disconnected veinlet replacing feldspar. In association with it and of contemporaneous origin is tourmaline, while the sericitization of feldspar was a simultaneous process. In the granite pegmatite, then, fluorite clearly originated after the solidification of the rock and was probably an effect of the process usually referred to as pneumatolitic action. The simultaneous alteration of feldspar to sericite was undoubtedly due to the gases or solutions which deposited the tourmaline and fluorite. In the granite porphyry associated with the granite-pegmatite, fluorite (see p. 65) probably fills miarolitic interstices between the other constituents.

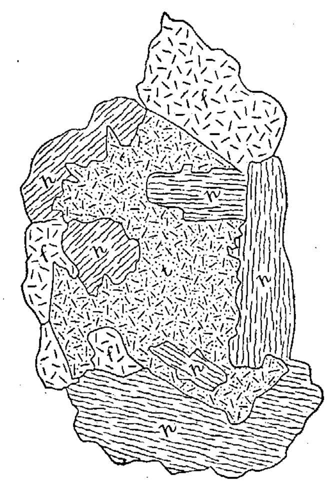


FIG. 25.—Titanite inclosing hornblende, hence a later product of crystallization. *t*, Titanite; *f*, feldspar; *h*, hornblende. × 3⅜. From monzonite, in the Central City quadrangle.

It has apparently eaten away the irregularities characteristic of the quartz individuals in the granite porphyry and has certainly replaced the feldspars to a limited extent. Its form and even distribution in the rocks of this series show, however, that it was probably deposited by vapors directly derived from the cooling graniteporphyry magma.

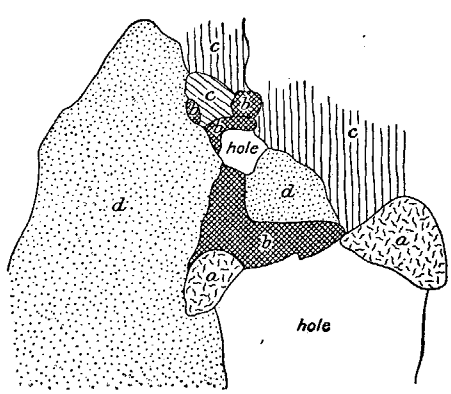
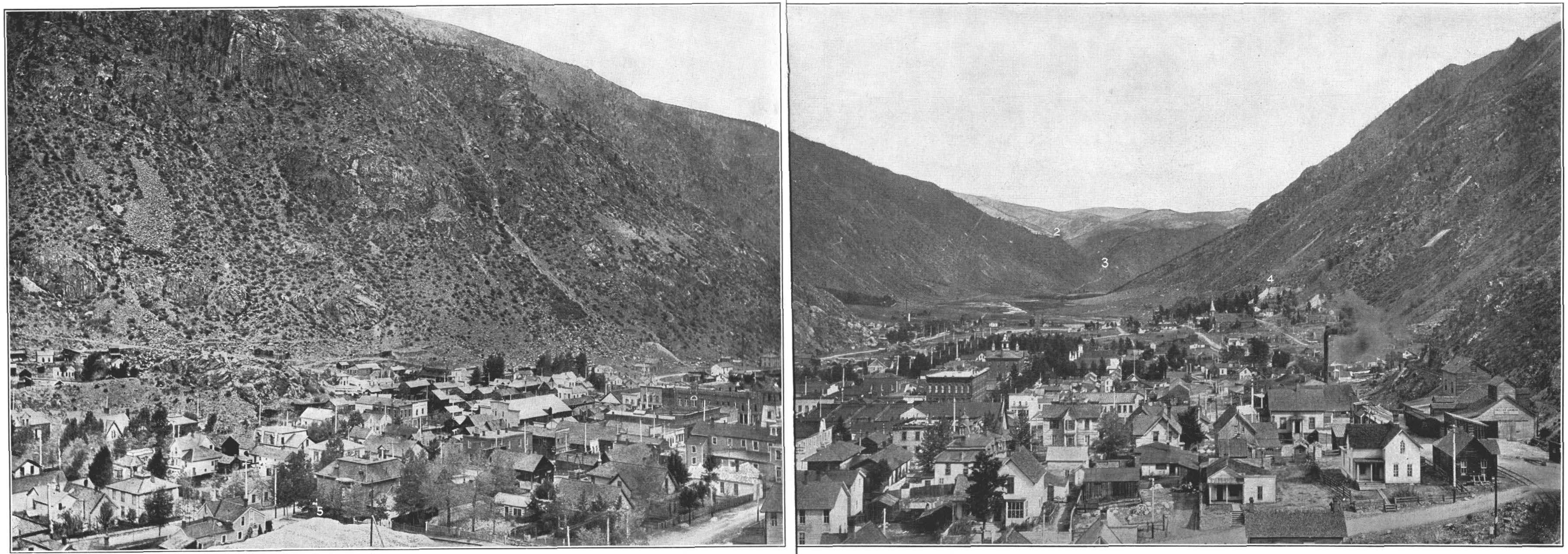


FIG. 26.—Fluorite (*b*), apparently original. *a*, Quartz; *c*, plagioclase; *d*, orthoclase. × 12. From monzonite, in the Central City quadrangle.

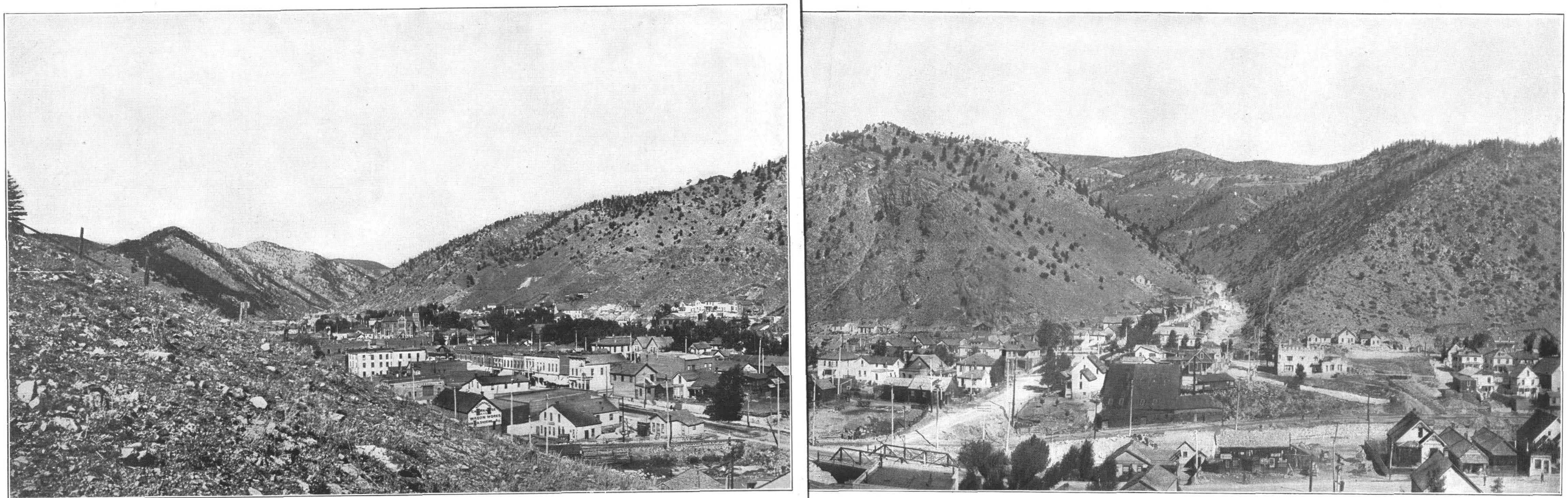
In bostonite fluorite either lies in wedges between the other constituents of the groundmass or replaces feldspar. Although the first occurrence of the mineral is similar to that of quartz in other thin sections and may be original, it is probable that all of the fluorite was deposited after the rock solidified, by gases or solutions genetically related to the bostonite magma. Fluorite was also deposited by emanations from the alkali syenite porphyry. Some of the fluorite of the monzonite of the Empire mining district, on the other hand, has every appearance of being an original mineral (fig. 26), while the rest was probably deposited after the final consolidation of the rock.

[a] Rosenbusch, H., Elemente der Gesteinslehre, Stuttgart, 1901, p. 533.



A. GEORGETOWN AND CLEAR CREEK VALLEY, LOOKING NORTHWARD EMPIRE FROM SLOPE OF LEAVENWORTH MOUNTAIN.

1, Kelly tunnel; 2, Empire mine; 3, Empire; 4, Griffith mine; 5, Centennial dump.



B. IDAHO SPRINGS AND THE MINES OF VIRGINIA CAÑON, FROM NORTH SLOPE OF FLIRTATION PEAK.

PART II.—ECONOMIC GEOLOGY.

By Josiah E. Spurr and George H. Garrey.

CHAPTER I.

DISCUSSION OF PRINCIPLES.

GOLD-BEARING AND SILVER-BEARING GROUPS OF VEINS.

RELATIVE DISTRIBUTION OF SILVER-BEARING AND OF PREDOMINANTLY GOLD-BEARING VEINS.

RECOGNITION OF DISTINCT SILVER-BEARING AND GOLD-BEARING AREAS.

The existence of areas or "belts" characterized by different vein materials within the region of the Georgetown quadrangle and the adjacent mineral districts to the northeast has been recognized since the early period of development. The stretch of mineralized country between Georgetown and Boulder has long been noted for the variety or ores which it has yielded. The greatest contrast perhaps has been between the silver-bearing ores, containing little or no gold, and those which contain gold in constant and important amounts. Certain veins and certain groups of veins are characterized by lead-silver ores; other veins and groups of veins are characterized by auriferous ores, with or without important quantities of lead and silver. Although in many places the silver-bearing veins and the gold-bearing veins occupy relatively distinct areas, or belts, yet in other places veins belonging to the two different types are found close together.

SILVER PLUME ARGENTIFEROUS REGION.

The famous and productive Silver Plume region, near Georgetown (see Pl. XIII, *A*), contains veins producing silver and lead to the almost total exclusion of gold, and the same is true of the Republican and Democrat Mountain veins; so that all the veins lying in a rough quadrangle bounded by Clear Creek on the south and east, by Bard Creek on the north, and by meridian 105° 45′ on the west come within this group. South of Georgetown is another smaller but famous silver region—that of the Colorado Central group, whose abundant ores, in large part of high grade, are substantially similar to those of the Silver Plume region. The northeastward-trending Colorado Central silver belt is continued still farther northeast by the Comet-Ætna and Magnet veins.

GOLD BELT NEAR GEORGETOWN.

On Leavenworth Mountain, immediately south of Georgetown, the width of the area lying between the two silver belts—that of the Silver Plume-Republican Mountain groups of veins on the northwest and that of the Colorado Central-Comet group on the southeast—is about three-fourths of a mile. In this area are gold-bearing veins, which contain also as a rule some silver. Of these veins perhaps the most typical is the Centennial, which has had a considerable production. This mine is situated in the southern part of Georgetown, and its northeastward-trending veins run under the north slope of Leavenworth Mountain. Southwest of the Centennial is the Central Colorado, another gold-bearing vein; and the further extension of this zone, along the north side of Pendleton and Leavenworth mountains, can be traced to the west border of the Georgetown quadrangle. Northeast of the Centennial mine the continuation of the gold belt is shown in the Griffith mine, which has a strong northeast vein running into Saxon Mountain. The ore here contains a fair amount of gold, although the silver content is more valuable. About a mile north of the Griffith is the parallel Anglo-Saxon lode, also running into Saxon Mountain; its ore contains gold and silver of approximately equal importance.

IDAHO SPRINGS AURIFEROUS AREA.

Along the northeastern extension of the mineral belt, that portion which lies within the Georgetown quadrangle embraces the mining region southwest of and tributary to the town of Idaho Springs. (See Pl. XIII, *B*.) Principally silver-bearing veins are present in this section; they are illustrated by the veins of the Cecil-Argo group (p. 368) lying south of Lamartine, in which the value of the gold is only a small percentage of that of the silver. In the larger proportion of the veins, however, including some of the strongest veins of the region—for example, the Stanley, Freeland, Little Mattie, and Lamartine—the gold values are equal to or in excess of those of silver.

Farther northeast the mineral belt passes into the areas of the Central City and Blackhawk quadrangles, which have not been geologically surveyed, and from Clear Creek County into Gilpin County. Here, between Idaho Springs and Central City, the chief ores are those of gold, though veins whose principal values are in silver are present, as, for example, on Seaton Mountain; and a definite silver belt has been recognized, running north and south, near the town of Blackhawk. In the gold-bearing veins of Gilpin County silver is associated with the gold in varying proportions, but the ores of the silver belt show little or no gold.[a]

CHARACTER OF VEINS BETWEEN GEORGETOWN AND EMPIRE.

That portion of the mineral belt within the Georgetown quadrangle which lies around Silver Plume and on Republican and Democrat mountains and consists entirely of practically nonauriferous veins is continued on the north by the veins of Lincoln Mountain. Some of these Lincoln Mountain veins, such as the Virginia City, are, like those of the group above mentioned, chiefly silver bearing, but others, such as the Ramsdale, contain ore showing predominant values in gold. North of Lincoln Mountain, and across West Fork of Clear Creek, is the Empire district, described on pages 383–410 of this report, where the typical veins are auriferous, with very little silver. On the eastern edge of the Empire district, however, there are silver-bearing veins that carry very little gold. These appear to form the eastern portion of a definite area or belt of silver-bearing veins, many of which outcrop on Red Elephant Hill.[b]

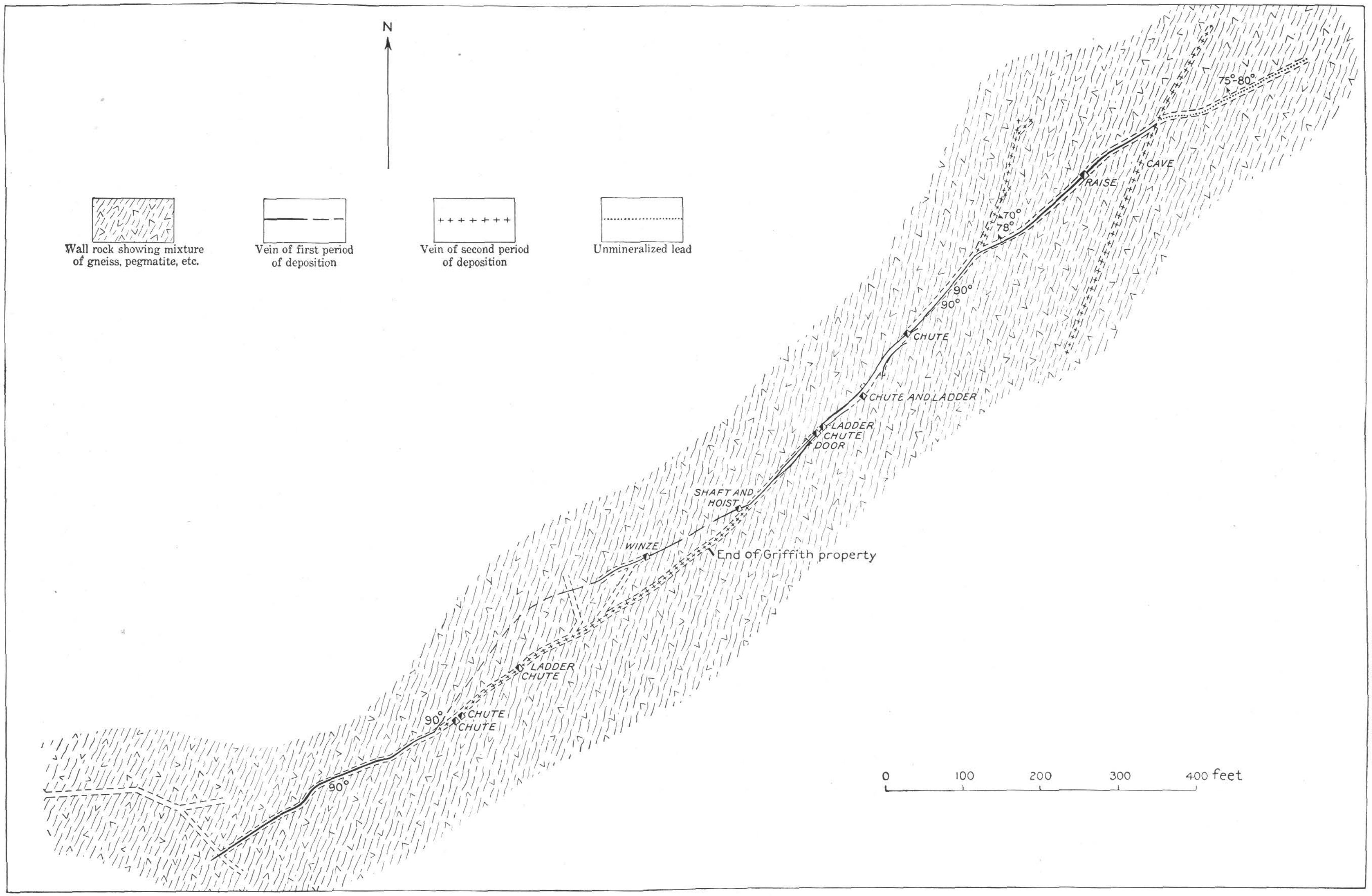
THE GEORGETOWN QUADRANGLE A PART OF A LARGE MINERAL-BEARING AREA.

The above sketch outlines the distribution of the two principal types of veins (those which are auriferous to an important extent and those which are not) within the Georgetown quadrangle. Southwest of Georgetown, along the mineral belt, the writers' investigations have also carried them as far as the Argentine district, 9 or 10 miles from Georgetown, where the numerous veins, so far as seen, are all of the silver-bearing, nonauriferous type.

From this it will be seen that the area of Georgetown quadrangle is not held to include a complete mining district, or a complete group of veins; it is a rectangular area arbitrarily taken, whose northern portion includes a segment of a northeastward-trending mineral belt that is evidently of considerable extent. From the facts accumulated in the studied segment conclusions will be drawn, and these will be adjusted by the consideration of the rather meager information available concerning the portions of the belt that lie to the northeast and to the

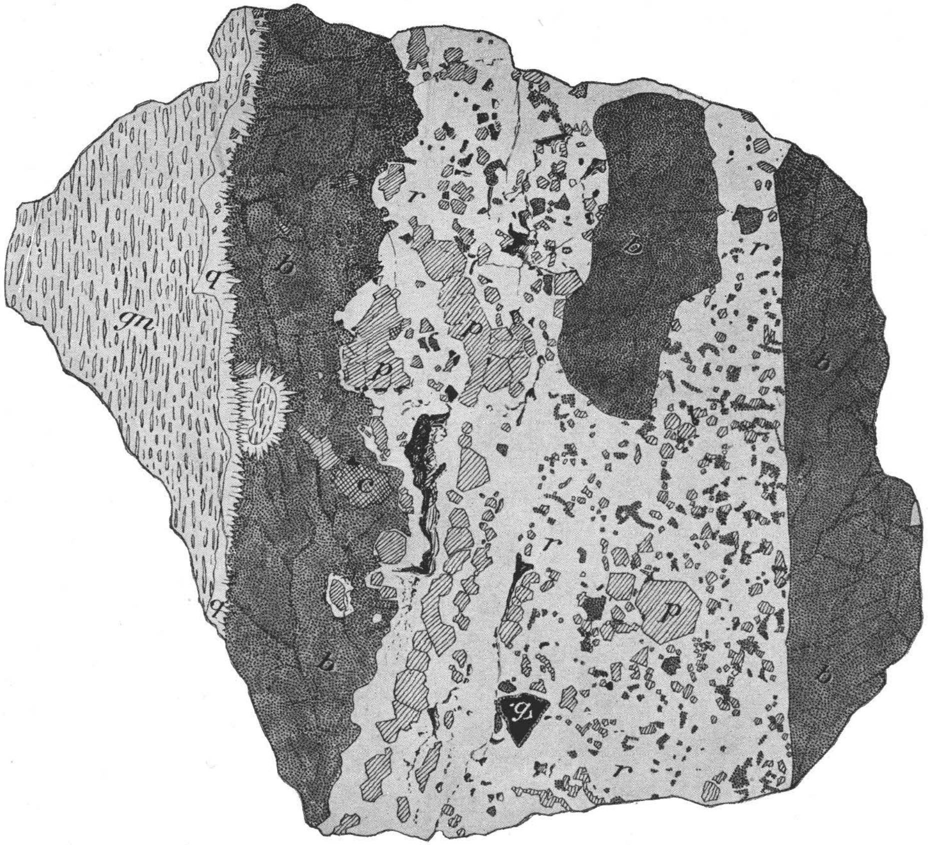
[a] Rickard, Forbes, Trans. Am. Inst. Min. Eng., vol. 28, 1899, p. 111.

[b] Fossett, Frank, Colorado, 1880, p. 353.



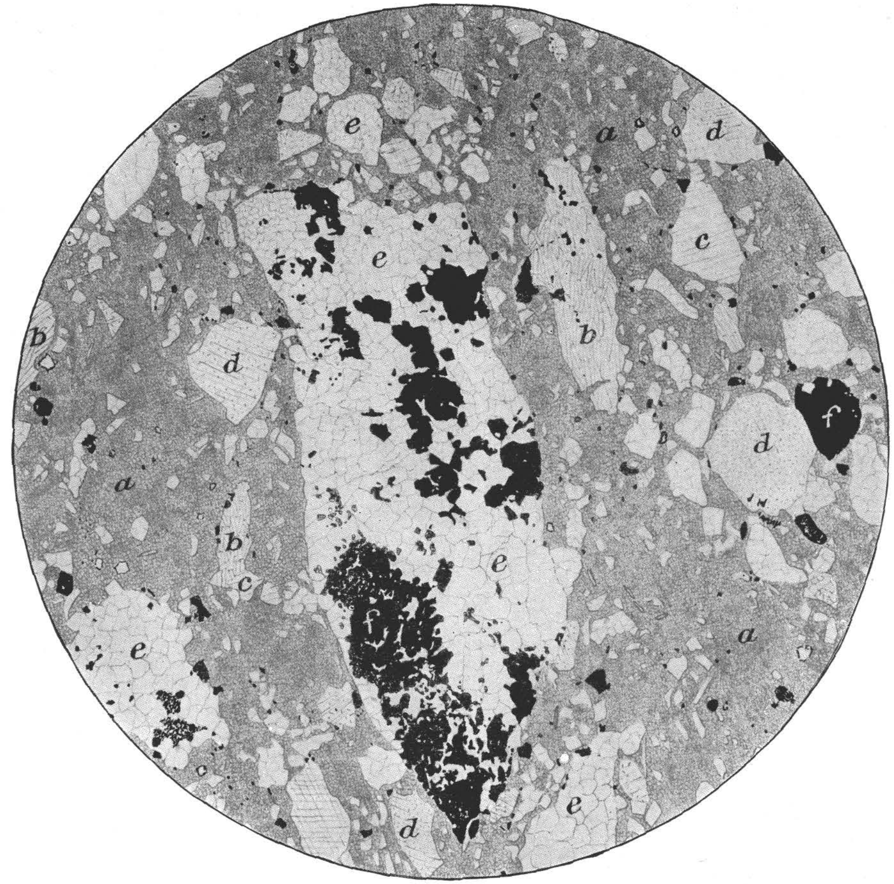
GEOLOGICAL PLAN OF ANNETTE LEVEL, GRIFFITH MINE.

Showing two periods of ore deposition.



A. SPECIMEN FROM GRIFFITH MINE, SHOWING TWO PERIODS OF VEIN DEPOSITION.

The wall rock is gneiss, which was split open by a fissure. Subsequently the walls of the fissure were coated by comb quartz (*q*). Later the fissure was cemented shut by blende, with some galena and chalcopyrite. This is the vein of the first period. Subsequently this vein was split open and a new fissure was filled by the vein of the second period, consisting chiefly of manganese-iron carbonates and pyrite, with inclosed broken fragments of the earlier vein. *gn*, Gneiss wall rock; *q*, quartz (comb structure); *b*, blende; *p*, pyrite; *c*, chalcopyrite; *g*, galena. Natural size.



B. THIN SECTION FROM STANLEY MINE, SHOWING FRAGMENTS INCLUDED IN GLASSY OR FINELY TRACHYTIC BIOTITE LATITE (*a*).

b, Bostonite (earlier dike rock); *c*, clear feldspar (usually microcline); *d*, sericitized and calcitized feldspar; *e*, vein quartz; *f*, pyrite. Enlarged 11 diameters.

SPECIMENS SHOWING HISTORY OF ORE DEPOSITION.

southwest of that segment. It is evident that satisfactory conclusions would depend on a close study of the whole belt, and that the conclusions herein reached, from a study of part of it, will need enlargements and modifications when all the facts become known.

DIVISION OF QUADRANGLE INTO TWO PRINCIPAL MINERAL-BEARING AREAS.

As a result of the classification of the veins into the two chief groups, (1) silver-bearing veins without important amounts of gold, and (2) gold-bearing veins with or without silver, the veins within the quadrangle could be roughly grouped in two chief areas—the Georgetown region, with greatly preponderating veins of the first class, those of the second class being exceptional, and the region southwest and west of Idaho Springs, where veins of the second class predominate and those of the first class are exceptional. Between the two areas the continuity of the belt is interrupted by a region of comparatively little mineralization, embracing the upper portions of Griffith and Saxon mountains.

RELATIVE AGE OF GOLD VEINS AND SILVER VEINS.

MINERALOGICAL CHARACTERISTICS.

MINERALOGICAL GROUPS.

Mineralogically the lodes of the quadrangle are roughly divisible into two groups, corresponding to the two chemical groups (of predominantly gold ores and of silver ores) above described. These mineralogical groups are (1) galena-blende ores with more or less pyrite, chalcopyrite, gray copper, and polybasite; and (2) pyritic ores containing chiefly pyrite, cupriferous pyrite, or chalcopyrite, and a subordinate amount of galena and blende, with tetrahedrite and other less abundant minerals.

BOTH TYPES OF VEIN FILLING IN THE SAME VEIN ZONE.

In the Griffith mine, which is near Georgetown, within the narrow gold belt that has been described as lying between silver belts on each side, certain phenomena of great importance were first noted, though afterwards they were observed elsewhere. These phenomena, which are described more thoroughly in the special account of the mine on page 285, will be briefly referred to here. The vein, which is a strong one, shows two distinct vein periods of fissuring and subsequent cementation (Pl. XIV). The result of the first dislocation of the rocks along the line of the present vein was a strong fissure, which was in part opened for a considerable width, as is shown by the angular fragments of wall rock that occur in and are cemented by the vein materials deposited subsequent to this dislocation. These angular fragments of wall rock indicate an original rubble-filled fissure like that characteristic of the Mendota and similar mines of the Silver Plume district, whose veins belong to the group of typical silver veins.

The filling of this original fissure of the Griffith vein was also similar to that of the silver veins mentioned. The first deposition was a coating of comb quartz, after which the interior of the fissure was completely filled with solid sulphides consisting of galena, blende, pyrite, and chalcopyrite, with practically no intermixed gangue, a feature which is also characteristic of the typical silver veins. Subsequent to the formation of this vein there was another dislocation and reopening of the old fissure, resulting in larger openings than the first disturbance produced. The new fissure in general followed along the line of the old one, splitting the old vein and breaking it up in various ways. On account of the greater brittleness of the original sulphide filling as compared with that of the wall rocks, the new fissure at many places split the vein in the middle, leaving a layer of sulphides clinging to each wall, a condition which, after the new fissure was cemented with the ore of the second period, presented a false appearance of crustification. (See Pl. XV, *A*.) In numerous other places the older vein was broken into angular fragments, which rested in the newly formed fissure in the shape of rubble, precisely as the fragments of country rock had filled the original fissure. The angular fragments of galena-blende ore now appear as inclusions in the later ore. This later ore, which completely filled the openings of the second period of dislocation, is of quite different character from that of the first deposition, consisting principally of pyrite and brown carbonates of iron, manganese, and magnesia, with more or less quartz and a little galena, blende, chalcopyrite, and barite. In some places the quartz exceeds the brown carbonate in amount.

The ores of the later period are stated to be generally of low grade, containing 10 to 12 ounces of silver and \$2 to \$3 in gold to the ton, though one stope is said to have yielded 20 to 25 ounces of silver and \$6 to \$10 in gold. The valuable ores are those formed during the first period and containing galena. The values in these ores consist chiefly in lead, next in silver; they contain also gold. They are reported to carry an average of 30 to 40 ounces in silver and \$8 to \$9 in gold. In general, however, owing to the brecciation of the original vein and the mixture of its ores with those of the later vein, the exact proportion of the metals in the ores of the two periods is rather uncertain.

The composition of the older vein was practically identical with that of the typical silver-bearing lodes, such as those of Silver Plume and of the Colorado Central mines; the younger vein formation is similar in composition to the Centennial vein, which lies almost in line with the Griffith and on the opposite side of the village of Georgetown. The two ores, however, are not identical, as the Griffith ore contains much more carbonates.

The Centennial vein has a gangue of quartz carrying pyrite, chalcopyrite, cupriferous pyrite, and secondary tetrahedrite, with very little galena and blende, so that the ores show only traces of lead and zinc. The values are in gold, silver, and copper, the silver running from 20 to 30 ounces, gold from 1 to 1½ ounces, and copper from 4 to 8 per cent. Both gold and silver seem to be chiefly associated with copper.

The Centennial lies southwest of the Griffith. Southwest of the Centennial, in turn, and in line with it and the Griffith, is the Central Colorado vein, which runs northeastward along the westward-sloping face of Leavenworth Mountain. This vein is mainly gold bearing, the ore carrying as much as 2 to 3 ounces in gold, with practically no silver. The gangue is quartz, with some siderite and ferruginous rhodochrosite. The metallic minerals consist chiefly of pyrite and cupriferous pyrite. Seams of zinc blende occur between the vein of cupriferous pyrite and the wall rock, as if the blende was of earlier origin than the pyritic vein. Probably the same two periods of vein formation are indicated here as in the Griffith, the old vein represented by the blende having been split open and cemented by later and much more abundant pyritic ores.

Phenomena similar to those above described were repeatedly noted elsewhere independently before their recurrence suggested that they marked an important distinction between the veins of different type. These phenomena were characteristically found on the borders between an area of predominantly gold-bearing veins and an area of silver-bearing veins. In the cases just described they characterize the wedge of territory containing gold-bearing veins which runs southwestward through Georgetown, with silver-bearing country on both sides. Phenomena of this kind were noted also on the borders of the Empire district. This is a district of gold-bearing veins adjoining on the north the district of silver-bearing veins that includes the Silver Plume, Republican Mountain, and Democrat Mountain areas, the two districts coming together on Lincoln Mountain. On the east the Empire gold-bearing district is adjoined by the silver belt of Red Elephant Hill, the two coming together just east of Empire.

On Lincoln Mountain the chief veins examined were the Virginia City and the Ramsdale, on the south slope, toward Democrat Mountain, and the Allen and the Hidden Treasure, on the north slope, toward Empire. The Virginia City lode is a typical silver-bearing lode of the Democrat Mountain–Silver Plume type. The ores consist of galena, blende, and pyrite, carrying several hundred ounces of silver and from 0.2 to 0.5 ounce of gold. The Ramsdale vein shows in places a vein of quartz 2 feet wide, containing some pyrite, copper pyrite, and a little blende. In some portions of the mine the earlier ore has been brecciated and cemented by pyritiferous quartz. The chief values of the vein are in the gold, some of which is considered to be associated with copper and runs as high as several ounces to the ton. A sample taken assayed 3½ ounces of gold and 12 ounces of silver. This vein is probably a composite vein like the Griffith.

The Allen mine is located north of the Virginia City, on the same general strike. The vein here has an interesting structure. It contains in places next to the foot wall a thin seam of blende and galena an inch or less in thickness adjoining the main material of the vein, which consists of gray jaspery quartz and pyrite. A similar but discontinuous seam of blende and galena lies on the opposite wall of the vein. The fact that these two seams of blende and galena are separated by a seam of pyrite-bearing quartz suggests that there were at least two periods of cementation similar to those observed in the Griffith mine, and that the zinc-lead ore represents an earlier ore deposit, which was reopened by a fissure in which pyritiferous quartz was subsequently deposited.

INTERSECTION AND FAULTING OF SILVER VEINS BY GOLD VEINS.

On the east side of the Empire district silver-bearing lodes containing galena occur close by pyritiferous lodes carrying gold. Phenomena of great interest were noted in the Harrison mine (Pl. XVI).

The main tunnel in this mine follows a vein of jaspery quartz containing pyrite. This lead strikes N. 10° E. and faults two veins of east-west strike that contain sphalerite, quartz, and pyrite. The displacement of the faulted vein is slight, amounting to a horizontal offset having a maximum of only a few feet. Between the faulted ends of the blende-bearing veins and along the wall of the pyritiferous vein is a breccia containing angular fragments of sphalerite ore and wall rock, representing the drag along the fault plane. These faulted veins by their composition plainly belong with the silver-bearing lodes of the vicinity, but the younger pyritiferous vein is a mineralogically typical gold-bearing lode. Another phenomenon, however, complicates the history. The older blende-bearing vein has been split open, in some places along the center, in others along the sides; in still other portions the ore has been brecciated. All these openings have been cemented by pyrite and quartz, and this cementation seems to have taken place somewhat earlier than the faulting of the veins and the subsequent deposition of the pyritic vein along the fault.

These different observations indicate that in general the silver-bearing veins, characterized by galena and blende, are older than the gold-bearing veins, characterized especially by pyrite and cupriferous pyrite.

NORTHEAST-SOUTHWEST MINERAL BELT.

EXISTENCE OF A MINERAL BELT IN THE AREA OF THE GEORGETOWN QUADRANGLE.

LIMITS.

The mineralized area of the quadrangle is confined to the northern portion and extends in a general east-northeast direction. Within this area there are many strong and persistent veins having a predominant northeast or east-northeast trend, though a smaller number of veins, some of them very strong, have a northwest trend. The predominant northeast trend is parallel to the trend of the mineralized zone. The edge of this zone, as shown on the map (Pl. II, in pocket), is fairly definite and strongly marked, and the remainder and greater portion of the quadrangle, which has been carefully surveyed, is quite barren of mineral indications.

RELATIONS OF THE VEIN BELT TO THE PORPHYRY BELT.

The pre-Cambrian rocks of the mineral belt do not differ essentially from those of the rest of the quadrangle. On plotting the dikes of porphyry, however, which are characteristic of a portion of this region, it was found that the belt of porphyry dikes coincides closely with the belt of mineral veins. In detail it has been found that the relation between the veins and the porphyry dikes is in some places close, but that in many other places important veins have no connection with individual dikes.

EXTENSION OF THE MINERAL BELT OF THE GEORGETOWN QUADRANGLE.

EXTENSION FROM BOULDER BEYOND LEADVILLE.

The fact that the mineral belt which passes through the northern part of the Georgetown quadrangle (Pl. XVII) extends farther to the northeast and southwest is fairly well known, and the continuity of the belt is sufficiently patent to have provoked attention from the earlier geologists and explorers. In general, it may be stated that this zone of ore deposits is practically continuous from the foothills of the Rockies near Boulder on the northeast at least as far as Leadville on the southwest.

At the northeast end of the belt are the Boulder County mines, which have long been known to be very productive. They have been developed in numerous districts. Southwest of Boulder County the mineral zone passes with no geologic break into Gilpin County, which also has long been a famous producing area. The Gilpin County belt in turn passes unbroken on the southwest into Clear Creek County, which embraces the portion of the belt included within the Georgetown quadrangle. Still farther southwest the mineral belt may be followed to the Argentine district and the neighboring Hall Creek, Geneva Creek, Montezuma, and Snake River districts, which are close to one another, but are partly in Clear Creek and partly in Park and Summit counties. From all available descriptions the mineral belt is continuously traceable from this region southwestward through the Breckenridge and Tenmile districts into Leadville. The Leadville region seems to mark the southwest end of the most productive portion of this practically continuous belt. There are indications, however, that a mineral zone extends beyond Leadville for a certain distance to the south, but it is broader and less strongly marked than the belt northeast of Leadville. This zone is in evidence on both the east and west sides of Arkansas River, along the Park and Sawatch ranges. In the Park Range veins are reported in the vicinity of Granite, and in the Sawatch there is a continuous north-south belt that embraces the Tincup and Monarch districts.

BELT INCLUDING ASPEN AND THE GUNNISON REGION.

A northeastward-trending mineral belt slightly offset from the main belt, which runs between Leadville and Boulder, includes the Aspen mining district. On the northeast this belt passes through Lenado and into the Frying Pan district. Some distance northeast of the Frying Pan region is the Redcliff district, which is only slightly northwest of the main Leadville-Boulder belt at Leadville. On the southwest the Aspen belt is traceable through Ashcroft and other mining localities across the Elk Mountain range into Gunnison County, where it includes the Ruby, Irwin, and neighboring mining districts.

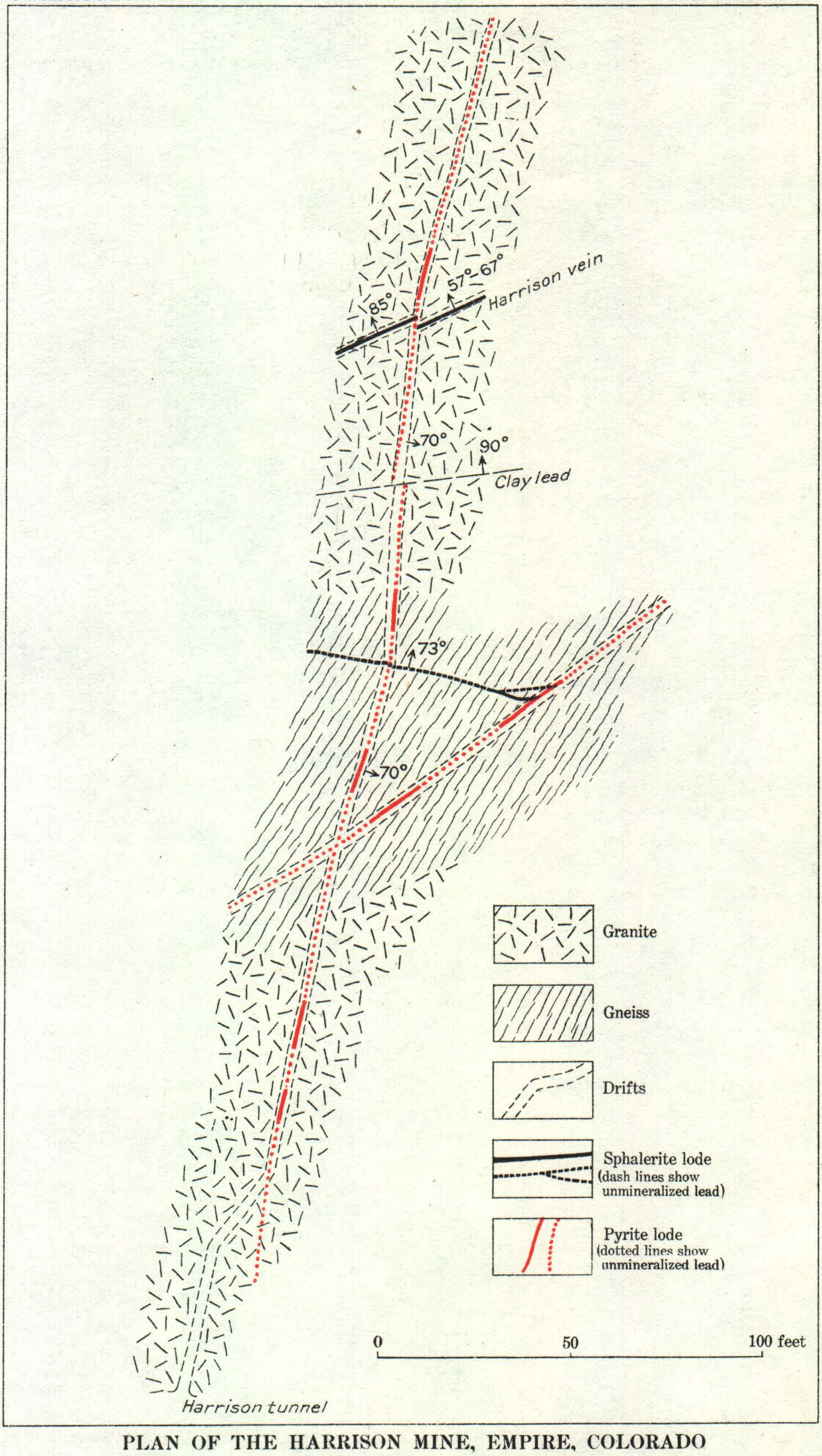
EXTENT OF THE MINERAL BELT.

The main belt, which runs from Boulder to Leadville in a direction nearly due southwest, is about 85 miles long and 5 to 12 miles wide. The belt which passes through Aspen, if considered to extend from the Frying Pan country to the Gunnison region, is about 45 miles long, and if considered to extend to Redcliff, about 65 miles long. This belt also has a northeast strike and is 5 or 6 miles wide. The total extent of this whole general belt as measured from Boulder to Ruby and Irwin is 130 miles.

OCCURRENCE OF ORES IN THE MINERAL BELT.

FORM OF ORE DEPOSITS.

Along this mineral belt from its northeast end near Boulder as far southwest as Breckenridge the ores occur in fissure veins in pre-Cambrian crystalline rocks. These veins have a steep dip and predominant northeast trend parallel to that of the belt, though many of them are oblique or transverse to it. In the Breckenridge district or farther southwest, in the Tenmile and Leadville districts, the mineral belt runs into Paleozoic and Cretaceous rocks, which overlie the pre-Cambrian. In these later rocks the ore deposits are still in part fissure veins, having the same predominant northeast trend; in part they take the form of more irregular deposits, especially



PLAN OF THE HARRISON MINE, EMPIRE, COLORADO

showing pyritic veins later than sphalerite lodes, which they cross and fault

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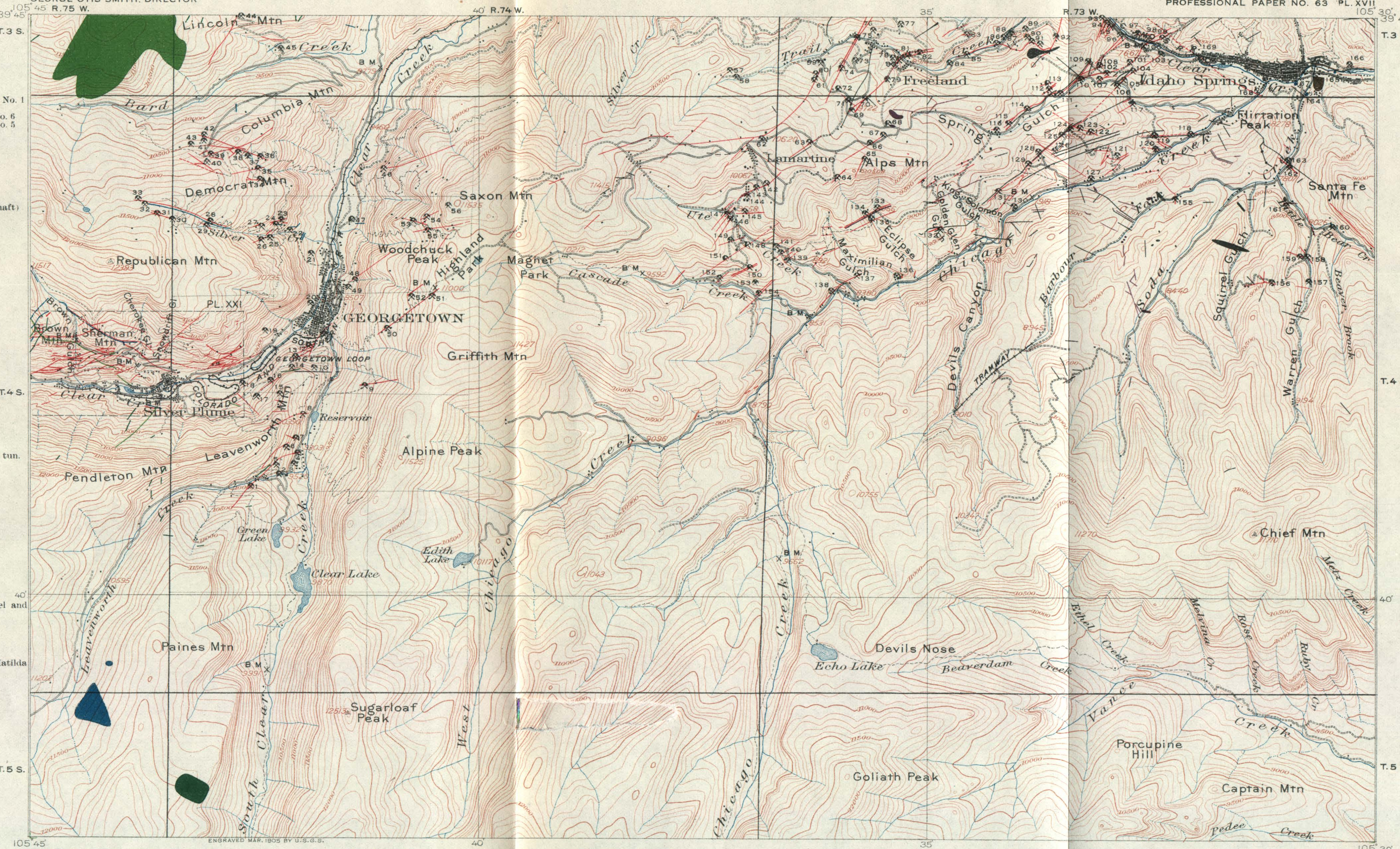

E. M. Douglas, Geographer in charge.
Topography by Frank Tweedy.
Triangulation by H. L. Baldwin, Jr.
Surveyed in 1903.

MAP OF NORTHERN PART OF GEORGETOWN QUADRANGLE, COLORADO, SHOWING DIKES, VEINS, AND MINES

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 kilometers

Contour interval 100 feet.

Dikes by S. H. Ball, assisted by O. Hershey.
Veins by J. E. Spurr and G. H. Garrey.
Mines by G. H. Garrey.
Surveyed in 1904-5.

where they occur in limestones, in which many large ore bodies are formed by replacement. These ore bodies, however, have been noted in a number of cases to have a general northeast trend, showing that they resulted from fracturing in that direction.

ORES IN BOULDER COUNTY.

In Boulder County, at the northeast end of the mineral belt, there are gold-bearing veins and silver-bearing veins, both of great economic importance. The silver-bearing group includes such veins as that of the Caribou mine, which contains galena, chalcopyrite, blende, gray copper, stephanite, ruby silver, and native silver. The gold-bearing veins form two distinct groups, those containing free gold and those containing tellurides. These veins also occupy fairly distinct belts. The telluride veins contain sylvanite, petzite, calaverite, ruby silver, and free gold. The gold veins contain free gold, pyrite, and copper pyrite, with small quantities of blende and galena. J. B. Farish [a] has described a free-gold vein cut through by a younger telluride vein. The former is called the Golden Age, the latter the Sentinel. The ore of the Golden Age is a hard white quartz, much of it vitreous, containing free gold, with but a small amount of sulphides. The Sentinel vein, which cuts through the Golden Age, has the bluish quartz common in the tellurium veins of Boulder County, with the characteristic chalcedony quartz crystals and finely disseminated pyrites. The value is in metallic gold, petzite, and sylvanite. From this Mr. Farish concludes that the gold mines of Boulder County belong to at least two distinct periods of vein formation.

ORES IN GILPIN COUNTY.

In Gilpin County, also, definite belts characterized by gold-bearing veins or by silver-bearing veins have been recognized.[b] The veins in this county occur along lines of slight faulting in metamorphic rocks, granite, and pegmatite. The ores of the silver belt carry little or no gold, but those of the gold belt carry silver in various proportions. Two sets of veins are present in the mineralized area, one having an east-west course, the other a northeast-southwest course. The main features of one group are similar to those of the other, and there is no reason to believe that they have originated at distinct periods. In the mineralized region are intrusive dikes, in part, at least, andesitic, whose trends correspond with both the principal trends followed by the veins. These dikes are earlier than the veins. In the veins of the gold belt the principal gold carrier is pyrite, commonly associated with chalcopyrite, blende, galena, and gray copper, including both tetrahedrite and tennantite. Carbonates of iron, manganese, lead, and copper occur in small proportion. Tellurium in appreciable quantities has been found in association with the ores at many of the mines and seems to play an important part as a gold carrier.[c] Bismuth and arsenic also occur, the former with the gray copper ores, the latter in small proportion in nearly all of the pyrite. Uraninite, or pitchblende, has been found in considerable quantities. Barite and calcite are of rare occurrence. The ores of the silver belt carry galena, zinc blende, and pyrite, with subordinate amounts of polybasite, stephanite, and horn silver. The gangue of the silver veins does not materially differ from that of the gold veins. Rickard notes in his description of the San Juan mine in this county the occurrence of large rounded bowlders in a vein at a distance of several hundred feet from the surface. These bowlders are very likely the same as the friction conglomerate described in the present report (p. 311) from many of the mines in Clear Creek County near Idaho Springs, and which is due to renewed movement along the vein zone subsequent to ore deposition.

ORES IN CLEAR CREEK COUNTY.

In the northeastern part of Clear Creek County the gold-bearing veins represent the southwesterly extension of the great copper-iron-gold belt of Gilpin County, which farther southwest becomes more argentiferous.[d] Still farther southwest, as already stated, lies the principal silver-producing district around Georgetown, and in the same direction, along a series of less important

[a] Proc. Colorado Sci. Soc., vol. 3, 1891, pp. 316-322.
[b] Rickard, Forbes, Trans. Am. Inst. Min. Eng., vol. 28, 1899, p. 108.
[c] Pearce, Richard, Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 451.
[d] Fossett, Frank, Colorado, 1880, p. 367.

veins, the Argentine district, which is near the summit of the Front Range. McClellan Mountain, in the northeastern portion of the Argentine district, contains a number of fairly strong lodes, which have formed along zones of slight faulting in granite and gneiss. Most of these veins trend northeastward, but some have a northwesterly direction. The ores consist of galena, blende, some cupriferous pyrite and pyrite, and some tetrahedrite. The sulphide ores are said to carry 25 to 30 ounces in silver and $2 to $3 in gold to the ton. The gangue is chiefly quartz, with considerable calcite and in many places much fluorite. There is a notable tendency for ore deposits to occur at the junction of branches.

ORES FROM THE ARGENTINE TO THE TENMILE DISTRICT.

In the immediate vicinity of the Argentine district are other mining districts in Clear Creek, Park, and Summit counties. These include the districts at the head of Geneva and Hall valleys. The main mineral zone runs through the crest of the range. In general the ores in this cluster of mining districts are stated to be argentiferous galena, gray copper, iron pyrites, ruby silver, brittle silver, and native silver. Argentiferous bismuth ores are reported to occur, but are not usually very plentiful. Most of the lodes of this section carry some gold.[a]

This belt of veins is described as extending southwestward along the mountain divide past the headwaters of Swan Creek.[b] The veins in this belt carry lead and silver. Near Breckenridge veins of argentiferous galena and zinc blende occur in sedimentary rocks and associated with intrusive porphyries. Some lodes contain auriferous pyrite, and others are free-gold lodes. Breckenridge is at present most widely remembered by the fine specimens of leaf and wire gold which occur in the shales of Farncombe Hill. This hill is traversed by a dyke of quartz porphyry, and the gold occurs in the dike as well as in the shales.[c] Well-marked quantities of bismuth and tellurium have been noted in the Ontario mine in an ore consisting of native gold crystals embedded in a matrix of hydrated oxides of iron and manganese.[d]

ORES OF THE TENMILE DISTRICT.

Directly southwest of Breckenridge is the Tenmile district, where the ores occur chiefly in an area of upper Carboniferous limestones and sandstones (Maroon formation), which is intruded by many sheets and dikes of porphyry. The ores consist chiefly of argentiferous galena, pyrite, and blende, and the gangue is quartz with some barite. The deposits have in part the form of fissure veins and in part that of irregular bodies replacing limestone. Three distinct types of deposits have been described by Emmons.[e] The Robinson mine constitutes one type. The ore lies along vertical faults of slight displacement, having a general strike of N. 60° E. The unaltered ore contains galena, blende, and pyrite, with rhodochrosite, calcite, barite, and quartz as gangue minerals. In the deposits of the type exemplified by the White Quail mine the ore is mainly pyrite or marcasite, with small amounts of zinc blende and argentiferous galena. These materials occur as replacement deposits along well-defined shoots, in which the existence of an earlier system of northeast-southwest fractures may be detected. In the deposits of the type exemplified by the Queen of the West mine the ores consist of galena, blende, and pyrite, with some sulphides and antimonides of silver, and calcite as the chief gangue. They occur in fissure veins which have formed in parallel fault fissures striking N. 60° to 70° E. In this district there is evidence of two periods of faulting, one previous to the ore deposition and one subsequent.

ORES OF THE LEADVILLE DISTRICT.

Southwest of the Tenmile district and connected with it by a belt of mineral-bearing country is the famous Leadville district. Here the ores are chiefly replacement deposits in limestone. They follow in general the stratification of Paleozoic limestones, especially the

[a] Fossett, Frank, Colorado, 1880, p. 381.
[b] Idem, p. 481.
[c] Lakes, Arthur, Geology of Western Ore Deposits, new ed., 1905, p. 225. Fossett, Frank, Colorado, 1880, p. 489.
[d] Pearce, Richard, Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 452.
[e] Emmons, S. F., Description of the Tenmile district: Geologic Atlas U. S., folio 48, U. S. Geol. Survey, 1898.

lower Carboniferous, or Leadville, blue limestone. Within these sedimentary formations they have formed mainly beneath sheets of intrusive porphyry (the principal varieties of which are called locally white porphyry and gray porphyry). The valuable ores include lead, silver, and gold. The gold belt is in general separated from the nonauriferous silver-bearing area and covers an extent of several square miles. It is marked by ores carrying more or less gold in addition to silver and the baser metals. According to Emmons,[a] the ores containing gold and copper are more frequently found in siliceous beds, in porphyries, or in crystalline rocks than in limestones. The silver ores consist of galena, blende, and pyrite, and contain also arsenic, antimony, molybdenum, bismuth, etc. The gangue is jasperoid or quartz, with some barite. The gold ores are more highly pyritiferous. Emmons recognizes the intimate relation of the ores to the porphyry, subsequent to whose intrusion they were deposited. He concludes that they were derived from the porphyry by circulating waters of original meteoric origin.

A. A. Blow[b] has shown that on Iron Hill in Leadville the ore shoots, which are replacement deposits in limestone, follow northeastward-trending zones which are parallel with, but not everywhere in contact with, cross-cutting sheets of gray porphyry. Blow concludes that the ores had been deposited by hot alkaline metal-bearing waters and vapors accompanying the period of solfatarism which followed and was consequent on the injection of the porphyries.

Richard Pearce[c] discovered tellurium in Leadville pyrites, containing silver and a small value in gold.

ORES OF THE REDCLIFF DISTRICT.

A few miles northwest of the Tenmile district is the Eagle or Redcliff district. The geology here is described as somewhat similar to that at Leadville. Above the fundamental granite lie in succession the Cambrian quartzite, Silurian and Carboniferous limestones, and the upper Carboniferous Weber quartzite. All these formations are intruded by porphyries. Argentiferous galena ores and gold ores are reported. The gold deposits occur in Cambrian quartzites; the silver-lead deposits in Silurian and Carboniferous limestones, intruded by porphyry sheets. The telluride of silver, hessite, has been found in large quantities in one or two mines.[d]

ORES OF THE ASPEN AND NEIGHBORING DISTRICTS.

Southwest of Redcliff, on Frying Pan Creek, the geologic formations in the mineralized area are described as including granite, quartzite, and limestone, and as being similar to those at Aspen.

About 10 miles southwest of the Frying Pan district lies the Lenado district, and near this the Aspen district.[e] In these districts the sedimentary strata have been folded against the pre-Cambrian mass of the Sawatch Range and have been profoundly faulted. The folding and faulting include the Cretaceous rocks of the district, and from what is known as to the history of the Rocky Mountains outside of this area the beginning of the vigorous dynamic disturbance is assigned to the general period embracing the close of the Cretaceous and the beginning of the Tertiary. Two varieties of igneous rock were intruded in the Paleozoic strata, one being a diorite porphyry similar to the rock of the porphyry laccoliths of the Elk Mountains and probably continuous with one of these. The other is a quartz porphyry, identical in composition and structure with the "white porphyry" of Leadville. These porphyry intrusives have been involved in most if not in all of the folding and faulting, but the period of their intrusion is believed to have coincided with the beginning of physical disturbances. The district is remarkable for complicated faults, whose development has proceeded from an early date in the history of the deformation down to the present day, the faults becoming more numerous and complicated, but having less throw, as erosion removed the overlying load of strata. Some faults are postglacial, and in many places fault movement is going on at present.

[a] Emmons, S. F., Geology and Mining Industry of Leadville, Colo.: Mon. U. S. Geol. Survey, vol. 12, 1886, p. 377.
[b] Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 145.
[c] Idem, p. 451.
[d] Pearce, Richard, Trans. Am. Inst. Min. Eng., vol. 18, 1890, p. 451.
[e] Spurr, J. E., Mon. U. S. Geol. Survey, vol. 31, 1898.

The ores of this district are lead-silver ores, containing no gold. The chief minerals are galena and blende, with polybasite, tetrahedrite, and tennantite, and with quartz, barite, and dolomite as gangue. The ores were deposited subsequent to the igneous intrusion and during the long period of faulting. They have been deposited along some of these faults and have been displaced by others. The mineralizing agent is believed to have been ascending hot waters.

ORES FROM ASPEN THROUGH THE GUNNISON DISTRICT.

From Aspen southwestward a mineralized belt is traceable almost continuously from Ashcroft across the Elk Mountains to the Ruby, Irwin, and other districts of the Anthracite-Crested Butte region. In this region the ore deposits occur near the contacts of bodies of igneous rock intrusive into Cretaceous strata, one of the principal igneous-rock varieties being similar to one of the intrusions at Aspen. Near many of these intrusions there are networks of small faults, usually with a vertical displacement of less than 100 feet and registering a dynamic movement since the deposition of latest Cretaceous strata. Along these faults the ore has formed in the shape of fissure veins, with strike mostly northeast and southwest or northwest and southeast, though some of them trend north and south or east and west. The dip is usually vertical. As a rule, each district in this region has two principal systems of veins, intersecting at angles of 40° to 60°. The principal ores are galena, blende, and pyrite, and are in the main of low grade in both gold and silver. In the Ruby district, however, arsenopyrite and ruby silver (both pyrargyrite and proustite) are present, with a gangue of quartz and calcite. Barite, siderite, and rarely fluorite also occur.[a] In the Ruby Chief mine some rhodochrosite is reported.[b] The best ores carry silver and locally a little gold.

ORES OF THE SAWATCH RANGE, SOUTH OF LEADVILLE.

The foregoing descriptions indicate the character and occurrence of the ore deposits along the principal mineral belt from Boulder to Leadville and along the parallel and slightly offset belt which extends from Redcliff to the Gunnison country. Besides these, there appears to be a belt forming a part of the general northeast-southwest zone of mineralization and extending in a direction somewhat west of north along the Sawatch Range. In the principal belt, running from Boulder to Leadville, the mineralization ceases to be conspicuous a short distance south of Leadville, though gold-bearing veins are reported in the vicinity of Granite and Buenavista.[c] The chief belt south of Leadville, however, lies on both sides of the Sawatch Range, along the nearly north-south line between Chaffee and Gunnison counties. This belt includes the Tincup, Alpine, Monarch, and other districts. The Tincup district is in Gunnison County, near Alpine Pass, in the Sawatch. The Gold Cup mine is in limestone, reported to be of Carboniferous age. The ores contain lead and silver. The Golden Queen mine is a fissure vein containing mostly gold.[d] In the Alpine region of Chaffee County, not far from the Tincup region, the ores are reported to be silver sulphides and galena, carrying silver, some gold, and a little copper.[e]

At the head of Tomichi and Quartz creeks, in the Sawatch Range south of Tincup, the country rocks are reported to include granite, quartzite, limestone, and porphyry. The ores are reported to include galena, pyrite, gray copper, and silver glance, and to occur as veins in granite, quartzite, and limestone.[f]

In this same belt is situated the Monarch district, at the headwaters of Arkansas River, in Chaffee County. The country rocks include granites and porphyries. The ores consist of carbonate of lead or galena, and are of low grade in silver. Copper and antimony occur in places.[b] This district has been relatively productive.

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[a] Emmons, S. F., Anthracite-Crested Butte folio: Geologic Atlas U. S., folio 9, U. S. Geol. Survey, 1894, p. 2.
[b] Rickard, T. A., Across the San Juan Mountains, 1903, p. 95.
[c] Kemp, J. F., Ore Deposits of the United States and Canada, 3d ed., 1900, p. 295.
[d] Fossett, Frank, Colorado, 1880, p. 570.
[e] Idem, 559.
[f] Idem, p. 560.

COINCIDENCE OF A BELT OF INTRUSIVE PORPHYRIES WITH THE ENTIRE BELT OF MINERALIZATION.

The question of the distribution of intrusive porphyries in this portion of Colorado has been investigated by Mr. Ball; the distribution of veins has been looked into by the writers. Mr. Ball finds that there is a belt of porphyries having the form of dikes and sheets intrusive into older rocks and extending with unimportant interruptions from Boulder southwestward past Leadville to Aspen and Crested Butte, across the Colorado, Park, and Sawatch ranges. According to Mr. Ball, the belt widens to the southwest, being but 10 miles wide at Boulder and at least 75 miles wide near the west end of the designated stretch. These intrusive porphyries are mainly of siliceous or intermediate composition, resemble one another in a broad way, and probably belong to a single general period of intrusion. The porphyry belt coincides more or less exactly with the mineral belt which has been described, and the fact noted in the detailed study of the Georgetown quadrangle, that the porphyry dikes and mineral veins occupy the same definite and restricted belt, is therefore characteristic also, though perhaps less exactly, of the whole mineral belt from Boulder to Crested Butte.

NATURE OF BELT MARKED BY DIKES AND VEINS.

DYNAMIC ORIGIN OF THE BELT.

Near the southwest end of this belt of igneous intrusion and mineralization, where the belt passes through alternating pre-Cambrian, Paleozoic, and Cretaceous rocks, both the igneous rocks and the ore bodies tend to spread out in the form of sheets or irregular masses, many of them occupying relatively wide and irregular areas. In this southwestern region the true nature of the ore zone is not so evident as farther northeast. For 60 miles, however, from the vicinity of Breckenridge to the foothills of the Rockies near Boulder, the belt of intrusion and mineralization runs through a broad area of pre-Cambrian crystalline rocks with practically no Paleozoic, Cretaceous, or Tertiary deposits. In this area the true nature of the belt becomes evident, and is seen to be due to dynamic movement, which has acted irrespective of geologic formations. In the study of the Georgetown quadrangle the exact nature of this belt has been made apparent as a zone of yielding to regional stress, characterized by fracturing, faulting, and fissuring.

CHARACTERISTIC FAULTING ALONG THE BELT IN THE GEORGETOWN QUADRANGLE.

In the Georgetown region these disturbances began before or at the period of the intrusion of the earliest dikes, and the earliest fractures, faults, and fissures were occupied by the intrusions. Taken as a whole, the porphyry dikes were intruded, as will be shown, at various epochs of a general period of volcanism, during which movements were renewed repeatedly along the old planes or along new planes more or less parallel to the old ones. A study of individual cases within the Georgetown quadrangle shows clearly that a given fault zone or fissure has been repeatedly opened up and repeatedly cemented shut again, either by injections of molten rock, forming dikes, or by deposition of minerals from solution, forming veins, or by both processes.

It was by no means uncommon for dikes of different material to be thus successively injected along the same line of fissuring (see description of Stanley mine, p. 341), and in some places as many as three different dikes were thus successively injected (see description of Golden Chariot mine at Empire, p. 396). Between the periods of dike injection, and in general after all injection had ceased, the reopened fissures were cemented by vein material. A complicated succession of reopenings and repeated depositions of vein material has been studied in a number of individual veins. In some cases where a vein was split open, the new fissure was as large or larger than the original fissure and was cemented by a later vein. The general result of the writers' investigations shows that repeated movements, associated with repeated dike injections, and with a continual process of healing by deposition from waters, have been going on, though with irregular and spasmodic intensity, since a time before the period of dike injection. There is evidence of the deposition of vein material very recently, and this, together with the existence of uncemented openings and fissures, accompanied in many localities by displacement, shows that the processes of faulting, fissuring, and cementation are still going on. Such more recent movements, later than the dikes and later also than the bulk of the mineralization, in general follow the old planes of weakness and are marked by open fissures along veins, by seams of gouge or triturated material, and (especially in the neighborhood of Idaho Springs) by characteristic zones of friction breccia in which the larger fragments are rounded by attrition, due to movement under comparatively slight pressure and comparatively near the surface.

SIMILAR FEATURES OF OTHER PORTIONS OF THE BELT.

The true character of this mineral belt as a zone of weakness, affording relief to expansile and contractile strains in a comparatively wide area of crust, is thus well shown in the area of the Georgetown quadrangle. This character is substantiated by the data at hand from other portions of the belt. Throughout that part of the belt which passes through the pre-Cambrian crystalline rocks the ore deposits have almost exclusively the form of fissure veins, and both veins and porphyry dikes have a predominant northeast trend and steep dip. In the more complicated portion of the belt, where it passes on the southwest into areas containing pre-Cambrian, Paleozoic, and Mesozoic rocks, similar northeastward-trending fissure veins are associated with replacement deposits in limestone, many of which have been found to fall into definitely aligned shoots with a northeast trend.

DYNAMIC MOVEMENTS ALONG BELT IN BOULDER AND GILPIN COUNTIES.

Intersection and faulting.—The intersection and local faulting of one vein by another in the Boulder region has been described,[a] showing different periods of movement and of mineralization. In Gilpin County Forbes Rickard has recognized the fact that the ore zone is marked by weakness and fissuring and has noted that the veins occur along faults which are, as a rule, of slight displacement.[b]

Amount of displacement along vein faults.—The above observation concerning the amount of displacement coincides with the observations in the Georgetown area, although in some localities the aggregate of all faulting movements which have successively taken place along a single line, plane, or zone is more considerable. In this pre-Cambrian region markers of displacement are usually wanting or difficult to find, but the dragging apart of separate fragments of what was once a probably continuous dike by strike faulting due to renewed movement along the zone of the dike has been observed at many places.

Similar strike faulting along veins has been frequently recorded. Where renewal of movement has thus taken place along old fault planes, if the plane of the new movement coincides in every detail with that of the old, it results only in parallel fissures or zones of gouge material or of breccia within or on the walls of the preexisting dike or vein, with no displacement of these older formations, and where the new fissures and zones of fracturing become cemented by vein material the amount and in many veins the existence of the strike faulting are difficult to decipher. If, however, the renewed movement takes place along a zone instead of a plane, and includes movement along minor oblique as well as along major parallel planes, the dike or the vein may be dragged apart and form separate shreds in the manner mentioned. Here and there dikes and veins are cut by later movements along transverse planes, the result being a horizontal displacement or offset. The amount of such offsetting in the Georgetown quadrangle is usually insignificant, the most extensive displacement observed being that of the large porphyry dike in the area of the Silver Plume special map by transverse faults, the offset amounting in some places to about 200 feet. It is probable that this displacement is very much less than that which has been accomplished here and there by strike faulting, though along other strike faults the aggregate of displacement since the movement began has been only a few feet.

[a] Lakes, Arthur, Geology of Western Ore Deposits, new ed., 1905, p. 209. Farish, J. B., Proc. Colorado Sci. Soc., vol. 3, 1891, pp. 316-322.
[b] Trans. Am. Inst. Min. Eng., vol. 28, 1899, p. 108.

FAULTING IN THE TENMILE, LEADVILLE, AND ASPEN DISTRICTS.

In the Tenmile district Emmons finds two periods of faulting, one previous to the ore deposition and one subsequent to it. In this region faulting took place at different periods along different planes, instead of being confined practically to the same plane, as in the Georgetown region. At Leadville, where the ores are later than the porphyry intrusions, both porphyry and ore deposits have been displaced by numerous faults, many of them heavy. This faulting movement was long lived, was even kept up in post-Glacial time, and is very probably still going on.[a] In the Aspen district, where, as in Leadville, the ores occur chiefly in Paleozoic limestone, the intrusion of porphyry dikes was followed by the development of a complicated series of faults. The movement along these faults has lasted from the period of intrusion through the Glacial period to the present day. In this district, although some systems of faults having a different strike and dip were developed later than others, there has also been a general movement renewed at intervals along the same fault planes. The main ore deposition began after the beginning of the main period of faulting and practically terminated before its close, so that the ore was deposited along the earlier faults. These ore deposits, however, have been broken up by strike faults due to renewal of movement along the fault planes where the ore deposition originally took place and also by transverse faults.

SUMMARY OF DYNAMIC HISTORY OF BELT.

Thus, in general, a similar history is recorded along the whole belt of mineralization. The whole belt has been subject to repeated and continued faulting from the time of the first intrusion of dikes. The phenomena of dike intrusion and vein formation have been more restricted in point of time, the former probably more so than the latter.

AGE OF PORPHYRY INTRUSIONS.

LACK OF EVIDENCE IN PRE-CAMBRIAN AREA.

Throughout the belt described, from Boulder to Leadville, and from Redcliff past Aspen to the Ruby and Irwin districts in the Crested Butte region, the ores are, as a rule, later than the intrusions of porphyry, which consequently afford the first evidence of the existence of the zone of regional weakness and fracturing. Where this zone lies in pre-Cambrian rocks, as it does throughout that region which includes the Georgetown quadrangle, we have no further evidence as to its age and that of the porphyries other than that these dikes cut all the pre-Cambrian rocks, and that the intrusions took place successively and probably occupied a considerable period of time.

EVIDENCE OUTSIDE OF PRE-CAMBRIAN AREA.

Around Breckenridge, Tenmile, and Leadville, however, intrusions of the same kinds of rocks cut not only the pre-Cambrian rocks but sediments of Paleozoic and Cretaceous age. In the Leadville district Emmons distinguished two groups of post-Paleozoic rocks, the younger consisting of extensive Tertiary rhyolites and andesites, with one occurrence of quartziferous trachyte,[b] the older including the intrusive porphyries which accompany the ore deposition and which are similar to the porphyries characterizing the mineral belt near Georgetown. Concerning the age of this older group, Emmons states that no exact definition is possible.[c] The period of chief orogenic movement, including folding and faulting, is placed by the consensus of geologists at the close of the Cretaceous, since Tertiary beds (not represented in the Leadville district) overlie the folded Cretaceous strata unconformably. The porphyries are found only in Paleozoic formations within the limits of the area shown on the Leadville map, but in other parts of Colorado the same rocks cut the latest Cretaceous beds. Since, however, both the porphyry sheets and the subsequently formed ore deposits were displaced by folding and faulting, which Emmons regards as accompanying the post-Cretaceous uplift, he regards the date of

[a] Emmons, S. F., Mon. U. S. Geol. Survey, vol. 12. 1886, p. 33. [b] Idem, p. 86. [c] Idem, p. 293.

intrusion as not later than the end of the Cretaceous. "It seems probable, therefore, that, though the eruption of this type of rock may have commenced much earlier, it lasted in this region till near the close of the Cretaceous."[a]

In the near-by Tenmile district are intrusive porphyries of which one at least (the Lincoln porphyry) is also represented at Leadville. Later than these porphyries and cutting through them are rhyolites. In this case Emmons[b] is inclined to think that the porphyry intrusions were pre-Cretaceous (or Jurassic), basing this supposition on the mapping by the Hayden Survey of the Mosquito fault, which in the vicinity of Leadville has been proved to be later than the intrusions. The Hayden map shows the Dakota (Cretaceous) overlying and unbroken by the Mosquito fault.[c] Cross,[d] however, points out that this mapping lacks confirmation, and presents arguments opposed to this conclusion as to the age of the porphyries, the principal one being that almost identical rocks are intruded in the Cretaceous strata of Middle Park, at Blue River Butte. Cross has described the laccolithic form of the principal porphyry intrusions, both in the Mosquito range, including Leadville, and in the Tenmile district. He considers that the same class of magmas, which in these districts have been injected into the older, more or less disturbed strata of the mountains, and are found as dikes in the fundamental Archean complex, were also in other districts injected, at probably the same period, into nearly horizontal strata.[e] These other districts include in Utah the Henry Mountains, in the southern part, and the Abajo Mountains, in the eastern part of the State; in Colorado the West Elk Mountains, the San Miguel and La Plata, and other mountains in the San Juan region, and the El Late Mountains, in the southwest corner; and in Arizona the Carriso Mountains, in the northeast corner. In all of these localities intrusive rock occurs in the form of laccoliths. The Spanish Peaks and adjacent mountains in southern Colorado are made up of probably similar rocks. Cross finds that although the rocks forming these intrusive masses show a considerable range in composition, yet the great majority of them belong to one well-marked structural type, with but slight variation in mineralogical constitution. "This is plainly the result of the similarity of conditions of consolidation upon magmas which are much alike in their controlling elements."[f] Cross concludes that these porphyry intrusions are of Tertiary age.[g]

ORE DEPOSITS SOUTHWEST OF THE BELT DESCRIBED.

The above-described belt of ore deposits has been considered separately from other Colorado ore deposits on account of their forming a connected chain and having characteristics so definite in common. If the trend of this belt is followed farther southwest, however, it is found that there are ore deposits notably massed along its projection.

VULCAN MINING DISTRICT.

The Vulcan mining district is encountered about 15 miles south of Gunnison, near the boundary between Gunnison and Saguache counties. In this district are white pre-Cambrian mica schists veined with feldspar and quartz and cut by basic dikes. These are overlain by nearly horizontal beds of Cretaceous (Dakota) sandstone. Lying up on the Dakota sandstone are bodies of coarse andesitic breccia 400 to 500 feet thick. Above this is a porous tuff, and, still higher, basaltic flows. The principal mine of the district, the Good Hope, lies in the schist. The vein strikes east and west and dips steeply to the north. The gangue is quartz, much of it opalescent and high in free gold. There are large bodies of low-grade pyrites. Specimens of native tellurium, petzite, and telluride of copper have been found. There is evidence that the

[a] Emmons, S. F., Mon. U. S. Geol. Survey, vol. 12, 1886, p. 294.
[b] Emmons, S. F., Description of the Tenmile district: Geologic Atlas U. S., folio 48, U. S. Geol. Survey, 1898, p. 3.
[c] An additional reason given in the Tenmile folio for assuming a pre-Cretaceous age for the Mosquito fault, was the transgression of the Gunnison-Dakota formations directly on the Archean across the range from Tenmile, in the Blue River valley.
[d] Cross, Whitman, Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 224.
[e] Idem, p. 219.
[f] Idem, p 225.
[g] Idem, p. 238.

vein has been shattered and reopened at a comparatively recent date, and has then served as a vent for hot springs. The older vein of opalescent silica has been split open and the fissures have been filled with siliceous sinter inclosing fragments of the vein.[a]

SAN JUAN REGION.

A short distance south and west of the Vulcan district is the northern portion of the San Juan region. This is a rugged, mountainous country containing many mining districts, including those of Lake City, Ouray, Telluride, Silverton, Rico, and Creede. During the last ten years this region has been considerably studied by the geologists of the United States Geological Survey, including Cross, Purington, Ransome, and Spencer. The following general description is taken largely from the Survey reports.

GENERAL GEOLOGY.

The term San Juan region[b] is applied to a large tract of mountainous land in southwestern Colorado. The chief mountain mass is known as the San Juan Mountains. The Needle Mountains are almost continuous with the San Juan proper. The La Plata Mountains form an isolated group on the edge of the San Juan Mountains, and the Rico Mountains constitute an outlying group having certain genetic features in common with the La Plata Mountains and distinct from the main range.

On the borders of the San Juan region are ancient pre-Cambrian granites, gneisses, and schists, above which Cambrian, Devonian, Carboniferous, Triassic, Jurassic, and Cretaceous strata were laid down. Cretaceous beds from the Dakota to the Laramie are represented. The long Upper Cretaceous sedimentation was terminated by a continental uplift of unknown but possibly great extent. In the San Juan region this was marked by folding. The San Juan Mountains represent a broad anticlinal or quaquaversal fold[c] which was formed during the post-Laramie uplift.

Local irregularities are shown by abrupt folds and faults.[d] Several domal uplifts, such as those of the Rico, La Plata, and Needle mountains, are probably of later origin and have been superimposed upon or added to the larger San Juan structure, in part obliterating it. During and subsequent to the uplift erosion was very active and produced a plane of moderate relief cutting across the obliquely upturned edges of the entire series of Mesozoic and Paleozoic formations. Upon this plane surface the succeeding formations were laid down, being separated from the Laramie by a striking unconformity which is one of the most important known in the Rocky Mountains. The first of the unconformable overlying formations is a conglomerate (the Telluride conglomerate), which has been derived from the erosion of the older quartzites, schists, granites, gneisses, sandstones, and limestones. This was a terrestrial deposit, which is exposed over certain portions of the San Juan region. It has been interpreted as the wash from a mountainous tract upon a plain stretched out at its base.[e] It occurs in various thicknesses up to 1,000 feet. After several hundred feet of this formation had been deposited a great epoch of volcanic activity began and a vast amount of material was emitted from volcanoes and fissure conduits. The earliest volcanic formation was a thick series of bedded tuffs, which were laid down immediately after the deposition of the Telluride conglomerate. They are intermixed with the conglomerates in their upper portion, and overlie them with an aggregate thickness of as much as 2,500 feet. This lower tuff series is called the San Juan tuff. Subsequent to its deposition was a period when rhyolitic and andesitic lavas were emitted as alternating flows, with accompanying deposits of tuff. The lavas and tuffs make up the Silverton volcanic series, which reaches a thickness of 4,000 feet or more. Above this series is a further accumulation of volcanic material, chiefly rhyolitic, which is called the Potosi volcanic series

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[a] Lakes, Arthur, Geology of Western Ore Deposits, new ed., 1905, p. 264. Rickard, T. A., Across the San Juan Mountains, 1903, p. 84.
[b] Cross, Whitman, and Howe, Ernest, Description of the Silverton quadrangle: Geologic Atlas U. S., folio 120, U. S. Geol. Survey, 1905, p. 1
[c] Ransome, F. L., Rico folio, No. 130, U. S. Geol. Survey, 1905, p. 7.
[d] Silverton folio, No. 120, U. S. Geol. Survey, 1905, p. 21.
[e] Cross, Whitman, and Howe, Ernest, Silverton folio, No. 120, U. S Geol. Survey, 1905, p. 21.

and has a thickness of 1,000 feet or more. The above-named three series of bedded volcanic deposits make up the greater part of the western San Juan Mountains. East of the Silverton region their thickness gradually lessens, and they disappear under later lavas, not fully investigated, but known to include rhyolite, andesite, and basalt. The source of most of the San Juan lavas is unknown, but it is recognized that the Silverton volcanic series was in part emitted through fissures now filled by dikes.

Subsequent to the formation of these surface volcanics occurred the intrusion of massive bodies of rocks such as diorite, gabbro, and monzonite, that were in many places coarsely crystalline. These intrusions were in the form of stocks and penetrated, and were therefore later than, all the bedded lavas described. Other igneous bodies, consisting of diorite porphyry and allied rocks, which occur as sheets and laccoliths in the sedimentary beds adjacent to the San Juan Mountains, are probably also of later date than many of the surface lavas. The laccoliths are thought to be earlier than the stock intrusions, since in the Rico and La Plata mountains the diorite and monzonite porphyries which occur elsewhere as sheets and laccoliths have been cut by diorite stocks.

The three different productions of the San Juan volcanic eruption, the surface lavas, the stocks, and the sheets of laccoliths, do not differ essentially in chemical composition. It is doubtful whether the reservoirs represented by the stocks and laccoliths ever furnished material for surface flows of any consequence. The laccoliths are similar to those of porphyry masses scattered through Colorado and adjacent parts of Utah, Arizona, and New Mexico. The latest of all the volcanic rocks were certain dike rocks, usually of basic character and probably connected with the stock and laccolith intrusions. They are regarded as probably the products of differentiation from the monzonitic magmas of the larger intrusions. In the Telluride quadrangle they comprise pyroxene andesite, plagioclase basalt, augite minette, vogesite, and augite camptonite.[a] In the La Plata quadrangle they are classified as pyroxenic, monzonitic, and dioritic lamprophyres. The basic dikes are made up of the same minerals as are present in the more abundant rocks with which they are connected, but in them the dark silicates attain more or less decided predominance.

Volcanic eruptions in the San Juan region probably continued at intervals until late in the Tertiary period, although only the products of the earlier outbursts are known.[b] Little evidence is available by which the sequence of events can be correlated with established divisions of Tertiary time. Certain calcareous tuffs of the Silverton quadrangle contain scanty plant and invertebrate remains, indicating that they were formed in Oligocene or early Miocene time.[c] The basal member of the nearly horizontal Tertiary series, the Telluride conglomerate, contains no fossils, but has provisionally been referred to the Eocene. Cross has called attention to the analogy in composition and general relations between the Telluride conglomerate and the Arapahoe formation of the Denver Basin.[d] Such a comparison carries with it the further correlation of the San Juan tuff with the Denver formation, which overlies the Arapahoe formation and which is composed largely of andesitic débris. The Arapahoe and Denver formations are fossiliferous, and although they are separated from the Laramie by the great post-Laramie uplift and subsequent erosion, the fossil evidence is still considered by paleontologists as indicating Cretaceous age.

While the principal quaquaversal uplift of the San Juan Mountains was pre-Tertiary, the smaller domal uplifts which have been added to this larger structure took place at a later period. In the Rico and the La Plata mountains are quaquaversal domes whose uplift took place in the Tertiary period, and possibly in the Eocene epoch, soon after the formation of the San Juan tuff.[e] These uplifts are regarded as having probably a genetic relation to the older San Juan structure. Some observed deformation was undoubtedly due to intrusions of igneous rock, but it appears certain that on the whole the Rico dome and probably the La Plata dome

[a] Telluride folio, No. 57, U. S. Geol. Survey 1899, p. 7.
[b] Cross, Whitman, and Howe, Ernest, Silverton folio, No. 120, U. S. Geol. Survey, 1905, p. 2.
[c] Cross and Howe, loc. cit.
[d] Telluride folio, No. 57, U. S. Geol. Survey, 1899, p. 13.
[e] Rico folio, No. 130, U. S. Geol. Survey, 1905, p. 11.

were formed by a single uplifting force, acting independent of any actual observed intrusion of liquid rock material. The San Juan structure, which is believed to have been an earlier and larger manifestation of the same force, was also probably accomplished by a force pressing upward from below and not represented by any known intrusives.

Subsequent to the eruption of all the volcanic rocks a complex fault system was developed in the San Juan Mountains. Many of these faults and attendant and largely subsequent fissures have become mineralized and form the veins of the region.

ORES OF THE SILVERTON REGION.

In the Silverton region it has been noted by Ransome[a] that, although the veins strike in nearly every direction, the most conspicuous set has a northeast trend and a steep dip, while a second set, slightly less marked, strikes northwest and also dips steeply. One very noticeable fault zone has been traced from the center of the Silverton area northeast for a distance of 7 miles, and is known to extend farther for a distance yet undetermined. This zone is 3 miles wide and within it there is complex faulting. The vein fissures, which have different strikes, intersect at numerous points, and Ransome regards it as possible that many of these intersecting fissures have been produced by a single stress and have been filled by one process of vein deposition. In some places, however, the intersecting fissures are shown to have been of different age, since they are filled by different material. In many such cases the older vein is crossed by the younger one without recognizable faulting. In a few places the older lodes have been faulted by the later transverse vein-filled fissures. In these cases the older lode, running more nearly north and south, has been faulted by barren or low-grade lodes trending more nearly east and west. Fissuring subsequent to the formation of the veins, and resulting in the reopening of the same fissures instead of the creation of new transverse fissures, has taken place in very many places, and the new openings have been subsequently filled with generally barren or low-grade quartz. Renewals of movement subsequent to all vein deposition are also shown by unfilled fissures and seams of gouge. The ores have a gangue of quartz, pyrite, calcite, dolomite, rhodochrosite, rhodonite, kaolin, and fluorite. The metallic minerals include pyrite, tetrahedrite, sphalerite, chalcopyrite, galena, polybasite, ruby silver, bismuthinite, argentite, and here and there tellurides of gold and silver in small amounts only. The mineralizing agents are believed to have been hot ascending waters, which derived their heat from volcanic rocks and which collected their mineral contents from the rocks through which they percolated on their downward journey from the surface to the heated regions and their ascent as hot springs. Since the lodes cut all the volcanic rocks of the region, their formation is regarded as not earlier than late Tertiary and as possibly having extended into the Pleistocene.

ORES OF THE TELLURIDE QUADRANGLE.

The veins of the Telluride quadrangle, which adjoins the Silverton quadrangle on the west, have been described by C. W. Purington.[b] His conclusions as to the relative age of the fissures agree closely with the later work of Ransome in the Silverton district. The fissures of the Telluride quadrangle, though of different strike, are probably mainly contemporaneous. To judge from the geologic map accompanying the report, the principal direction of the veins appears to be northwest, a smaller number having an east-west or northeast-southwest strike. There are in this region gold lodes and silver lodes, many of them quite distinct from one another, although there is no evidence of more than one distinct widespread period of ore infiltration. Only one place was noted where intersecting veins have been deposited during a different period. In this case a number of northwest veins are crossed and faulted by the Pandora vein, which runs east and west. The ore in the Pandora is of a different character from that in the veins which it faults, indicating that the east-west fissuring was later than the filling of the northwest veins by ore. The Pandora is regarded as probably the same as the Camp Bird vein in the Silverton quadrangle.[c]

[a] Ransome, F. L., Bull. U. S. Geol. Survey, No. 182, 1901, p. 46.
[b] Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 751-848.
[c] Ore Deposits, A Discussion (reprinted from Eng. and Min. Jour.), 1903, p. 88.

Evidences of recent strain and movement were noted along the veins, and in general the rock fracturing of the quadrangle is considered to be due to an extensive, far-reaching cause.[a] The gangue minerals include quartz, barite, fluorite, calcite, rhodochrosite, and siderite, and the metallic minerals pyrite, galena, blende, polybasite, ruby silver, chalcopyrite, and sphalerite. No tellurides are described from the region. The ores are believed to have been deposited from surface waters heated by volcanism and deriving more or less of their constituents from the exhalations of the magmas. The occurrence of fluorite in the gangue makes it probable that the ore was of deep origin. The ore deposition is assigned to a comparatively recent date, since it is believed that the last eruptions occurred in late Tertiary time, and thus were older than both the fissuring and the ore filling.

ORES OF THE RICO QUADRANGLE.

In the Rico Mountains, according to Cross and Spencer,[b] the ore deposits, together with those of the La Plata Mountains, belong to a great epoch of ore formation which succeeded the early Tertiary igneous intrusions and more typical volcanic eruptions in many parts of the Rocky Mountains. Ransome,[c] however, basing his estimate on the same facts, considers that the ore deposits are probably late Tertiary and possibly extend into the Pleistocene. Ransome assigns the same origin to these lodes as in the Silverton district, considering that they were deposited by waters of atmospheric origin which became heated in the neighborhood of volcanic rocks and ascended along the lode fissures. The veins may be grouped into two sets, of which the principal one strikes northeast and contains profitable amounts of ore. The next most numerous set of fissures strikes northwest and is not ore bearing. It is regarded that both the northeast and northwest sets of fissures were initiated at the same time, but that the northeast fissures were the first to open and to permit vein deposition. The northwest fractures probably existed while the ore was being deposited in the more open northeast fissures, but the principal movement of the northwest lodes was later than the ore deposition in the northeast lodes. At a period subsequent to this ore deposition many of the northeast fissures were reopened and the new fissures were filled with barren quartz and pyrite, and the opening and filling of the northwest fissures is believed to have been synchronous with this period of reopening. The northwest lodes have been planes of movement up to recent times, as is shown by the shattered condition of their filling at many places and by the occurrence of strips of gouge marking movement planes. As a rule, the lode fissures were clean, open fractures of slight tangential displacement and were later than the major faults of the region. The gangue minerals include quartz, rhodochrosite, calcite, fluorite, gypsum, and barite; the metallic minerals are pyrite, galena, sphalerite, chalcopyrite, tetrahedrite, ruby silver, and argentite. The bulk of the Rico ores may be divided into (1) pyritic ores, usually of low grade, and (2) argentiferous galena ores, some of which contain rich silver minerals. The two kinds are not capable of sharp distinction and are not necessarily of different age.[d] In some veins of the district the rich silver ores (proustite, argentite, and polybasite) formed subsequent to the galena, sphalerite, and rhodochrosite; and also subsequent to these minerals, and, as it is supposed, to the rich silver ores, practically barren quartz containing a little pyrite was deposited.[e]

ORES OF THE LA PLATA QUADRANGLE.

The La Plata quadrangle adjoins the Rico quadrangle on the south. Here the Mesozoic strata have been uplifted by numerous masses of molten magma which consolidated as sheets and small laccoliths of porphyry. Later, stocks of igneous rock were injected. At a period subsequent to the igneous intrusion ores of iron, copper, lead, and zinc were deposited, with variable amounts of gold and silver. The La Plata uplift, which is in part contemporaneous

[a] Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, p. 781.
[b] Cross, Whitman, and Spencer, A. C., Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 34.
[c] Ransome, F. L., Twenty-second Ann Rept. U. S. Geol. Survey, pt. 2, 1901, p. 304.
[d] Idem, p. 248.
[e] Idem, p. 253.

with the igneous intrusions, was probably Tertiary, and presumably early Tertiary.[a] This uplift, however, together with the neighboring and similar Rico Mountains uplift, was not due chiefly to the igneous rocks now exposed at the surface, since the existing porphyry masses are not capable of having produced the full domal structure at the center of the uplift. The intrusions are believed to be due to the same earth stresses which have produced the principal structure.

The veins in the La Plata district may be grouped into three sets, according to their strike. One of the sets strikes east and west, and the two others strike northeast and northwest, respectively. The northeast and northwest fissures seem to have been formed latest. All the evidence points to the fissures having been formed by a force acting from the north, beyond the limits of the field.[b] The strongest veins follow the northeast-southwest and east-west fissure systems. The metalliferous minerals include gold and silver tellurides (sylvanite, petzite, and probably calaverite), argentiferous tetrahedrite, other sulphantimonides and sulpharsenides of silver, pyrite, chalcopyrite, galena, and zinc blende. The gangue minerals include quartz, calcite, rhodochrosite, dolomite, barite, and fluorite. The ores are of two kinds—telluride ores and ores in which the gold occurs free or associated with pyrite. The most important ores are believed to have been derived from the basic constituents of igneous rocks, from which they have been abstracted by waters that, having penetrated downward and become heated by the proximity of the volcanic intrusions, subsequently ascended as hot springs and deposited the ores. The ore deposition is believed to have followed closely the igneous intrusion, which, as stated above, was regarded by Spencer as presumably early Tertiary.

ORES OF THE NEEDLE MOUNTAINS QUADRANGLE.

The Needle Mountains quadrangle adjoins the Silverton quadrangle on the south. The general geology has been described by Whitman Cross and Ernest Howe, and the economic geology by J. D. Irving and W. H. Emmons.[c] The oldest rocks in this quadrangle are pre-Cambrian schists and gneisses, probably of igneous origin, and greenstones, with a great thickness of overlying quartzites, slates, and conglomerates, which have been named the Needle Mountains group. These pre-Cambrian sediments are possibly equivalent to the schists of sedimentary origin (Idaho Springs formation) which form the oldest known rock in the Georgetown quadrangle, though in the Needle Mountains the strata referred to are not metamorphosed to anything like the extent of the Schists of the Georgetown district. Overlying these pre-Cambrian rocks in the Needle Mountains quadrangle is a succession of Paleozoic sediments, including Cambrian, Devonian, and Carboniferous strata. The Paleozoic rocks are overlain by the Tertiary (Eocene?) conglomerate, which in earlier reports was named the Telluride conglomerate. The older schists of probable igneous origin and locally the sedimentary rocks of the Needle Mountains group are cut through by a variety of pre-Cambrian granite intrusions, which have been separately mapped. These granitic intrusions are accompanied by dikes of aplite and pegmatite. They may correspond in general with the intrusive granites which cut through the Idaho Springs formation in the Georgetown quadrangle. In the pegmatites connected with some phases of the granites of the Needle Mountains magnetite occurs regularly though not abundantly, a fact which supports (so far as it goes) the suggested correlation with the Georgetown rocks, since magnetite is common in the pegmatites connected with certain of the granites of the Georgetown district, and in places, as described elsewhere, becomes an abundant and striking constituent.

Tertiary volcanic rocks make up the same formations as described elsewhere in the San Juan region, comprising the San Juan tuff, composed of andesitic material, and the overlying Potosi volcanic series, consisting of andesitic and rhyolitic lavas and tuffs. There is also some intrusive rhyolite. The Needle Mountains are due to a local domal uplift superimposed upon the great San Juan dome and probably caused by an early Tertiary movement. The structure is similar to that of the Rico and La Plata mountains.

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[a] Spencer, A. C., La Plata folio, No. 60, U. S. Geol. Survey, 1899, p. 10.
[b] Purington, C. W., La Plata folio, No. 60, U. S. Geol. Survey, 1899, p. 12.
[c] Geologic Atlas U. S., folio 131, U. S. Geol. Survey, 1905.

The ore deposits are in the form of veins, which in most places have filled open fissures, while in others they are due to replacement of rock along fractures or fracture zones. The veins may be grouped into two chief classes, according to the dominant direction. The stronger system consists of veins striking N. 10° W. and dipping usually 60°, though they vary from that angle to vertical. The other vein system has a strike of N. 80° E., exactly at right angles to the first. At many points the veins belonging to the two systems cross each other without displacement, or a vein belonging to one set may terminate on intersecting the other. The formation of the fissures appears to have been accomplished at a single period.

The original ore materials of the veins comprise pyrite, chalcopyrite, and galena, with a little sphalerite. The gangue consists of quartz, rhodochrosite, fluorite, chalcedonic silica, and a little barite and calcite. Many of the veins are well crustified. There is evidence of two distinct periods of fissuring and subsequent vein deposition, the later fissuring having reopened the older veins. The filling of the original fissures consists of a fine-grained gray siliceous gangue containing cupriferous pyrite, which carries both gold and silver, the latter mineral forming a slightly greater proportion of the actual value of the ore. This earlier vein filling was shattered so that angular fragments of the vein remain, partly filling the new fissure. The resulting spaces were cemented with white quartz, rhodochrosite, and fluorite, with some galena and barite. The layers of quartz and fluorite were several times repeated, at some points the fluorite filling being last, while at others the final deposition was of white quartz. The values in the ore, except where enriched near the surface, are low, averaging $19, of which $4 to $6 is in gold, $5 to $9 in silver, and the rest in copper. The pay values are contained chiefly in the pyrite of the first period of mineralization. Richer secondary ores due to the alteration of the original ores by superficial waters contain brittle silver, argentite, and native silver. The veins are of small vertical as well as horizontal extent. From this circumstance it is assumed that they are the remnants of more extended fissures whose upper parts have been eroded.

It is therefore supposed, in view of the extensive assumed erosion, that the veins were not formed at a recent period. This deduction, however, appears to the writers as not following fairly from the fact on which it is founded. The relatively superficial character of the veins is on the whole characteristic of the San Juan region, as well as of many other Colorado regions. Ransome has noted this fact in the Silverton area, and from the further circumstance that the veins are limited in downward extent to about the same degree, whether they are located high up on mountains or far down on the valley sides, he has inferred a relation between the downward limit of the veins in different parts of the district and the present surface. He considers that such a relation can hardly be accidental, and concludes that at the time of the vein formation the surface configuration could not have been very different from what it is now. As a corollary of this conclusion, he considers that the veins were formed in comparatively recent time.

ORES OF OTHER SAN JUAN DISTRICTS.

The other districts of the San Juan region are very similar in character to those described, although they have not been so thoroughly investigated. Near Ouray are silver ores containing galena, gray copper, ruby silver, and brittle silver, the gangue vein minerals including quartz and barite. There are also gold ores consisting of copper and iron pyrites, galena and blende, tellurides of gold and bismuth, and in some places free gold.

The general geology is similar to that in other parts of the San Juan.[a] Near Lake City are silver lodes containing galena, copper pyrites, gray copper, ruby silver, and brittle silver.[b] Near Creede the rocks are all volcanic, consisting mainly of rhyolitic and andesitic breccia and quartz porphyry. The veins are fissure veins, with a gangue of quartz and barite, and are traceable long distances. This is essentially a lead-silver camp.[c] In Rio Grande County, especially around Summitville, are important gold-bearing veins.

[a] Fossett, Frank, Colorado, 1880, p. 543. Lakes, Arthur, Geology of Western Ore Deposits, new ed. 1905, p. 277.
[b] Fossett, Frank, op. cit., p. 517.
[c] Lakes, Arthur, op. cit., p. 283.

SUMMARY OF CONDITIONS OF ORE DEPOSITION IN THE SAN JUAN REGION.

The ore deposits in different portions of the San Juan region exhibit many characteristics in common. They are typically fissure veins along fracture zones or fault fissures having slight displacement, whose formation has followed the formation of faults of larger magnitude which have accompanied or followed domal uplifts considered to have been produced by an impulse exerted from below upward. These fissure veins have a predominant northeast strike and an approximately vertical dip. The predominance of a northeast system is especially evident in the Silverton quadrangle, where there exists a broad zone of complex faulting that is 3 miles wide and has been followed along its strike northeastward for 7 miles, beyond which it has an unknown further extent.

The next most common system with regard to strike is the northwest system. Other veins, numerous but on the whole of subordinate importance and of less number, run in various other directions, especially north-south and east-west. The two chief sets of vein fissures, the northeast and the northwest as well as the subordinate sets, are considered to have been formed at the same time. Evidence of an extensive and far-reaching stress which has caused them has been noted in individual fissures and becomes plain when the close relationship of the strikes of the veins in all the districts examined is considered. Following the well-known laws concerning the attitude of fractures formed under a given pressure, several writers have postulated the existence of a more or less horizontal force acting in a direction which bisects the two chief vein systems. It has been sometimes further postulated that this stress came from the north, though the physical requirements are answered as well by supposing that it came from the east or west. The more extensive faults, which in general are older than the vein fissures, follow the same systems of trend, and, like the vein fissures, have a predominant steep or vertical dip.

The domal uplifts began with and were part of the widespread post-Laramie disturbances, whose first conspicuous results were the formation of the San Juan dome and the accompanying but more local folding and faulting. After this event, and also after the considerable period of erosion which followed it, a basal series of conglomerates and a great thickness of later volcanic flows and tuffs were laid down unconformably upon the pre-Laramie rocks. Subsequently all these beds were intruded by sheets, dikes, stocks, and laccoliths of porphyritic and granular rocks.

During the deposition of the bedded post-Laramie formations the doming movement which is manifested in the San Juan dome, formed previous to this deposition, continued and resulted in local domal structures that were superimposed upon the older and larger San Juan dome. These later upthrusting or doming movements were accompanied by and were largely accomplished by complex faulting, which has affected all the rocks mentioned. Along these faults, especially along the later and minor faults and fractures, the ores were deposited by ascending hot waters. Hence they followed and were probably consequent upon volcanic activity and seem to be more definitely connected with the latest volcanic event, the intrusion of the porphyries, since, so far as reported, veins older than the porphyries do not exist. The various sets of vein fissures, as stated above, were mainly formed by a single general stress and at the same period, and filled during a single period of mineral infiltration. In detail, however, there is evidence that some fissures were developed or opened later than others, and accordingly some veins were filled somewhat later than other veins which they may in places cross or even fault. The formation of fractures and fissures, with or without faulting, did not cease with the period of main vein deposition, but has continued up to the present day. The postmineral fractures and fissures usually act along the planes of the old vein fissures, showing a continuous or recurrence of similar stress. The results have been the reopening of veins, and some of these new fissures have been recemented by later vein material, whereas other fissures, probably comparatively recent, still remain open and uncemented.

SIMILARITY OF SAN JUAN CONDITIONS TO THOSE OF THE BOULDER-GUNNISON BELT.

It will be seen that the essential features of this history—namely, the post-Laramie disturbances, continuing at intervals, though with decreasing intensity, throughout the Tertiary, manifested in the earlier stages more by flexing of the formations and in later stages as the overlying load of rocks was gradually removed by erosion, more by faulting; the intrusion of igneous rocks during the earlier stages of folding and faulting, and the subsequent flexing, tilting, and displacement of these igneous rocks by later warping and faulting—are essentially similar to those recorded in the mineral belt which stretches from Gunnison to Boulder and has been discussed in preceding pages. Moreover, the San Juan region is approximately in the path of the Boulder-Gunnison belt projected toward the southwest. It is suggested, therefore, that the intrusions, faulting, fissuring, and vein formation in the San Juan are due to the same general causes as have been found to be responsible in the belt described, and that they occur in especially close association and are localized along this northeast-southwest belt on account of the existence in the earth's crust of a northeastward-trending zone of weakness, which was formed at the time of the post-Laramie disturbances and has existed as such a zone of weakness throughout the Tertiary to the present day. Along this zone of weakness there have been repeated almost continuous openings and reopenings of fault and fracture zones, which at intervals have afforded access to intrusive rocks and circulating waters.

ORIGIN OF THE ZONE OF WEAKNESS.

Assuming, therefore, that this general belt of initial weakness and igneous intrusion, faulting, and ore deposition extends, though with very irregular strength, through from Boulder to the San Juan region, we find that it is characterized throughout by the persistent predominance of northeastward and northwestward trending fissures and faults. Of these the northeast system is invariably predominant if any extensive region is considered, though the northwest fissures are everywhere striking and important. These faults and fissures, moreover, are typically of steep dip or vertical, and in most of the districts which have been carefully examined it has been concluded by different geologists independently that in general both sets of fissures were formed at the same time. These facts imply the existence of a stress acting in a direction bisecting the chief directions of fissuring and faulting, namely, an east-west stress or a north-south stress. That the direction was east and west and not north and south is shown by the folding, which was also accomplished by the post-Laramie disturbance, and therefore was contemporaneous with the formation of the fault and fracture systems. These folds, as shown on the Hayden map, have a strong and definite trend west of north or north-northwest. Emmons [a] states that the post-Laramie dynamic movements may be most simply conceived as a pushing together from the east and from the west of the stratified rocks against the relatively rigid and already existing pre-Cambrian land masses. This compressing force was part of that great mountain-building pressure which, uplifting the whole Rocky Mountain region in post-Laramie time, upthrust the strata and compressed them into north-south folds. Simultaneous with the folding along north and south or north-northwest and south-southeast axes (the direction of these axes being normal to the pressure from the west) the two lines of fractures were developed diagonally to the stress. Subsequent stresses, resulting in displacement along already formed fractures, selected especially the northeast direction, and the faulting resulting from these stresses became localized in this remarkable belt which cuts diagonally across the folds and mountain ranges and traverses the most of Colorado, though it is marked by only minor folding. The repeated fault movements recorded along this belt since its inception suggest that it has performed the function of accommodating and relieving major and minor strains which have repeatedly accumulated in a great mass of rigid crust on either side, thus performing the same function as the sliding joints employed by engineers to accommodate expansion and contraction in large structures of rigid material.

[a] Emmons, S. F., Mon. U. S. Geol. Survey, vol. 12, 1886, p. 32.

DURATION OF ERUPTION AND MINERALIZATION IN THE REGIONS DESCRIBED.

CRITERIA IN THE SAN JUAN REGION.

In the San Juan region the intrusive monzonitic porphyries have cut through older Tertiary volcanics, and hence are themselves of Tertiary age. No Cretaceous porphyries are known in this region. The only possible reference to such pre-Tertiary porphyries is contained in the description of the Telluride conglomerate, which is the basal member of the Tertiary bedded series in the San Juan. Among the pebbles and bowlders of granite, gneiss, and schist in this formation are numerous pebbles of igneous rock having a prominent porphyritic structure.[a] Cross observes that this rock, which he does not further describe, is unlike any of the Tertiary porphyries and is probably of much greater age. It is possible that the rocks referred to are the frequently observed porphyritic phases of the pre-Cambrian granular intrusives.

CRITERIA IN THE LEADVILLE, ASPEN, AND GUNNISON REGIONS.

In the Leadville region are abundant porphyries belonging to varieties which, as Emmons mentions,[b] cut through the latest Cretaceous rock in other parts of Colorado, though since, at Leadville, they have been included in the post-Laramie uplift Emmons regards the eruption as having begun much earlier than the close of the Cretaceous. Inasmuch as the ores whose deposition followed the porphyry intrusion have also been much disturbed by folding and faulting, he regards the igneous intrusions as having lasted until a time near the close of the Cretaceous, though they may have begun much earlier. The fact that the porphyries cut the latest Cretaceous strata, taken by Emmons to signify that the igneous intrusion lasted nearly to the close of the Cretaceous, is taken by Cross [c] as proof of the post-Cretaceous or Tertiary age of these Leadville porphyries and other intrusive rocks having similar relations to the Cretaceous strata.

Moreover, the evidences in the San Juan Mountains show that the strongly marked dynamic disturbance which began and was most active immediately after the deposition of the Laramie (Cretaceous) did not cease at this period, but continued into the Tertiary, and that most of the frequently complicated faulting immediately followed the major portion of the folding and was of Tertiary age. The continuity of the development of flexing and faulting since the beginning of the disturbance at the close of the Laramie even down to the present day has been also plainly shown by Spurr[d] at Aspen, and the same continuity of faulting has been shown by Emmons, both at Leadville and in the Tenmile district. Therefore the fact that the porphyries and subsequent ores at Leadville have been included in folding and faulting movements does not prove that the porphyries were earlier than the post-Laramie uplift, though they may have been contemporaneous with its earlier stages and may have participated in most of its subsequent disturbances. The latter view was the conclusion drawn by Spurr[e] at Aspen, where intrusive porphyry similar to and probably contemporaneous with the white porphyry of Leadville occurs. The strong probability of the correctness of this view is further shown by the presence at Aspen not only of the white porphyry of Leadville, but of intrusive diorite porpyhry in the form of a sheet, which extends with increasing thickness toward the Elk Mountains and is similar to the diorite porphyries that in the Elk Mountains intrude the Ruby formation. This formation is supposed to be the uppermost of the Cretaceous rocks in that region and is of post-Laramie age.[f] The diorite of the Elk Mountains has therefore been considered Tertiary. The diorite porphyry intrusive sheet at Aspen has participated in the folding and faulting to the same extent as has the white porphyry of Leadville in the same district, so that there is no evidence of a distinctly different age for the two rocks.

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[a] Telluride folio, No. 57, U. S. Geol. Survey, 1899, pp. 4, 13.
[b] Mon. U. S. Geol. Survey, vol. 12, 1886, p. 294.
[c] Fourteenth Ann. Rept., U. S. Geol. Survey, pt. 2, 1894, pp. 219-238.
[d] Spurr, J. E., Mon. U. S. Geol. Survey, vol. 31, 1898, pp. 143-150.
[e] Idem, p. 53.
[f] Anthracite-Crested Butte folio, No. 9, U. S. Geol. Survey, 1894 pp 5, 7.

GENERAL TERTIARY AGE OF VOLCANISM.

The known period of volcanism can therefore be stated with a strong degree of probable truth as having begun with the post-Laramie upheaval and continued throughout a great portion of the Tertiary. Taken all together, it may be conveniently designated as Tertiary, though it probably began in the late Cretaceous.

DIFFERENT PERIODS OF INTRUSION WITHIN THE GENERAL VOLCANIC EPOCH.

The diorite and diorite porphyry, which form laccoliths in the Elk Mountains, are considered by Cross to be approximately of the same age as similar porphyries of variable composition, but on the average representing a monzonitic magma, which occurs as dikes, sheets, and laccoliths in the San Juan and other regions. While this is probably true in a large sense, as Cross states,[a] and also the statement that all are Tertiary, yet it is probable that in different localities the intrusion of these similar magmas took place at quite different Tertiary epochs. Probably very early Tertiary or late Cretaceous porphyries of this group, including the porphyries belonging to the Mosquito Range and Elk Mountains types found in the mining districts of Leadville, Tenmile, and Aspen, have been involved in most, if not all, of the post-Laramie folding and faulting. In the Leadville region above the folded porphyries and sedimentary rocks lie unconformable Tertiary volcanics, including rhyolitic and andesitic lavas, which, according to Emmons,[b] are younger than the ore deposition of the district. In the San Juan, however, the prophyries of this intrusive monzonitic group, instead of being involved in a post-Laramie uplift and having been upturned before the deposition of the overlying nearly horizontal Tertiary beds, are intrusive into these beds and into a thick series of nearly horizonal bedded Tertiary volcanics, which form the latest bedded rocks exposed. The age of these intrusive porphyries in the San Juan has been variously assigned by geologists as early Tertiary and late Tertiary,[c] but it is probable that a very considerable period of Tertiary time separated this intrusion from that of the Mosquito Range and Elk Mountains porphyries and that the group of monzonitic intrusives in Colorado, though forming a connected whole and erupted during the same general period of igneous activity, is made up of individuals which are of quite different age.

DIFFERENT PERIODS OF ORE DEPOSITION WITHIN THE GENERAL MINERALIZING EPOCH.

Similarly it appears certain that the mineralization in different places did not take place simultaneously. In various districts, such as the Boulder, Empire, Georgetown, and San Juan, veins of different age occurring close together have been described, though the various geologists who have made important contributions to the geology of the San Juan region are agreed that its veins are referable to a single general period. There is probably often a greater difference in age between the ore deposits in different regions than between veins of different age which, as already stated, have been described as occurring in the same district. For example, the probably distinct age of the porphyries of Leadville, Tenmile, Redcliff, and Aspen from that of the porphyries of the San Juan region, which has just been pointed out, carries with it the probably distinct age of the ores of these districts (and probably also of the ores of the Gunnison region, including the Ruby and Irwin districts) from that of the mineral deposits of the San Juan.

In every one of the districts mentioned all the United States geologists who have examined the geology have considered that the mineralization is intimately connected with the porphyry intrusion and has followed it closely. If this is so, then the Leadville and Aspen ores, and others of this group, began to be formed in early post-Laramie time, which may mean very late Cretaceous or very early Tertiary, according to the placing by paleontologists of post-Laramie strata, such as those of the Ruby and Arapahoe formations.

In the San Juan region geologists have observed that the ores are later than the porphyry intrusions, which in turn are younger than the surface volcanics. Therefore a Tertiary age has

[a] Rico folio, No. 130, U. S Geol. Survey, 1905, p. 11.

[b] Mon. U. S. Geol. Survey, vol. 12, 1886, p. 39.

[c] Ransome, F. L., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 304. Cross, Whitman, Rico folio, No. 130, U. S. Geol. Survey, 1905, p. 11; La Plata folio, No. 60, U. S. Geol. Survey, 1899, p. 10.

been assigned to the mineralization, which more definitely has been variously called probable early Tertiary and probable late Tertiary; and it is stated that in some places the ore deposition probably continued to Pleistocene time. There seems, however, little warrant for assigning an exact age to these deposits further than that they are probably later in general than the probably very early Tertiary group at Leadville. It is perhaps inadvisable to assign a too recent date to the San Juan ores, since they are considered to have followed, probably directly, after the intrusions of the monzonitic porphyries in the form of sheets, laccoliths, and dikes. The crystalline condition of the more massive bodies of igneous rock presupposes several thousand feet of strata above them at the time of intrusion.[a] The time required for the erosion of this amount of overburden is considerable, though it is true that erosion and mineralization probably went on simultaneously and that at the end of the mineralization the surface may have been much lower than at the beginning.

CONTINUITY OF VOLCANIC AND MINERALIZING ACTIVITY BETWEEN DIFFERENT TERTIARY PERIODS.

Some conclusions reached in the Aspen district weaken to a certain extent the reasons given above for determining a sharp age distinction between the ore deposits of the Leadville district and those of the San Juan district. The results of the study of the geology in this district[b] show that the post-Laramie folding resulted in the uplifting of the Sawatch Range as a comparatively gentle, broad anticline, on whose western flanks the Aspen district is situated. During this same post-Laramie epoch of mountain uplift there were intruded into the Aspen strata, certainly within a single general period, porphyries representing the white porphyry of the Mosquito Range and the diorite porphyry of the Elk Mountains. From the study of the Elk Mountains geology we know that this period of intrusion was not only post-Laramie but post-Ruby, and therefore probably Tertiary. These igneous intrusions were followed, probably very closely, by the locally intense folding characteristic of the Aspen district. This deformation seems to have been due to a lateral thrust, which pushed the sedimentary beds against the hard, resisting mass of the Sawatch Mountains. The cause of this lateral thrust was probably the uplifting of the Elk Mountains, which lie to the west, and this uplift was probably due to the intrusion in the Elk Mountains of large masses of molten material forced upward into the sedimentary beds. Continuation of the same force, therefore, which thrust the intrusive rocks into the sedimentary beds brought about the folding and breaking of these intrusive sheets along with the inclosing strata. The disturbance arising from the lateral thrust is restricted to a comparatively narrow zone running parallel to the main axis of the Sawatch. Its most important result was a steep local overthrust anticlinal fold, the compression of which terminated in a fault plane passing through its axis.

Immediately after the formation of this great fault, or perhaps synchronously with it, there began an uplift such as might arise from a vertically exerted force, that resulted in the formation of a local domal structure near Aspen. A similar though less strongly marked dome was also formed at Lenado. With the beginning of the formation of this local dome at Aspen there also began a system of local faulting which has continued from that time to the present, and by the displacement afforded by these faults the final uplift of the dome was largely accomplished.

Immediately following the faulting and fracturing at the beginning of the uplift came an epoch of ore deposition. This epoch was short compared with that of faulting, for we know that the faulting has been continuous and can trace several distinct systems that have developed successively from the earliest period to the present. The systems first formed are ore bearing, showing that they existed at the time of the presence of the mineral-bearing solutions. Later systems are, however, barren, and evidently no ore-bearing waters have circulated along them.

The domal uplift at Aspen is purely local and has no apparent connection with the structure in the surrounding rocks. It does not seem probable that it has been formed by regional

[a] Cross, Whitman, Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 238.

[b] Mon. U. S. Geol. Survey, vol. 31, 1898, p. 143.

stress or by lateral thrust, but might have been formed by a vertical push from below by some restricted force. The period at which its formation began was one of intense eruptive activity, and immediately previous to its formation the intrusive porphyries were injected into the strata. The explanation advanced[a] for the cause of the uplift was that molten rock, probably derived from the same reservoir as the previously intruded porphyry, accumulated in a restricted area, that the upward propulsion of this rock elevated the overlying rigid formations, and that this uplift caused the fracturing and faulting.

These domal structures at Aspen are similar to the larger domal uplifts which have been described as present in the San Juan region, as, for example, those of the Rico and La Plata mountains; and the cause of these San Juan domes has been assigned independently by other students to a similar vertically acting uplifting force. Inasmuch as the uplift at Aspen probably began with the period of porphyry intrusion and of lateral folding that was synchronous with the intrusion of the Elk Mountains dioritic masses, and continued and was chiefly accomplished subsequently, much of the deformation which has affected the porphyry sheets and dikes and the ore deposits was not contemporaneous with the immediately post-Laramie folding; and if the later deformation, as is probable, was due to the slow upward intrusion of an igneous mass that did not reach the surface, certainly at least a portion of the gap which occurred between the intrusion of the porphyries of the Elk Mountains and Mosquito Range and that of the porphyries in the San Juan was bridged over by this period of probable upward migration, though not of actual expulsion, of the monzonitic magma in the Aspen district.

In this district the ore deposition has been estimated to have occupied a restricted period in comparison with that taken up by the faulting, but it is judged that this mineralizing period lasted through two-thirds or even more of the interval between the beginning of the uplift and the present day—in other words, two-thirds of the Tertiary; which, being roughly though perhaps unwarrantedly expressed in more tangible form, would place the ore deposition as lasting through the Eocene and Miocene.

GENERAL TIME RANGE OF ORE DEPOSITION.

In the light of these conclusions it is by no means certain that the period of ore deposition at Aspen and other districts of this group and that in the San Juan mineral districts, where it is consequent on the intrusion of monzonitic domes, do not overlap. Indeed, this conclusion seems probable, though in at least some of the San Juan districts the mineralization may have continued long after it became extinct in the Aspen and neighboring districts. The best broad conception appears to be that there was a general Tertiary period of ore deposition, which ensued locally after local intrusions of monzonitic magmas that were injected at many different epochs in different localities throughout the earlier half or two-thirds of the Tertiary. Thus the epoch of mineralization, which began later than the earliest intrusion and considerably outlasted the latest intrusion, ranges from early Tertiary to later Tertiary in age.

MINING DISTRICTS DEFINITELY OUTSIDE OF THE BELT DESCRIBED.

There are in Colorado certain mining districts, some of which are important, that evidently have no connection in origin with the northeast-southwest zone of fissuring, intrusion, and mineralization already described. Most of them are connected with volcanic eruptions from single isolated centers, where an initial volcanic explosion has blown out a channel in the crust in a region where there are no well-defined preexisting zones of weakness. In many of these districts, also, the mineral-bearing veins are limited in distribution and cluster around the volcanic center or centers. Moreover, their attitude does not indicate that the fissures which they occupy were due to any extensive or regional force, as is the case in the principal mineral belt described. In many places they have a radial arrangement with reference to the volcanic center around which they occur, showing that the fissures were due to quite local causes connected with the volcanic eruption.

[a] Mon. U. S. Geol. Survey, vol. 31, 1898, p. 148.

CENTERS OF MONZONITIC ERUPTIONS.

SPANISH PEAKS MINING DISTRICT.

One of these isolated centers of eruption and mineralization, of no great importance commercially, is situated in the Spanish Peaks, in Huerfano County. This has been briefly described by R. C. Hills.[a] The structure of the region is referable to two distinct periods. In the first period—that after the close of the Laramie—a long synclinal trough was formed, which has a north-south axis diverging toward the northwest. The Spanish Peaks country occupies the southern half of this trough. In the second period, which was more striking in this particular region, deformation was due to local lava eruptions. The effect of these eruptions was to produce in the very bottom of the previously formed trough a great upward bulge, "rent and faulted at the summit, warped by the intrusion of huge masses of igneous rock, and ribbed by a magnificent system of dikes."

The igneous rocks, which represent a long series of eruptions centering in the Spanish Peaks, consist of stocks, dikes, and sheets. The dikes are arranged radially around a large igneous stock which is of later age than the dikes and probably occupies the focus of the eruptions. The igneous-rock varieties include monzonite porphyry, augite granite, augite diorite, granite porphyry, granite, felsophyre, lamprophyre, and basalt. The earliest eruptions were subsequent to the close of the Bridger (Eocene) epoch, and later eruptions have taken place intermittently nearly to the present time. The general magma is regarded as monzonitic, from which the more siliceous and the more basic rocks, including granite porphyry, lamprophyre, and basalt are differentiation products. The lodes are grouped around the great stock of augite diorite, around which the dikes are radially arranged and which, as already stated, probably occupies the old volcanic neck. They contain galena, gray copper, chalcopyrite, sphalerite, and siderite. The gangue is quartz, with calcite and locally barite. While ore-bearing veinlets have been found in the eruptive parts of the mountains, the most promising deposits are confined to the surrounding zone of metamorphosed Eocene sediments.

To judge from Hills's description, the igneous rocks and the consequent ores of the Spanish Peaks district are similar to those of the San Juan and other correlated regions.

CENTERS OF ALKALINE LAVA ERUPTIONS.

The volcanic rocks found in connection with ores around other isolated volcanic centers are quite different from the abundant class which has been described, and the ore deposits also have corresponding peculiarities. This statement applies particularly to two districts—that of Silver Cliff and Rosita and that of Cripple Creek.

SILVER CLIFF AND THE ROSITA HILLS.

GENERAL GEOLOGY.

The connected mining districts of Silver Cliff and the Rosita Hills are situated in Custer County, about 40 miles south of the Cripple Creek district. The whole mining region has a length in a northeast-southwest direction of 9 or 10 miles, and a width in its shorter northeast diameter of 3 or 4 miles. The general geology has been described by Whitman Cross, and the economic geology by S. F. Emmons.[b] The area includes pre-Cambrian granite and gneiss and Tertiary volcanics. The volcanic history began with the outbreak of an active volcano somewhere near the present site of Rosita, which emitted lavas, ashes, and fragmental material. The first two eruptions were of andesite, followed by dacite and rhyolite. Later there came another andesite eruption, followed by one of trachyte. Subsequently ores were deposited by hot ascending waters and possibly by volcanic (fumarolic) vapors. Later than the ore deposition was the intrusion of a dike of basic basalt or limburgite, whose fresh condition, where it intrudes andesitic agglomerate altered and silicified by the mineralizing agents which deposited the ores,

[a] Spanish Peaks folio, No. 71, U. S. Geol. Survey, 1901.

[b] Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, pp. 269-472.

shows that it is of more recent date than the ore formation. According to Cross[a] the products of the volcano accumulated on a surface very similar in character to that of to-day. The age of the volcanic activity, however, is considered to be fixed as early Eocene by fossil leaves found in the rhyolitic flows. The lavas were erupted in the following order: (1) Andesite, (2) andesite, (3) diorite, (4) dacite, (5) rhyolite, (6) andesite, (7) trachyte, (8) agglomerate (Bassick agglomerate), (9) miscellaneous rocks (including limburgite). The fossil leaves above referred to were associated with No. 5 of this series, and their age, if correctly determined, is therefore somewhere near that of the middle portion of volcanic activity. The last member of the series which was erupted in any considerable amount and whose age is well determined was the trachyte, which forms dikes and surface flows.

The different rocks are considered to be clearly a related group, characterized by the high percentage of combined alkalies, potash in particular maintaining a prominent place throughout.

The interesting formation known as the Bassick agglomerate outcrops in a roughly square area between 3,000 and 4,000 feet in diameter, surrounded chiefly by Archean granite and gneiss, with considerable andesite, rhyolite, and trachyte. The agglomerate which fills this area extends almost vertically downward and evidently represents the filling of a volcanic neck. The material consists of unsorted angular and rounded fragments and bowlders up to several feet in diameter, with the interstices between the larger fragments filled with smaller ones down to the size of fine dust. The rocks making up these fragments consist mainly of andesites, whose mineralogical characteristics enable their reference to several of the distinct andesitic eruptions above mentioned. Granite and gneiss also make up a large proportion of the fragments. Trachyte occurs in the lower workings as bowlders or dikes. Charcoal is occasionally found down to a depth of several hundred feet. The agglomerate is supposed to be the result of an explosive eruption and to consist of material which was thrown out of a volcano and fell back again, filling up the open pit. The charcoal is supposed to represent the remains of trees which covered the surface previous to the eruptions.

DESCRIPTION OF THE ORE DEPOSITS.

Through the region as a whole the ore-bearing veins cut the trachyte, proving them to be younger, while the Bassick volcanic neck above described, which is considered probably later than the trachyte, contains a pipe of ore that was formed probably soon after the volcanic explosion that produced the agglomerate, since a subsequent dike of limburgite which traverses the agglomerate is later than the period of mineralization.

Most of the veins of the region are fissure veins, many of them occurring along faults or fault zones. Friction breccias containing bowlders of volcanic and pre-Cambrian rocks rounded by attrition are found along some of these faults. In one of these fissure veins, the Humboldt, the ore is described as principally tetrahedrite, with a gangue of barite and subordinate calcite, striking S. 50° W. and dipping 60° to 72° SW.

The ore shoot in the Bassick volcanic agglomerate neck has the form of a pipe, with elliptical horizontal cross section, whose dimensions vary from 20 to 30 feet on the shorter diameter to nearly 100 feet on the longer. It extends downward vertically nearly 800 feet, without walls or distinct boundaries between it and the barren agglomerate, the ore being richer in the center of the pipe and becoming scarcer and poorer toward the periphery. The metallic minerals include sphalerite, galena, jamesonite, tetrahedrite, smithsonite, calamine, free gold, chalcopyrite, and telluride minerals, probably petzite. Some quartz is present, but no barite or calcite. The mineral has been deposited in successive scales or shells around bowlders in the agglomerate. Usually three, in some places four, distinct layers can be distinguished. The first layer consists of sulphides of zinc, antimony, and lead, carrying about 60 ounces of silver and 1 to 3 ounces of gold to the ton. The second layer is lighter in color and contains more lead, silver, and gold, running as high as 100 ounces of gold and 150 to 200 ounces of silver. The third layer is made up of zinc blende, containing considerable iron and some copper. This constitutes the principal source of value in the ore, containing 60 to 120 ounces of silver and

[a] Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 272.

15 to 50 ounces of gold to the ton. This is in many places the outermost coating, but locally there is a fourth layer formed of chalcopyrite which carries up to 50 or 100 ounces of gold and silver. Outside of all there occurs in places a thin sprinkling of pyrite.

The ore body at the Bull-Domingo mine, which is several miles distant from the Bassick mine, occurs in Archean granite and gneiss. The ore consists of concentric shells of galena and spar around bowlders of country rock. These bowlders consist of gneiss and granite, with no volcanic rocks. The minerals which have been deposited around them embrace galena, zinc blende, and pyrite, with calcite, dolomite, ankerite or siderite, and quartz (usually in the form of chalcedony). The first band around the bowlder is either galena alone or galena and zinc blende. Around this band there is in some places a coating of galena, which may be associated with pyrite. Outside of the metallic bands come the various spars, which invariably form the interior linings of vugs. The order of deposition of these is (1) white dolomite, (2) ankerite or siderite, (3) calcite, (4) chalcedony. The galena contains silver. There is no sharp line between pay ore and the barren bowlder mass. The deposit has been frequently supposed to represent an old volcanic chimney like the Bassick, but Emmons believed that the bowlders represented a friction breccia or conglomerate somewhat rounded by attrition and further rounded by percolating solutions, and that the ore channel or chimney was formed primarily by the complicated intersection of a number of fracture planes.

Near Silver Cliff is the Geyser mine, the main shaft of which is sunk through rhyolite and rhyolite tuff down to the older granite beneath and had reached a depth of 2,100 feet at the time of the report. The main vein was cut at a depth of 1,800 feet, and though very thin was remarkably productive. The ore minerals are galena, blende, chalcopyrite, argentite, tetrahedrite, and ruby silver. The telluride of silver (hessite) and free gold are reported. The earthy minerals include barite, calcite, and quartz, generally chalcedonic.

Fluorite and barite, with chloride of silver, are said to occur in the Silver Bar mine.

MINE WATERS.

Interesting analyses of the water in the Geyser mine were made. In the upper part of the mine considerable water was encountered at depths of 340 to 420 feet. This was undoubtedly surface water. It decreased in amount downward, and practically ceased at 1,000 feet. On the 1,450-foot level abundant subterranean waters slightly charged with gas were encountered, and from this level to the bottom, at 2,100 feet, there is a constant flow of highly carbonated water, apparently ascending along fissures parallel with the ore-bearing fissure. On access to the air these waters deposit sinter, which consists mainly of carbonates of iron, lime, and magnesia. A comparison of the analyses of the vadose waters and of the deep waters shows that, though the latter contain about twenty times as much dissolved matter as the former, the relative proportions of the principal constituents are not radically different. Emmons considers that this circumstance allows the assumption that these dissolved materials have been derived from a similar source, which in the case of the surface waters must have been the material of the rocks through which they had passed. The greatest discrepancy in the analyses is the tenfold greater proportion of silica in the vadose waters than in the deep waters. The alkalies have the same relative proportion in each class. In the vadose waters iron and manganese are of nearly equal amounts, while in the deep waters iron is in one hundred fold greater relative amount. In the deep waters chlorine and sulphuric acid are in about equal proportions, and carbonic acid is greatly in excess of both combined. In the vadose waters, while carbonic acid is still in excess, sulphuric acid is in relatively greater and chlorine in relatively smaller proportion than in the deep waters. Emmons concludes that the deep waters have obtained their constituents, at least in great part, from the surrounding rocks, while the great excess of carbonic acid in these waters, combined with the presence of a considerable amount of fluorine, boric acid, and chlorine, points to a source where chemical decomposition is actively going on. This source might be supposed to be a body of still uncooled igneous rock which surface waters had reached and from which they were sent back toward the surface again along the present lines of fissuring.

Although they contain most of the metals that are found in the vein deposit of the Geyser mine, it is not easy to conceive how the metallic sulphides of that deposit could have been derived from waters of such a chemical composition as these have, and it seems more reasonable to assume that these vein materials were formed by earlier waters of somewhat different composition, that carried more barium and silica and were characterized by sulphureted hydrogen rather than by carbonic acid.[a]

RESEMBLANCE TO CRIPPLE CREEK.

Emmons points out the various points of resemblance between this region and the Cripple Creek district. In each the main ore deposit has taken place around a central volcanic focus where comparatively recent volcanics have broken through pre-Cambrian rocks, and in each the principal deposition has taken place along a system of fracture planes, more abundant in the eruptions than in the older rocks. Mineralogically, the contrast is greater. In Cripple Creek the important metalliferous gold is mainly in the form of telluride, and the prominent gangue mineral fluorite. In the district under consideration gold telluride occurs in certain portions and fluorite is sparingly found, but the greater part of the minerals are the silver minerals, associated with sulphides of lead, zinc, and iron, and with barite as the prominent gangue.

ORIGIN OF ORES.

Emmons calls attention to the peculiar features of the Bassick ore body from the point of view of its origin—first, that its form is that of a long, slender, nearly vertical chimney in an agglomerate which appears to fill an old volcanic neck; second, that in the composition of the ore the earthy minerals, such as barite, calcite, and quartz, which are common in the other ore deposits of the region, do not form an essential part of the vein material, but occur, if at all, in subordinate amount and are apparently later than the deposition of the other minerals. He adds that the conclusion from these facts seems unavoidable that the ore deposition was here a phase of the volcanic eruption after all explosive action had ceased. The metallic minerals were evidently deposited as sulphides, and to a limited extent as tellurides. It seems therefore reasonable to assume that they were formed during the closing phases of fumarolic activity when H_2S and SO_2 were the prevailing gases, if, indeed, it was in a gaseous form that they were introduced. It is not impossible, however, that the aqueous vapors carrying the sulphides and tellurides were under so great a pressure that they were condensed into liquid form.[b]

In the case of the Bull-Domingo mine the conclusion reached is that the deposition of the ore seems to have been distinctly accomplished by aqueous solutions.[c]

In treating of the whole district, embracing the different types of ore deposits mentioned, under the heading "Source of the metallic minerals," Emmons remarks that it seems probable that not only the recent eruptives but the older granites through which the ascending solutions must have passed contain enough of the precious metals, and presumably, also, of the other vein materials, to furnish material for the formation of the existing ore bodies. The analysis of the vadose waters in the Geyser mine demonstrated the capability possessed by cold surface waters of taking up such materials in their passage through surface rocks. The subterranean waters that were circulating here at the time of the ore formation must have been more energetic solvents, being heated by contact with the cooling masses of igneous rock and probably deriving a certain amount of active and energetic mineralizing agents, such as fluorine, chlorine, etc., from these igneous masses at the time of contact. Emmons concludes that it is fair to assume that the vein materials in this region were originally derived from both recent and ancient eruptive rocks.[d]

As the writers understand the foregoing conclusions, Emmons considers the ores and the vein materials to have been leached out of the rocks of the region, both Tertiary and pre-Cambrian, by circulating waters which, descending from the surface, became heated by proximity to the volcanic rocks and ascended toward the surface, depositing ore on their way. He regards it as probable that mineralizing agents more active than water, such as fluorine, chlorine, etc.,

[a] Emmons, S. F., Seventeenth Ann. Rept. U. S Geol. Survey, pt. 2, 1896, p. 465. [b] Idem, p. 437. [c] Idem, p. 446. [d] Idem, p. 472.

which were contained in the ore-depositing solutions, may have been derived directly from the volcanic accumulations, as in the Bassick mine, where such gaseous volcanic emanations were the chief mineralizing agents.

CRIPPLE CREEK MINING DISTRICT.

The ore deposits of Cripple Creek have been described by Cross and Penrose,[a] and later by Lindgren and Ransome.[b]

GENERAL GEOLOGY.

The prevailing rocks in the region around Cripple Creek are pre-Cambrian granites and schists, which have been broken through at Cripple Creek by Tertiary volcanic eruptions. The main products of the Cripple Creek volcano now occupy a rudely elliptical area about 5 miles long in a northeast-southwest direction and about 3 miles wide.

The lavas which were successively erupted from the Cripple Creek volcano are phonolitic and comprise phonolite, latite-phonolite, alkali syenite, trachydolerite, vogesite, and monchiquite. All these volcanic rocks have unquestionably been derived from the same magma, the average composition of which is close to that of phonolite. The age of the eruptions is considered to be Miocene, since phonolite is found cutting Miocene or at least post-Oligocene rhyolite. The greater portion of the rocks which now remain are intrusive. The first rock was latite-phonolite, with syenite, followed by phonolite and the basaltic dike rocks which have been designated as trachydolerite, vogesite, and monchiquite. The dikes of these various rocks are grouped around the volcanic neck with a radial arrangement.

This region is considered an excellent example of a petrographic province, the sequence beginning with a rock of intermediate composition, passing to one extreme, the phonolites, and thence finally to the other extreme, the basic dike rocks.

ORE DEPOSITS.

The veins are in fissures which have a genetic connection with the local volcanic center, occurring mainly within and near the volcanic neck, with a rough radial arrangement. They are as a rule nearly vertical.

The fissures have little or no displacement and were formed under light or moderate load, and their evident relation to the volcanic neck suggests that they were formed by the settling of the material in this neck after the cessation of eruption. The chief mineralogical feature of the veins is the occurrence of ore combined with tellurium, mainly as calaverite, partly as more argentiferous sylvanite, and probably to a minor extent as other gold, silver, and lead tellurides. The metallic associates of the tellurides comprise pyrite, blende, and galena in varying proportions, with some stibnite and tetrahedrite and rare chalcopyrite. The chief gangue materials are quartz, fluorite, and dolomite, with celestite, orthoclase, roscoelite, chalcedony, opal, rhodochrosite, calcite, and barite. In some of the veins which have a quartz gangue, galena, or blende and galena, are the prominent metallic minerals. There is no sharp line between these veins and the telluride veins. Silver is frequently found in varying amounts. The wall rocks have been altered principally to sericite and adularia, involving chemically a loss of soda and a gain of potash. As a rule, the alteration is remarkably slight.

ORIGIN OF ORES.

The fluorite in the veins and in the wall rocks is regarded as having been given off by the phonolitic magmas on consolidation. Likewise, the carbonic acid shown by the presence of carbonates was probably an emanation of the crystallizing magma, as well as the sulphur content in the sulphides. The mineralizing solutions contained very little iron, that in the pyrite having probably been derived from the country rock. The lime and magnesia in the solutions

[a] Cross, Whitman, and Penrose, R. A. F., jr., Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 13-209.
[b] Lindgren, Waldemar, and Ransome, F. L., Prof. Paper U. S. Geol. Survey No. 54, 1906.

had probably a similar origin. It is considered that the gold, tellurium, and perhaps the rarer sulphides, including blende, galena, stibnite, tetrahedrite, and molybdenite, were given off from the magma. The ores are regarded as having been formed at depths varying from a few hundred feet to 3,000 feet. The ore deposition followed closely the intrusion of the basic dikes and is believed to have taken place at the close of the Tertiary period.

REMARKS ON THE CRIPPLE CREEK AND ROSITA DISTRICTS.

FEATURES COMMON TO THE TWO DISTRICTS.

The two districts which have just been summarized have much in common. In both places there has been a single volcanic center, situated in an area of pre-Cambrian gneisses and granites and furnishing a succession of various lavas, tuffs, and breccias, with basic dikes as the last phase of extrusion. The lavas emitted by each volcano, though differing considerably in detail, were chemically and mineralogically related to one another. Those from the Cripple Creek volcano were marked by the large proportion of alkalies, and have been classed all together as products of a phonolitic magma. The lavas of the Rosita volcano also contain an unusual proportion of alkalies, especially in certain members, such as the trachyte, and in the mica dacite, a rock which is intermediate between rhyolite, trachyte, and dacite.[a]

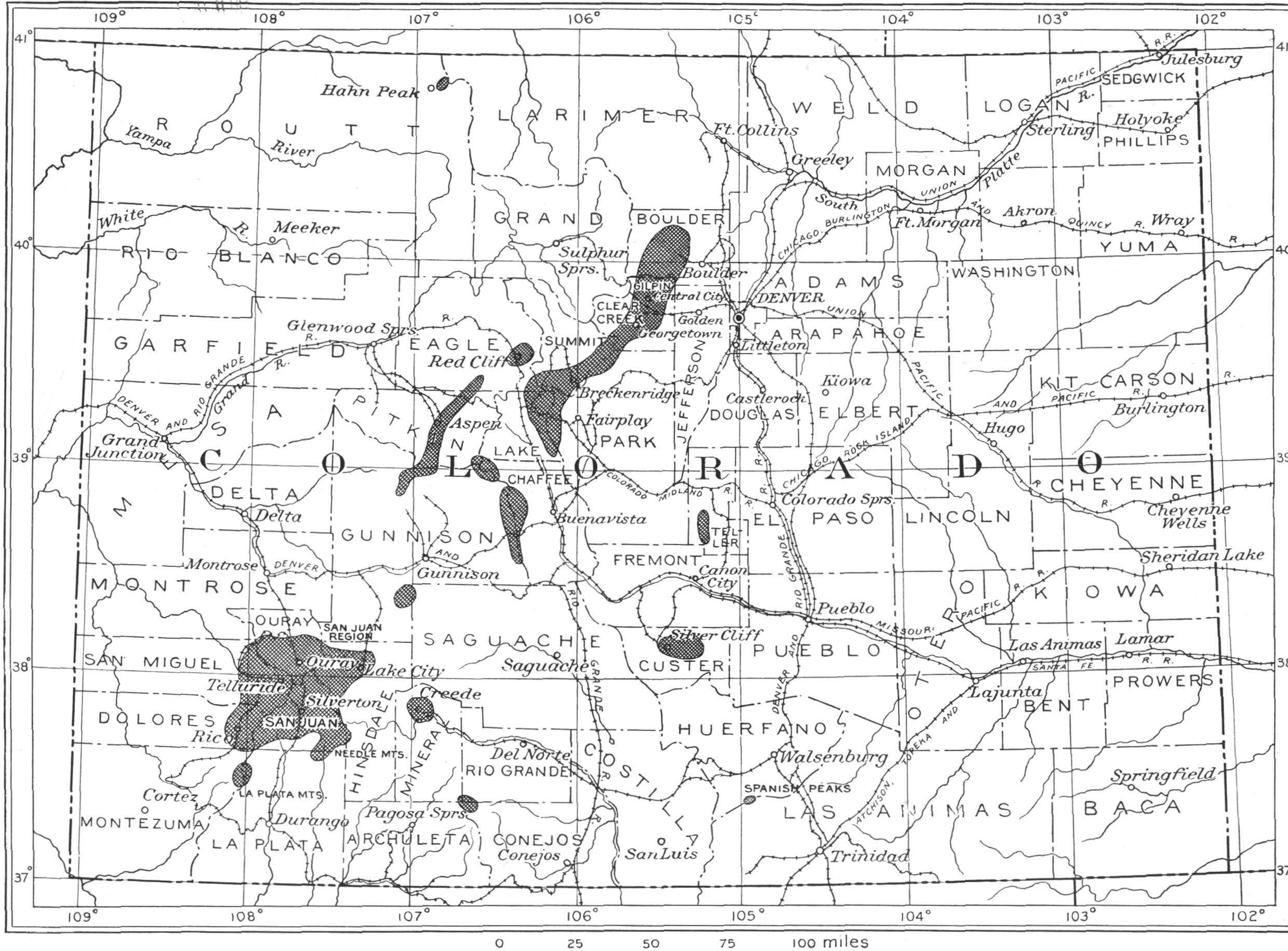
AGE OF ERUPTION AND MINERALIZATION.

Fossil leaves in rhyolitic material at Rosita show that the most plausible date of this rhyolitic eruption was early Eocene, and these rhyolites occur near the center of the series of eruptions. Cross regards the Rosita Hills and the Cripple Creek volcano as small outlying vents connected with much larger eruptions in the San Juan and South Park region, which were in part also of Eocene age, though probably continuing into the Miocene.[b] In an earlier publication[c] the volcanic phenomena of the region including Cripple Creek are described as Eocene, possibly continuing into the Miocene. This determination is based primarily on evidence afforded by fossil plants and insects in a small ancient lake basin at Florissant, which had been determined to be Oligocene. These lake beds are made up chiefly of volcanic ash and are overlain by volcanic breccia and by the remnants of rhyolite flows. In High Park, 5 miles from Cripple Creek, identical rhyolite flows are overlain by a local lake deposit (inferred, from its position above the Florissant lake beds, to be Miocene), which is older than a large intrusive mass of phonolite. In the Cripple Creek district there are certain roughly bedded arkoses or grits which Cross has correlated with the High Park probably Miocene lake deposits, since both are considered to be older than the phonolite. According to this, the age of the Cripple Creek volcano is Miocene and probably late Miocene.[d]

Later, however, L. C. Graton[e] showed that at Cripple Creek the rhyolite is intrusive into the grits and so is younger than them, instead of being older, as Cross believed. This destroys the correlation of the grits with the High Park lake beds, and with it the foundation for the specific determination of the age of the Cripple Creek volcano. Lindgren and Ransome[f] discuss the age of these grits and note the possibility that they are the remnants of the Fountain formation, which is of Carboniferous age, but agree with Cross's suggestion that it seems more likely that they are formed of detritus blown out of the Cripple Creek volcano at an early stage of the volcanic activity. If this is true, since in the Cripple Creek district both grits and rhyolite are intruded by the phonolite, it follows that the Miocene, or at least post-Oligocene, rhyolite was erupted within the period during which the Cripple Creek volcano was active.

Similar residual bodies of grits, apparently waterlaid but of uncertain age and origin, occur in the Georgetown quadrangle. It is possible that these are to be correlated with those at Cripple Creek. Since the locality where they occur is about 70 miles from Cripple Creek, the materials undoubtedly do not represent the results of the explosion of the Cripple Creek

[a] Cross, Whitman, Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 326.
[b] Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 273.
[c] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2 1895, p. 18.
[d] Prof. Paper U. S. Geol. Survey No. 54, 1906, pp. 2, 23.
[e] Idem, p. 100.
[f] Idem, p. 22.



MAP SHOWING APPROXIMATE DISTRIBUTION OF PRINCIPAL SILVER, LEAD, AND GOLD REGIONS IN COLORADO.

volcano, and are probably not of volcanic origin. If the possible correlation with the sandstones of the Cripple Creek district, as above suggested, is true, the latter may, as mentioned by Lindgren and Ransome, correspond with the Fountain formation or may represent the sediments of a distinct period. If this is the case, the fact that the phonolite intrudes the rhyolite shows only that the former is younger than the latter. If the rhyolite is Miocene or post-Oligocene, the Cripple Creek volcano is of similar or later age and may be considerably younger.

It will be seen that the data, principally founded on the paleobotanists' determinations of fossil leaves which assign an early Eocene age to the Rosita volcano and inferentially and by correlation a Miocene or later age to the Cripple Creek volcano, are at variance with the evidence derived from the study of volcanic action and the comparison of magmas and ore deposition, which led Cross to infer a similar age for the two centers.[a] Of the two bases of age determinations, the senior writer is inclined to regard the latter, though imperfect, as rather the more reliable and to assume in general a like age for the two volcanoes. He questions, however, whether these two volcanoes are to be correlated with the extensive volcanic eruptions which have been described in the United States Geological Survey folios covering the San Juan, as Cross has supposed.[a] According to this supposed correlation, the San Juan ore deposits, which followed porphyry intrusions of later age than the surface volcanics, would be younger than the ore deposits of Rosita and Cripple Creek, which were formed in the closing stages of eruption of surface volcanoes. The writers have no convincing evidence to offer on this question, the chief consideration to be presented involving the relative ages of the different magmas and their associated veins within the Georgetown quadrangle. In general, however, they are inclined to frame a hypothesis that the reverse of the age relations above mentioned for the San Juan and the Rosita and Cripple Creek ores is true, and that the alkaline volcanics represented by Rosita and Cripple Creek were erupted subsequent to the monzonitic porphyry intrusions. As the monzonitic intrusions have been roughly considered (see p. 121) to represent chiefly the earlier Tertiary period, say the Eocene and Miocene, the latest date (late Miocene) set to the age of the Cripple Creek volcano in the above discussion accords more with the writers' conception than the earlier dates which have been assigned, and it appears that there is no evidence that the eruption did not last into the Pliocene. That the vents which were formed in the closing stages of eruption, however, are not of recent age is shown by the extensive erosion which has formed surface placers and by the considerable depth of oxidation. On the whole the following characterization by Lindgren and Ransome as to the period of ore deposition conforms with the writers' conception: "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."[b]

RÉSUMÉ OF THE PRINCIPAL ORE DEPOSITION IN COLORADO.

As a result of the above investigation we have found that most of the important gold, silver, and lead deposits in Colorado (see Pl. XVIII) belong to two chief groups—those whose formation followed and appears consequent on the intrusion of porphyritic igneous rocks which are of varied character but in general represent a monzonitic magma, and which were injected in the form of dikes, stocks, laccoliths, and sheets; and those which followed the outburst of isolated volcanic centers whose varied magmas had an alkaline or phonolitic tendency. Both of the consequent periods of ore deposition are of Tertiary age. Practically all the data available for fixing the age determinations more closely are of a vague and unsatisfactory character. It seems probable, however, that the monzonitic intrusion began early in post-Laramie time, though it probably continued for a very long period throughout the earlier portion of the Tertiary and very likely lasted through the Eocene and Miocene epochs. In later Tertiary time the intrusion of these monzonitic porphyries and related igneous rocks derived from the same magma was probably not nearly so active, though there is some evidence of igneous action

[a] Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 273.

[b] Prof. Paper U. S. Geol. Survey No. 54, 1906, pp. 226-227.

connected with the monzonitic centers and lasting practically throughout the Tertiary. It also seems probable that the volcanic eruptions of Cripple Creek and Rosita did not begin so early as did the intrusions of monzonitic porphyry and that they may have continued later than the end of the main period of monzonitic intrusion. There is no evidence, however, that the periods covered by the eruption of the two magmas did not overlap; though from what rather unsatisfactory evidence there is it appears a better hypothesis to consider that the Cripple Creek and Rosita volcanic eruptions are later than the monzonitic eruptions and to conceive of the latter as covering a period lasting from the earliest to the middle or later Tertiary and of the former as enduring from the middle to the later Tertiary.

RELATION OF DIKES TO VEINS IN THE GEORGETOWN QUADRANGLE.

DEFINITION OF THE TWO CHIEF MINERAL DISTRICTS.

As already stated, there are evidently within the Georgetown quadrangle certain distinct mineral districts. The roughest division makes of these two separate districts, one characterized by silver-lead ores containing little or no gold, and the other characterized by ores which may or may not contain silver but which in general contain gold as the most profitable constituent. Mineralogically the ores of the first group are typical galena-blende ores; those of the second group are pyritic ores, usually cupriferous. The territory covered by veins containing auriferous pyritic ores embraces the region southwest of and tributary to Idaho Springs. That containing argentiferous galena-blende veins includes the territory around Georgetown, with the exception of a narrow northwestward-trending gold belt which runs through the silver district and includes the Central Colorado, Centennial, Griffith, and Anglo-Saxon veins. In the Empire district are pyritic gold-bearing ores, bordered on the south and east by argentiferous veins.

GENERAL RELATIONS OF PORPHYRY DIKES TO VEINS.

The ores of both these groups lie throughout in similar pre-Cambrian gneissic and massive crystalline rocks, and they have the same general relations to the accompanying porphyry dikes. As a rule, they are later than these dikes, having formed since the dikes cooled, and certainly in some places after the porphyries were decomposed by percolating waters. Many of them follow the dikes, being formed along strike faults which have originated subsequent to the dikes' consolidation; others occur far from any porphyry body. In fact, the circumstance that many of the veins follow along the walls of dikes or lie within the dikes depends simply on the fact that these dikes offer lines of weakness in the rock fabric and have afforded less resistance than the surrounding rock to later faults and fissures, which have become the sites of ore deposition. While this is true of the detailed relation between dikes and veins, there is a larger relation, already noted, in that the belt of porphyry dikes coincides with the belt of mineral veins, indicating a genetic connection between the two.

It was at first regarded as possible that this association was due to both having been localized in the same zone, because the presence of preexisting planes of weakness gave rise to repeated fissuring and faulting which afforded access to molten rock and to circulating waters alike, and that therefore the dikes and the veins had no necessary interconnection; yet the fact that the veins were invariably subsequent to the dikes led finally to the idea that the mineralization was directly dependent on and consequent to the porphyritic intrusion. There was for a long time, however, no evidence that there was not a fairly well-defined interval between the period of dike intrusion and that of vein formation, so that this idea remained more or less a plain hypothesis.

More definite evidence was afterwards procured by a study of the Stanley mine, where it was proved that along a single fault fissure two dikes had been successively injected and that an important and rich vein had formed in the interval between the two intrusions. The deposition of this vein, one of the typical veins of the Idaho Springs region, was thus fixed as having occurred in a comparatively restricted time and having followed closely and vigorously on the intrusion of the earlier dike, which was of a different type from the later one. A direct genetic connection between the first dike and the vein seemed certain, and a consideration of the mineralization as directly consequent on the intrusion became unavoidable. The same conclusion, moreover, was thus extended to other veins of the district.

RELATION OF THE SILVER-BEARING AND THE PREDOMINANTLY GOLD-BEARING VEINS TO DIFFERENT GROUPS OF DIKES.

After the intimate relation between the igneous intrusion and the vein formation in the area of the Georgetown quadrangle had been determined, and the existence of two principal classes of veins—the argentiferous galena-blende veins and the auriferous pyritic veins—had been recognized, as well as the fact that the porphyry dikes were of different kinds of rock, the question as to a possible relation between different kinds of veins and different kinds of dikes was looked into. A comparison of the two classes of veins as mapped by the writers with the different varieties of dikes as determined and mapped by Mr. Ball (all the work having been done before the possibility of any relation was considered) showed unmistakably broad relations.

The hiatus in the vein zone between the Georgetown and Idaho Springs districts, occupied by the upper portions of Saxon and Griffith mountains, is marked by a corresponding hiatus in the dike zone. Moreover, the two districts, marked by ores mineralogically and chemically different, also contain totally distinct groups of dike rocks. In each district there is a considable variety of rock types, but the types of one district do not occur in the other. Mr. Ball has determined the dikes in the Georgetown district to be alaskite porphyry, granite porphyry, quartz monzonite porphyry, and dacite, the first two being most closely connected with the ore deposition, which, however, was later than the intrusion of all four. The dikes in the Idaho Springs region, in the northeast corner of the quadrangle, have been determined to be bostonite, alaskitic quartz monzonite, biotite latite, and alkali syenite porphyry, the first two being the most abundant.

In the Silver Plume area no bostonite, alaskitic quartz monzonite, biotite latite, or soda syenite were found, and in the Idaho Springs area no alaskite porphyry, granite porphyry, quartz monzonite porphyry, or dacite. Therefore the two mineral districts appear to represent distinct petrographic provinces. The bostonites of the Idaho Springs area have been traced southwestward at least as far as the top of Saxon Mountain, while the alaskite porphyry of the Georgetown area has been found as far northeast as the slopes of Saxon Mountain near Georgetown. Thus the boundary between the two provinces runs north and south, on the east side of Clear Creek valley.

The Empire district shows predominant bostonite, with alaskite porphyry, quartz monzonite porphyry, alaskitic quartz monzonite porphyry, and andesite. These dikes represent a mingling of the igneous materials of the two provinces. There is also on the borders of the Empire district a mingling of the argentiferous galena-blende veins and the auriferous pyritic veins, the former being cut by the latter, instead of the two groups being separated by a barren area as in the case of the two principal and larger districts above mentioned.

RELATIVE AGE OF DIFFERENT DIKE SETS.

No relations have been observed that determine beyond question the relative age of the different dike sets. The two come together only in the Empire district, and here no completely convincing relations were observed. Although in several places dikes belonging to the different provinces have been successively injected along the same fissure, the age relations were not definitely determinable. In this district, however, the gold-bearing veins characteristic of the Idaho Springs province have been injected into fissures which have followed and reopened the silver-lead veins characteristic of the Georgetown province, showing that the pyritiferous or gold-bearing veins are distinctly the younger of the two classes, a relation which is also shown in several other clear-cut cases. Therefore, it is probable that the dike sets have the same relative age as their associated vein sets, and that the Idaho Springs dikes were in general intruded subsequent to those of the Georgetown region.

SUMMARY.

The two distinct petrographic districts exhibited by the Tertiary dike rocks within the area of the Georgetown quadrangle and covering the region adjacent to Idaho Springs and that near Georgetown are referable to two types of magmas, which have been described as having been associated with at least the greater portion of the deposition of ores containing silver, gold, and lead in the State of Colorado. The Georgetown dikes are referable to the monzonitic magma, with which are definitely known to be associated the ores occurring in many portions of the great northeast-southwest mineral belt which runs across the State and includes the Leadville-Aspen-Gunnison group and the group of the San Juan deposits; while the rocks of the Idaho Springs district are referable to the alkaline magma best known and described where it has been extruded at the volcanic centers of Rosita and Cripple Creek.

The writers' idea of the relative age of these two groups in Colorado, as already stated, is that the eruption of the alkaline magma was in general later than the intrusion of the monzonitic magma. This idea rests largely, though not entirely, on the probable age relations of the products of these magmas in the area of the Georgetown quadrangle.

It likewise follows that the ores attending the eruption of these separate magmas in the area of the Georgetown quadrangle belong, respectively, to the two great divisions of ores mentioned, which we may conveniently designate, selecting a characteristic example from each division to furnish a name, as the Aspen ore group and the Cripple Creek ore group. The Georgetown silver ores, according to this classification, represent the former group and the Idaho Springs gold ores or gold-silver ores the latter.

DESCRIPTION AND CORRELATION OF THE DIKES IN THE GEORGETOWN SILVER REGION.

FEATURES OF THE PETROGRAPHY.

The alaskite porphyry of the Georgetown silver region has as mineral constituents mainly quartz and orthoclase, with a little albite-oligoclase and sparse phenocrysts of biotite and original muscovite. The granite porphyry contains orthoclase, biotite, and quartz, with a little oligoclase-albite, together with accessory zircon and magnetite. The quartz monzonite porphyry, which occurs in greater bulk than any of the other dike-rock types in this district, contains orthoclase, oligoclase-andesine, quartz, biotite, hornblende, and a little augite. The dacite contains chiefly the soda-lime feldspars, quartz, green hornblende, and biotite, with accessory titaniferous magnetite and apatite.

It is evident that these four different rock types are closely related and are evidently variations of a granitic or monzonitic magma.

CORRELATION WITH INTRUSIVES OF OTHER COLORADO DISTRICTS.

The alaskite porphyry has been compared by Mr. Ball to the white porphyry at Leadville and found to be practically identical, and the quartz monzonite porphyry of Georgetown was also found to be practically the same as the Lincoln porphyry of Leadville, of which the gray porphyry is a variety. The presence of muscovite phenocrysts in the porphyries is very remarkable. Muscovite is not a volcanic mineral, though it occurs in isolated quartz porphyries.[a] Muscovite was found by Cross in the white porphyry of Leadville as an original constituent, forming dark hexagonal phenocrysts at first supposed to be biotite, but proved by optical and chemical tests to be muscovite.[b] Similar original muscovite was found by Mr. Ball in the alaskite porphyry of Georgetown, thus confirming his correlation of the two rocks. In the Tenmile district,[c] also, the Lincoln porphyry occurs, preceding, as at Leadville, the ore deposition; and at Aspen porphyry similar to the white porphyry at Leadville bears the same relation to the ore deposits.[d] In this porphyry at Aspen, the occurrence of original muscovite phenocrysts[e]

[a] Rosenbusch, H., and Iddings, J. P., Microscopic Physiography of the Rock-Making Minerals, 2d ed., p. 264.
[b] Mon. U. S. Geol. Survey, vol. 12, 1886, p. 77.
[c] Tenmile folio, No. 48, U. S. Geol. Survey, 1898.
[d] Mon. U. S. Geol. Survey, vol. 31, 1898, p. 48.
[e] Idem, p. 50.

resembling biotite in the hand specimen has been described by Spurr. The dacite of Georgetown also is of very similar composition to the diorite porphyry of Aspen, which is similar to the Elk Mountains injections. It also corresponds in composition to one of the porphyries (Quail porphyry) at Tenmile.[a]

Without further comparison, it is plain that these Georgetown dikes belong to well-defined and characteristic types derived from the early Tertiary monzonitic magma which stands in such vital relations to the ore deposits of this great mineral belt.

RELATIVE AGES OF THE DIKES.

In the Baltimore tunnel near Georgetown a dike of alaskite porphyry cuts one of quartz monzonite porphyry, and a surface exposure in the same general region shows granite porphyry also cutting quartz monzonite porphyry. These are the only observed relations, for in general the dikes do not intersect. The more monzonitic magma represented by the quartz monzonite porphyry was evidently injected earlier than the more siliceous magma represented by the granite porphyry and the alaskite porphyry. All, however, were earlier than the ore deposition, since subsequent veins have formed along dikes belonging to each of these types.

DESCRIPTION AND CORRELATION OF THE DIKES IN THE IDAHO SPRINGS GOLD-BEARING REGION.

FEATURES OF THE PETROGRAPHY.

The alkali syenite porphyry, or pulaskite porphyry, which occurs near Idaho Springs, is in many places a very fresh rock, with a groundmass made up of anorthoclase with some orthoclase and a little quartz. The phenocrysts consist of ægirine-augite, garnet (melanite), and anorthoclase, with titanite, magnetite, and apatite as abundant accessories. Here and there are small crystals of zircon and biotite. Fluorite occurs in irregular masses, probably belonging to the pneumatolytic period of consolidation and later than the bulk of the rock. Small areas of analcite having similar relations occur.

The bostonite porphyry is a very abundant type, and is almost invariably more or less altered. It is characterized by sodium-rich feldspars and is poor in the ferromagnesian minerals. The groundmass, which has a trachytic texture, is composed of anorthoclase laths having a flow arrangement, together with some orthoclase, quartz, and magnetite, with predominant phenocrysts of orthoclase with some anorthoclase and oligoclase. There are pseudomorphs after pyroxene, which has never been found fresh. Accessories include titaniferous magnetite, apatite, and a little zircon. Fluorite is very common in the bostonite and much of it is certainly subsequent to the consolidation of the rock, while some of it may very well be an original constituent belonging to the latest period of consolidation.

The biotite latite is usually a remarkably fresh dike rock, which occurs much less abundantly than the bostonite, but more so than the alkali syenite porphyry. The dikes of this rock occur in a long chain or string, running northeast and southwest for several miles along the valley of Chicago and West Chicago creeks and extending to Clear Creek (in the Stanley mine). The groundmass of the rock is ordinarily dense and glassy, although in many places where the crystallization is better developed there are numerous lath-shaped feldspars determined in part as labradorite and orthoclase, which have a flow structure and locally resemble on a finer scale the trachytic structure of the bostonite groundmass. Small biotite crystals are very sparsely disseminated in the groundmass. The phenocrysts consist of abundant orthoclase, biotite, and plagioclase, with some brown hornblende. The accessory minerals are magnetite, apatite, and zircon.

The alaskitic quartz monzonite porphyry is a monzonite porphyry poor or lacking in biotite, amphibole, and pyroxene, and containing quartz. The dikes which in this region have been thus designated are white or light-gray rocks, having a holocrystalline groundmass consisting of orthoclase, quartz, and oligoclase. The phenocrysts consist of orthoclase and

[a] Tenmile folio, No. 48, U. S. Geol. Survey, 1898, p. 3.

oligoclase. In one or two specimens of these dike rocks probable crystals of biotite, now entirely altered, were observed. Titanite and apatite are common; magnetite and zircon rare.

Evidently all these described types are closely related rocks, representing allied feldspathic magmas high in alkalies and with unusually low amounts of lime, iron, and manganese.

Quartz is present in all the types in variable amount, being highest in the alaskitic quartz monzonite.

COMPARISON WITH SIMILAR ROCKS IN OTHER COLORADO DISTRICTS.

Mr. Ball has already pointed out the chemical resemblance of the alkali syenite of Idaho Springs to the trachyte of the Rosita volcano (p. 83). There is a still closer resemblance between this Idaho Springs rock and some of the phonolitic rocks of the Cripple Creek volcano. This is shown by the comparison of analyses 1 to 3 in the subjoined table. The analysis given from the Rosita Hills is that of the Pringle andesite, which is closely related to the trachyte of that district and is rather closer to the Idaho Springs rock than is the trachyte. The relation between the Idaho Springs rock and the latite-phonolites of Cripple Creek, illustrated in analyses 1 and 2, is very intimate, and the two represent practically the same class of magma.

The chemical composition of the biotite latite and of the bostonite of the Idaho Springs region, as given in analyses 4 to 7, shows the strong relationship of these rocks to the alkali syenite, the characteristics of the group being the very low amount of iron and magnesium, the subordinate amount of lime, and the relatively large amount of the alkalies. Of all the rock analyses contained in Washington's publication[a] those which correspond most closely to the figures of the Idaho Springs analyses are those of the rocks of the Rosita volcano. This relationship is expressed in the table.

Analyses of Colorado igneous rocks.

	1.	2.	3.	4.	5.	6.	7.
SiO_2	60.30	58.05	63.49	66.44	65.67	67.41	65.41
Al_2O_3	18.12	17.66	18.40	14.98	13.48	16.23	18.78
Fe_2O_3	2.45	3.51	2.44	1.57	1.51	.85	.94
FeO	1.25	1.65	1.09	.43	n. d.	1.14	.72
MgO	.28	1.55	.66	.18	.31	.15	.16
CaO	3.89	4.48	2.30	2.47	2.41	.14	1.58
Na_2O	5.83	5.80	5.70	1.12	1.52	3.95	5.91
K_2O	5.01	4.06	4.62	3.32	2.42	7.19	5.41
H_2O-	.75	.35	1.04	4.60	....	.67	1.38
H_2O+	.77	.87		4.06	12.27	.88	
TiO_2	.55	.91	Trace.	.20	....	.16	....
ZrO_2	.01	.02	....	.01	....	.11	....
CO_2	None.	None.	Trace.	.67	....	.56	....
P_2O_5	.25	.40	Trace.	.11	Trace.	.05	Trace.
SO_3	.06	.04	....	None.	....	None.	....
Cl	....	Trace.	....	Trace?	....	None.	....
S	None.	None.	....	.02	....	Trace.	....
Cr_2O_3	....	None.	....	....	....	....	....
MnO	.12	.13	.16	.13	Trace.	.16	Trace.
BaO	.26	.19	....	.11	.32	Trace.	....
SrO	....	.08	....	Trace?	....	None.	....
Li_2O	....	....	....	None.	....	None.	....
	99.90	99.75	99.90	100.42	100.19	99.65	100.29

1. Alkali syenite porphyry, Idaho Springs.
2. Latite-phonolite, Anaconda mine, Cripple Creek. Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 104.
3. Pringle andesite, Rosita Hills. Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 324.
4. Biotite latite, Chicago Creek, near Idaho Springs. W. T. Schaller, analyst.
5. Pitchstone, Silver Cliff. Cross, Whitman, and Eakins, L. G., Am. Jour. Sci., 3d ser. vol. 44, 1892, p. 101
6. Bostonite, Red Lyon lode, Idaho Springs. W. T. Schaller, analyst.
7. Trachyte, Silver Cliff. Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1896, p. 324.

The characteristic minerals of the Cripple Creek group of phonolites are alkali feldspars, chiefly soda orthoclase, nepheline, sodalite, nosean, analcite, and ægirine-augite. Accessory minerals include apatite, magnetite, and here and there small amounts of blue amphibole, biotite, and zircon. Fluorite and biotite occur as secondary minerals near veins. The description of the

[a] Washington, H. S., Chemical analyses of igneous rocks: Prof. Paper U. S. Geol. Survey No. 14, 1903.

mineral composition of the Idaho Springs alkali syenite shows its phonolitic character. The trachytic rocks of the Rosita volcano, as shown above, correspond closely with the bostonite and biotite latite of Idaho Springs; and the alaskitic quartz monzonite of Idaho Springs is another variant of this feldspathic group.

RELATIVE ABUNDANCE OF DIFFERENT DIKES.

By far the greater proportion of dike rocks in the Idaho Springs district consists of bostonite and alaskitic quartz monzonite, types which are about equally abundant, while the amount of biotite latite and alkali syenite is relatively very small.

RELATIVE AGE OF IDAHO SPRINGS DIKES.

In the Stanley mine bostonite and biotite latite have been successively injected along the same fissure zone, the latite being younger, and between the two periods of dike injection the chief period of vein deposition has intervened. In this case the biotite latite is characteristically much fresher than the bostonite, a distinction which is also common for the whole district. In general, the biotite latite dikes are not so closely associated with mineral veins as the bostonite dikes, and where this is the case the age relations may be the same as in the Stanley.

The alaskitic quartz monzonite, like the bostonite, is characteristically associated with the ore deposits.

The alkali syenite has been found only in two small areas near Idaho Springs, and these areas are not associated with ore deposits. The rock is typically very fresh. Very near or at the contact of these syenite intrusions carbonated springs issue, some of which are hot and others cold.

From the fresh character of the rocks and their lack of connection with ore deposits and association with the only hot springs in the region, it is very likely that the alkali syenite is the youngest of the Tertiary intrusives.

According to these facts, the relatively more abundant bostonite and the alaskitic quartz monzonite are earlier than the ore deposition, while the relatively very subordinate biotite latite and alkali syenite are younger than the other two and are also later than the main period of mineralization.

COMPOUND VEINS.

The relative age of the veins of the two main periods has been discussed, and it has been shown that in a number of localities a vein belonging to the later or Idaho Springs period has filled a fissure which has been opened along a preexisting vein belonging to the earlier or Georgetown period. The result is a compound vein, the joint work of both periods of mineralization, and partaking in its mineralogical and chemical peculiarities of the nature of both. Outside of the specific cases where this has been determined and described, it is not known to how large an extent this addition of one vein to another has taken place. The presence within the Idaho Springs mineral district of a subordinate number of silver-lead veins similar to those near Georgetown, and the fact that in the auriferous veins near Idaho Springs the relative amount of silver and gold is very variable, combined with the abundant evidence that these veins have been repeatedly reopened, suggest that some of these may be composite veins, the net result of the two periods of mineralization, even where this fact has not been determined by local evidence. How far this is the case can hardly be determined, since it is positively known that a variable though usually small amount of lead, silver, and zinc occurs in the purest and most typical auriferous pyritic veins of the later period. Thus the exact nature of the gold-silver veins, as to whether they have originated as composites of the two periods or simply represent argentiferous variations of the ores of the second period, must be usually open to some doubt; while in the case of the auriferous pyrite veins containing little or no silver and lead, and in the case of the argentiferous galena-blende veins containing little or no gold, the simple nature is evident.

GENERAL FEATURES OF THE ORE DEPOSITS.

FEATURES OF THE SILVER-LEAD DEPOSITS.

COMPOSITION OF VEINS.

METALLIC MINERALS.

Occurrence.—The principal metallic minerals of the silver-lead deposits are blende and galena, with locally considerable pyrite, which is in many places more or less cupriferous and grades here and there into chalcopyrite. The blende occurs in two distinct varieties, one being light yellow (resin blende) and the other dark colored (blackjack). The galena and to a less extent the blende are argentiferous, the resin blende more so than the dark-colored variety. The silver content varies in amount from very little up to several hundred ounces per ton. Typically, the ores contain a little gold, the usual quantity being one-tenth of an ounce to the ton, while in places it is practically absent. The main silver values are contained in the minerals polybasite, argentiferous tetrahedrite, argentite, pyrargyrite, and proustite. Stephanite has also been reported, and locally there is considerable native silver. Mercurial tetrahedrite has been determined in the Colorado Central mine.

Changes in the relative proportions of the above metallic minerals bring about the principal variations in the veins from an economic standpoint, so that ores may be high in silver or in lead or both, or may be unfit for mining, in porportion as galena and the rich silver minerals or blende and pyrite predominate.

A quite exceptional occurrence of hematite was observed in the Colorado Central mine, where this mineral occurs in small crystals at a depth 1,050 feet.

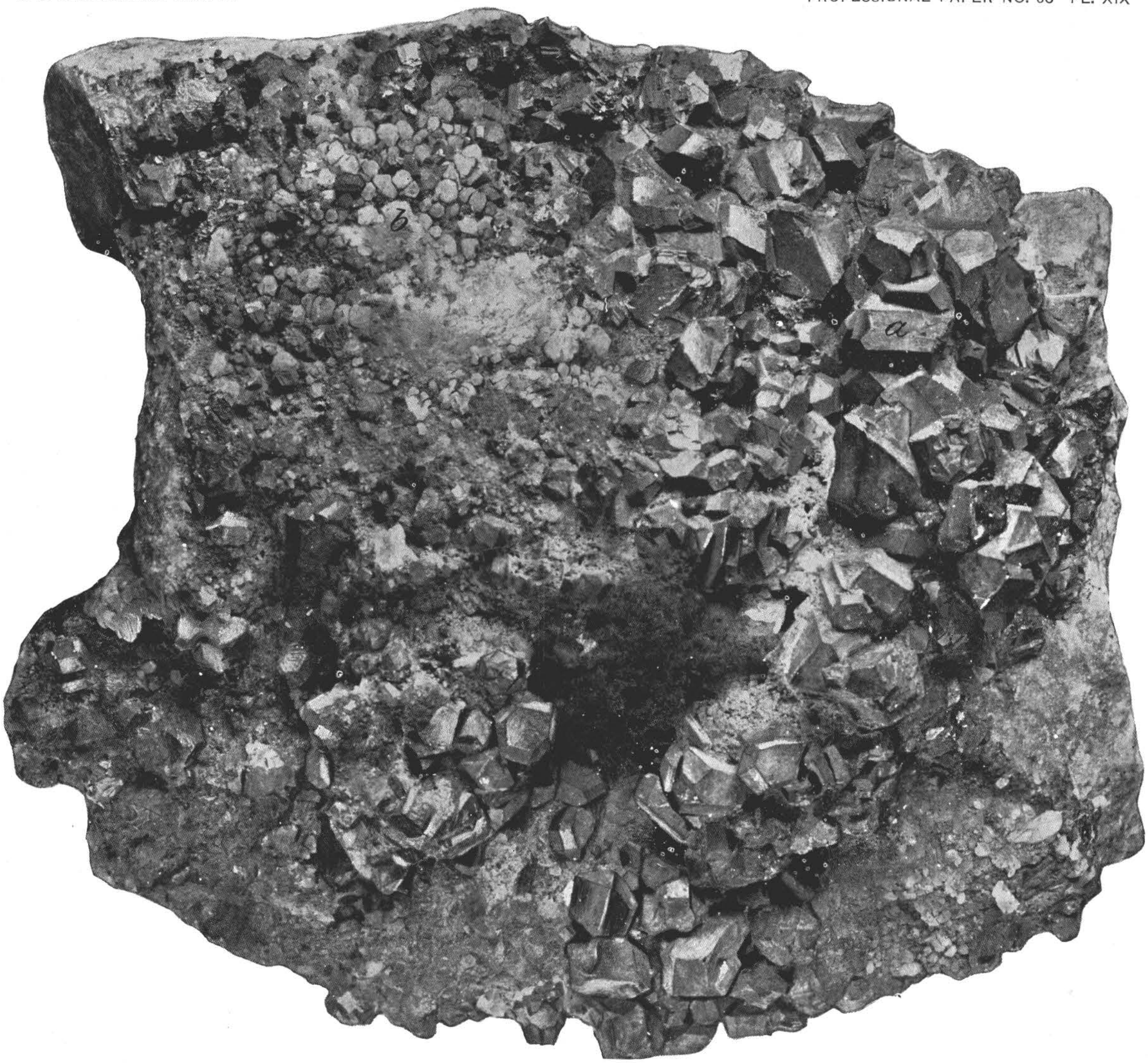
The chief gangue mineral is crystalline quartz, with brown carbonates, barite, calcite, cherty or chalcedonic silica, and local kaolinite. The brown carbonates include those of iron, manganese, magnesia, and lime in varying proportions, forming the species siderite, ankerite, rhodochrosite, magnesite, calcite, dolomite, and mesitite. Fluorite occurs as a rare gangue mineral in the Georgetown district, although at McClellan Mountain, in the Argentine district, where the ores are of the Georgetown type, it is relatively abundant.

Paragenesis.—Galena and blende usually occur intercrystallized in all proportions to form the main mass of the veins. They are in general associated with more or less pyrite, much of which is cupriferous to a varying degree. As a rule the lead and zinc sulphides are contemporaneous, but a number of different veins were noted in which the galena in the massive ore was of later introduction than the blende. It is also frequently found to be the case that the pyrite in this class of ore is later than both the lead and the zinc sulphides.

Besides the galena and blende occurring in the massive portion of the vein and representing the earlier-formed minerals, both these minerals occur at many places in a second generation, being among the last minerals to crystallize and forming free crystals on the walls of geodes.

Pyrite occurs in veins everywhere, but not in great abundance. Its period of formation has lasted from the beginning to the end of mineral deposition. It is frequently found in the quartz that has been the first deposit in the typical fissure vein of the region. As noted above, it is closely associated with galena and blende in the main body of the ore, and also occurs among the latest-formed minerals, lining vugs. These generalizations apply also to the cupriferous varieties and to chalcopyrite.

Polybasite, argentiferous tetrahedrite, pyrargyrite, proustite, argentite, and native silver form the chief silver values in the ores. Polybasite and tetrahedrite are the most common and abundant. All these minerals are closely associated and are among the last minerals which have been deposited. They form on the walls of fractures in the older and baser ore, or cut these older deposits veinwise. They also very commonly form free crystals on the walls of druses.



SPECIMEN FROM WALDORF MINE AT ARGENTINE, SHOWING CRYSTALS OF GALENA WITH SOME BLENDE AND QUARTZ, WHICH HAVE FORMED ON THE WALLS OF VUGS.

a, Galena crystals (with some blende crystals); *b*, quartz crystals. One-fifth natural size.

EARTHY MINERALS.

Quartz, like pyrite, has been deposited during the whole period of mineral formation. It is very characteristic of the veins which have filled fissures (and this includes a large proportion of the veins of the district) that the first lining of the fissure has been of comb quartz, much of it containing a little pyrite. It also occurs as a usually not very abundant gangue, associated with lead, zinc, and iron sulphides of the main period of ore deposition, and is very commonly also among the lastest-formed minerals, occurring as free crystals lining vugs.

The brown carbonates, including those of lime, iron, magnesia, and manganese, occur rather commonly and in some places are relatively abundant. Their period of formation resembles that of quartz, as they have been formed at all stages of the vein deposition. Here and there these carbonates take the place of the quartz, that usually lines the walls of fissure veins, forming, like the quartz, a barren preliminary deposit which was followed by a deposit of the lead and zinc sulphides. In many places they are among the latest or are the very last minerals to crystallize, growing as the final deposit in empty cavities.

Chalcedony or chalcedonic quartz is found locally, though not very common. Its occurrence bears no close relation to that of the crystalline quartz. It characteristically belongs among the later deposits of the vein filling, and very commonly forms the latest crust lining the walls of geodes. In some veins that have been reopened and recemented the jaspery or cherty quartz has cemented broken fragments of white crystalline quartz.

Barite is found in small quantities in most of the veins, though it nowhere becomes even a slightly important gangue. Its place is characteristically among the latest-formed minerals, and it is in many veins the last in the sequence. It has no close relation to the metallic minerals, and its favorite mode of occurrence is in fine crystals lining druses. A vein on Republican Mountain (p. 218) carries a considerable amount of barite with some calcite and chalcedonic quartz, but contains no metallic sulphides whatever.

Fluorite is rare in the Georgetown group of veins, though, as already noted, it is abundant in veins of the Georgetown type on McClellan Mountain, in the Argentine district. Wherever it has been observed it is among the last minerals which have crystallized. In the McClellan Mountain mines it was observed to be partly contemporaneous with and partly later than the crystalline vein quartz.

Calcite has not been noted among the earlier-formed constituents of the veins, and it is in many places the last mineral which has crystallized. It is not especially associated with metallic minerals, but occurs rather commonly as the last deposit on the walls of cavities, where it is usually associated with the brown carbonates.

Kaolinite occurs as a mineral which has been deposited from solution like the other minerals mentioned, and is not a product of decomposition in place. It is not abundant, but is frequently found forming veinlets and occurring on the walls of geodes. It is plainly one of the later-formed minerals.

SUMMARY.

To sum up the foregoing observations, it appears that galena, blende, and pyrite (the pyrite being locally cupriferous and verging to chalcopyrite), with quartz as gangue, constitute the oldest minerals, and that these minerals, especially the first two, comprise the chief vein filling. Typically, as shown in the filling of fissure veins, the deposition of the main metallic filling, consisting of massive galena and blende, was preceded by a deposit of barren comb quartz, much of it containing a little pyrite. Much more rarely the place of this quartz lining was taken by a lining of brown carbonate, probably siderite. The quartz, and in much less quantity the siderite, forms universal gangue minerals which are among the earliest and the latest depositions. Characteristic minerals of the later stages of ore deposition include the rich silver sulphides and sulphantimonides, and rather common but not abundant gangue minerals, including chalcedonic quartz, kaolinite, calcite, and barite. The last three do not seem to have any definite or close relationship to metallic sulphides. Fluorite is rare, and is generally one of the last-formed minerals. Besides the typical or invariably late-formed minerals, all the older minerals, including quartz, siderite, galena, blende, and pyrite, are repeated in many places as later generations and are frequently found in close association with the characteristically last-formed minerals.

ACTION OF PRESENT UNDERGROUND WATERS.

GENERAL DISCUSSION.

The upper surface of the vadose underground waters generally stands close to the topographic surface in this region. At the time of the examination, in the summer season, water was standing in many shafts at a depth of 50 or 60 feet below the surface, even on the mountain tops. A study of the underground workings shows that these waters are most abundant near the surface, occurring in considerable quantity there, but lessening with depth, so that in many mines at depths of 500 to 1,000 feet the rocks become comparatively dry. However, along strong fracture zones the surface waters penetrate much deeper, probably to a depth of several thousand feet. They have been encountered in places in the deepest workings. The relatively dry deeper rocks, moreover, so far as seen, are not entirely without water, a good deal being contained in their interstices.

The effects of ascending surface waters in altering rocks at some distance away from veins have been observed at various depths from the surface. Wherever descending waters which have passed through a few hundred feet of rock (usually alkaline granite and granitic gneiss) are encountered in the numerous tunnel workings these waters are found to have acquired a surprising amount of calcite and iron oxide, which they precipitate when they come into contact with the air in the tunnels. A pipe taken from the Colorado Central mine, which had been used for conveying ordinary cold underground waters for twelve or thirteen years, was lined with a deposit 0.4 inch thick, made up of calcite with a little iron and traces of manganese. (See Pl. XX, *A*.)

The maximum alteration takes place along water courses which follow along fracture zones, and is not directly dependent on distance from the surface.

Granitic quartz gneiss, 600 feet below the surface in the Baltimore tunnel and not near any vein, was found to contain fresh quartz, biotite, microcline, and orthoclase, with another feldspar which has been completely altered to kaolin with some carbonates and which inferentially was a soda feldspar. The effect of carbonated descending waters at this depth seems to have been a solution of soda and some lime.

In the Lebanon tunnel, at a depth of 700 feet, calcite is formed wherever water drips down. The heaviest deposit is in a drift which has been open about twenty-three years. The waters have formed on the floor a crust of calcite from 3 to 4 inches thick, and a beautiful deposit on the walls. From the roof depend fine stalactites upward of 6 inches long, and there are various other calcareous formations. It has been estimated that this whole drift, 8 feet high, would be cemented solid with calcite in five hundred or six hundred years. The calcite is in many places stained with iron and manganese, and locally with a little copper.

In the Silver Ore tunnel, at a depth of 800 to 900 feet, the granite is decomposed and disintegrated along a zone where abundant water seeps through the rocks and accumulates in the bottom of the drifts. On the walls of the drift the waters have left soft stalactites of manganese peroxide, and where the water forms pools on the floor a plentiful surface scum of calcite is formed.

In the Baltimore tunnel, at a depth of 1,100 feet, alaskite porphyry, which is nowhere near any known vein, has suffered alteration from surface waters. The feldspars have been mainly altered to kaolin, with a subordinate amount of quartz and sericite and a little pyrite. The waters which accomplished the alteration were evidently slightly sulphureted and have abstracted the alkalies and lime from the rock. At the same locality is a dike of quartz monzonite porphyry. In this rock the biotite has been partly altered to secondary quartz, calcite, and siderite. The principal feldspar, andesine, has been largely or entirely altered to abundant carbonates of iron, lime, and magnesium, and to kaolin.

A. CROSS SECTION OF PIPE, SHOWING PRECIPITATE OF CALCITE (WITH A LITTLE IRON AND A TRACE OF MANGANESE) FORMED IN TWELVE YEARS BY COLD MINE WATERS.

Natural size.

B. SPECIMEN FROM ALIUNDE FOURTH LEVEL, SHOWING NEARLY HORIZONTAL GROOVING OF WALL ROCK PITCHING 12° SW.

This indicates the nature of movement along the fault, which has later become cemented by the vein. Natural size.

GEOLOGICAL FEATURES IN COLORADO CENTRAL MINE.

In the Ashby tunnel every stream of water that enters along a fracture zone has coated the rocks of the tunnel floor with copious deposits of calcite, hydrated iron oxide, and manganese dioxide. The metallic oxides are in many places distinct from one another and from the calcite, though in other places the deposits are mixed. At the breast of the tunnel, where as elsewhere the process has been active, the depth is 1,200 feet. Here the granite is bleached along joints to a light color, stained with red iron oxide. The fresher and darker granite contains feldspar, quartz, biotite, and muscovite, with apatite and zircon and a little pyrite. The pyrite is fairly fresh. The soda-lime feldspars, albite and oligoclase-albite, are partly sericitized, but other feldspars, including microcline, microcline-orthoclase, and microcline-anorthoclase, are clear and unaltered. The bleached granite adjoining the fractures shows the biotite completely altered and bleached, with the deposition of carbonates. The fresh microcline feldspar of the darker granite remains fresh in this bleached rock, but the soda-lime feldspars, albite and oligoclase-albite, are further altered, being almost entirely decomposed to sericite, carbonates, and some kaolin. In this process of alteration the biotite has yielded to the waters abundant iron, which went into solution in the form of bicarbonate and a little manganese. The albite-oligoclase has yielded soda and some lime, which were taken into solution by the carbonated surface waters in the form of carbonates. The universal importance of this process is shown by the surprising abundance of calcite, limonite, and manganese dioxide precipitated from waters in underground workings, and by the universal alteration of the granites near the surface. The cause of the precipitation in underground workings is the access of air to the waters. Under normal conditions, at the underground depths mentioned, the solutions would normally deposit iron and manganese along the channel in the form of carbonates.

Descending waters are active along the veins also and accomplish much solution and precipitation. In the upper Maine tunnel, 300 feet below the surface, hair-like crystals of sodium sulphate have formed in the drift. These contain traces of calcium, magnesium, and chlorine. In the Frostberg vein, in the Burleigh tunnel, 750 feet below the surface, needle-like crystals which also may be sodium sulphate were found. Along the Mendota vein in the Victoria tunnel workings, at a depth of 450 feet below the surface, the walls of the drift are covered with stalactites and incrustations of zinc carbonate, some of them as much as half an inch thick. In one place a white carbonate was covered by a turquoise-blue mineral, which is zinc carbonate containing basic copper sulphate, with traces of lime and magnesia. This drift has stood open for twenty years. Probable zinc sulphate was also noted on the Frostberg vein, in the Burleigh tunnel, at a depth of 750 feet below the surface. At a point where the descending waters enter the drift was an abundant precipitation of yellow iron oxide. At this point, also, water dripping from the roof of the drift has precipitated basic sulphate of copper and lime carbonate, with possibly some copper carbonate.

In a number of mines wet places or watercourses were found to be lined by black, soft, pulverulent material which consists of sulphides of lead and zinc, with sulphantimonides (probably tetrahedrite and polybasite) containing silver. These are rich silver ores, carrying several hundred ounces.

In the Snowdrift mine chalcedonic silica was found lining water-filled vugs, associated with limonite, and in the Colorado Central mine barite was noted in separate crystals embedded in a soft clay zone traversed by present surface waters.

SUMMARY.

To sum up the effects of descending waters at the present day, it appears that they do an enormous work in dissolving, removing, and precipitating material in the rocks of the veins. These waters attack granites or similar rocks, leaving the microcline fresh, while the soda-lime feldspars, albite-oligoclase, oligoclase-albite, and to a less extent the orthoclase, are vigorously attacked, the alteration products being kaolin, quartz, carbonates, sericite, and pyrite. The waters are slightly carbonated and contain a little sulphur, and by their reactions with the wall rocks, in the course of which the above-described alterations take place, they abstract the alkalies, especially soda, with iron, lime, and magnesia, and to a minor extent probably most of the other rock constituents. The simultaneous formation of kaolin and sericite by descending surface waters, the easy alteration of the soda-lime feldspar and the freshness of the microcline, and the abstraction from alkaline granite of so much lime, iron, and manganese that copious precipitates of these materials are thrown down when the waters are oxygenated, form the most interesting features of the investigation.

In veins the metallic minerals, including zinc, copper, iron, lead, and silver, are dissolved by these descending waters and may be precipitated at a greater depth. In the mine workings zinc has been found deposited as carbonate; copper as basic sulphate, and possibly as carbonate; iron and manganese as oxides, rarely as carbonates. Along wet water courses, where the oxidizing conditions which prevail in the mine workings are not present, the waters precipitate lead, zinc, and silver in the form of sulphides and sulphantimonides. From these descending waters also chalcedonic quartz is deposited, and, in one place at least, barite.

DERIVATION OF VEIN MATERIALS.

DERIVATION OF CERTAIN METALLIC MINERALS.

The highly argentiferous minerals, including tetrahedrite, polybasite, ruby silver, and argentite, on whose presence the richness of the ores invariably depends, have been found to be mainly subsequent to massive galena-blende ores (fig. 27) containing a relatively small quantity of silver, say 8 to 30 ounces. These rich silver minerals occur as fresh, clean crystals lining the walls of geodes and of water-courses which are full of circulating water. Associated with them and forming part of the later generation of crystals is also usually some well-crystallized blende, pyrite, and galena. In the Waldorf mine, in the Argentine district, where this second generation of galena forms very large and abundant crystals in cavities (Pl. XIX), this ore is reported very low in silver. It seems probable that the rich silver ores have been derived from the older vein ores by circulating waters subsequent to the first deposition. Certainly, however, the silver has not been concentrated from the present superficial portion of the vein and carried down to lower levels. The uppermost portions of these veins are almost invariably the richest, the amount of silver diminishing from the surface downward. Evidently, therefore, it has been concentrated in part from the eroded portions of the veins and in part from the locally dissolved and reprecipitated primary ore beneath the present surface. The galena and blende of the second generation may well represent the galena and blende taken into solution from the upper portions of the veins which are now being removed, and also to a certain extent from the minerals of the present vein, and precipitated with less silver values than originally. The deposition of the rich silver-bearing sulphides has taken place to a greater extent in some localities than in others, producing the rich ore bodies.

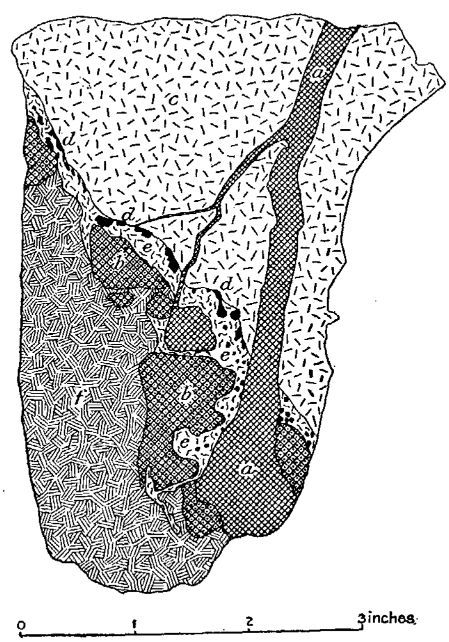


FIG. 27.—Sketch of specimen from Colorado Central mine, 1,050-foot level, showing primarily veinlet of polybasite subsequent to other sulphides. *a*, Polybasite; *b*, blende; *c*, granite; *d*, pyrite; *e*, quartz; *f*, galena. The following general order of deposition in the older vein fissure is shown: (1) Quartz and pyrite, (2) blende, (3) galena.

Following this reasoning and considering the amount of silver concentrated in the rich shoots and the quantity of original blende and galena which must have been taken into solution to furnish this silver, it seems certain that a very large amount of the original ore has been worked over by this process. Indeed, so abundant is the evidence of the continued work of solutions since the formation of the original vein opening that we can hardly be sure in many places as to what is really primary and not rearranged ore. Near the surface, for example, where the lead and zinc belonging to the second generation increase in amount, a comparatively massive ore may consist of secondary galena and blende intercrystallized with contemporaneous polybasite, which then has the appearance of being a primary mineral.

DERIVATION OF CERTAIN EARTHY MINERALS.

The wall rocks of the veins are everywhere altered, a change which has been accomplished both by the mineralizing solutions and by the ground waters. The alteration products include fine quartz, sericite, kaolin, carbonates of lime, magnesia, manganese, and iron and pyrite.

In the fissure veins, which are very common in this district, the most persistent feature is the presence next to the walls of a band of comb quartz, locally containing a little pyrite and barren of values. This quartz represents the first deposition in an open fissure and has no evident connection with the ore deposit. Subsequently the remaining and greater portion of the fissures was filled with massive galena and blende, with very little quartz. Therefore, throughout the district the fissure stood open for a considerable time during the deposition of the comb quartz before there was any ore deposition. This quartz has grown out perpendicularly from the walls of altered rock, which contain fine secondary quartz, and the universal presence of this lining and its occurrence in virtual continuity with the quartz of undoubted local origin points strongly to the conclusion that the source of the quartz was the wall rock, and that the lining originated by lateral secretion in its narrowest sense.

The quartz which was deposited later within the vein may well have had a like origin. A similar consideration applies to the scanty pyrite that is found at many places inclosed in this comb-quartz lining, the iron for which seems to have been indigenous in the rock, though probably the sulphur was not. In many places pyrite is more characteristic of the altered rock than of the veins. Within the rock siderite is more abundant than pyrite and both are contemporaneous, showing that the waters which altered the rock were carbonated as well as sulphureted. As seen under the microscope, this indigenous siderite, derived in part from the alteration of the biotite, forms tiny veinlets. Some of the larger fissures in the rock have been lined with siderite, which has taken the place of the ordinary quartz lining, and, as in the case of the quartz, its derivation from the wall rock seems certain. It is likewise probable that a similar origin can be assigned to much of the subsequently formed siderite, though some of this has probably not a direct derivation from the wall rock, but comes from a more remote source, being immediately due to the oxidation of the pyrite in the veins. This subsequent siderite is especially abundant near the surface, indicating the work of atmospheric waters.

The fact that probably 99 per cent of the veins which have filled fissures have a lining between the ore and the wall rock, consisting of quartz with some siderite and pyrite which were plainly derived from the exudation of the adjacent rock, shows that these fissures were not filled with circulating solutions for a considerable period after their formation.

Afterwards ore deposition set in, and the larger portion of the fissures was filled with coarse interlocking crystals of galena and blende, associated with very little gangue, a fact which suggests rapid deposition. Since the active precipitation of galena and blende is by no means a universal process, it is probable that it took place in all the veins at the same time and was due to the same cause, and since all of these veins are lined with approximately the same thickness of laterally secreted material, it follows that the fissures were opened simultaneously, a catastrophic phenomenon like the fissuring which attends an earthquake shock.

Calcite is formed in the altered rocks as the result of alteration of the soda-lime feldspars. Under the microscope calcite veinlets are found which are beyond any question whatever due to the local segregation of the indigenous mineral. These veinlets increase in size to macroscopic dimensions. Many altered rocks are cut by barren calcite veinlets, and these have no significance as to the proximity of an ore deposit. Where calcite does occur in the ores it is in small amounts and is among the latest minerals which have crystallized. In the mine workings it is abundantly deposited from underground waters, both near the veins and remote from them. All the evidence, therefore, points strongly to the derivation of the calcite in the veins from the wall rock, and this is probably a comparatively recent phenomenon due to descending atmospheric waters.

Kaolinite is an alteration product of feldspar and is associated with sericite and calcite. In the veins it occurs as a chemically precipitated mineral associated with carbonates and sulphides, which represent the latest depositions. It is often found on the walls of cavities, forming both microscopic and macroscopic veinlets. This mineral, like the calcite, is probably in all cases derived from the wall rock and is mainly at least the result of descending waters.

Barite, also one of the last-formed minerals, has been noted as contemporaneous with calcite and kaolinite, and is not associated with the metallic minerals in a close way. It has been noted in separate crystals embedded in the clay of a watercourse. The largest amounts of barite occur in scattered veins, which so far as observed are free from metallic minerals. Barite is undoubtedly present in the feldspar of the granites in small quantity, and probably passes into solution when the rocks are altered. Sulphuric acid, derived from the oxidation of sulphides by waters, precipitates the barium in solution as barite.

DERIVATION OF FLUORITE.

The sericitization of the wall rocks of the silver-bearing veins argues the presence of a little fluorine in the mineralizing waters, although not necessarily so much that fluorite should have crystallized from these waters. The occurrence described in the Seven-Thirty mine (p. 202), where fluorite in small crystals and veinlets was detected in the sericitized wall rocks of the Seven-Thirty vein though no fluorite was found in the vein itself, is of interest in this connection and indicates that here the fluorite was really precipitated by the mineralizing waters. Elsewhere the evidence suggests that if the mineral was originally deposited by the primary mineralizing solutions it has since been reworked and deposited in a concentrated form by surface waters.

The derivation of the fluorine in the original mineralizing solutions is also a matter open to doubt. The veins under discussion occur partly or wholly in granite. Granite is known to contain fluorine, which is present in mica, hornblende, and apatite, as well as in other minerals, and granitic rocks very commonly contain fluorite-bearing veins, in which the fluorite is either due to segregation from the granite or has been formed during the final process of consolidation. At many places vadose underground waters contain fluorine, derived from the rocks which they have traversed. Within the area of the Georgetown quadrangle the granites not only contain fluorine in small quantities in the silicates, but more abundantly in the form of fluorite. Mr. Ball has found fluorite especially abundant in the granite porphyry in the southeastern portion of the quadrangle, where this mineral forms a rather constant accessory. The place of this occurrence is 10 miles distant from any known ore-bearing veins, and it is believed that the mineral is due to the after processes of pre-Cambrian granitic consolidation. In the Pikes Peak region, around Cripple Creek, fluorite is present as a rare constituent of the granites, and this mineral is distributed in remote and widely separated parts of the Pikes Peak quadrangle in localities far removed from vein mineralization.[a]

No fluorite has been observed in the Silver Plume variety of granite, which forms the oldest rock of the veins in question. Yet since this mineral is of rare occurrence in the veins, its total amount might have easily been furnished by the fluorine in the granite. The present descending surface waters which attack and decompose the biotite of the granite must contain fluorine, and the sericitization which, together with kaolinization, is accomplished by these waters, shows that this is probably the case.

On the whole, therefore, the amount of fluorine indicated both in the original mineralizing waters and in the later descending waters that have altered the veins is not more than the amount that must have been derived from the altered wall rocks, though it is possible that a small quantity had a deep source.

SUMMARY.

It is therefore probable that the gangue minerals are derived from the wall rocks. Moreover, a large part of the materials in the veins, including metallic minerals and earthy gangue minerals, are probably immediately due to the precipitation of ordinary atmospheric ground waters. The original derivation of the metals—zinc, lead, silver, copper, arsenic, antimony, mercury, cadmium, gold, etc.—has not been decided by this inquiry.

[a] Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 47.

ALTERATION OF WALL ROCKS.

The alteration of the wall rocks near the veins has resulted in the formation of quartz, sericite, various carbonates, and kaolin. Of these products the sericite remains practically insoluble, while the quartz, carbonates, and kaolin have been taken into solution and deposited in tiny cavities and veinlets. Fluorite was observed in one place among the secondary products, and probably occurs in another place in the form of small grains in a microscopic veinlet of translucent kaolinite. Kaolin has been found at various depths up to at least a thousand feet. Its formation, however, in the wall rocks was undoubtedly contemporaneous with that in the veins, which has been found to have taken place during the last periods of deposition and to be probably the work of descending waters. It is therefore probable that the kaolin in the wall rock is an alteration product which is later than the sericite that accompanied the original ore deposition. The waters which accomplished this original alteration must then have contained some carbon dioxide, sulphur, and fluorine, since fluorine is inferred to be necessary for the formation of sericite.[a]

Both the original mineralizing waters and the subsequent atmospheric waters have exercised a very remarkable preference for some varieties of feldspar over others. Microcline has been notably immune from all alteration, remaining fresh and clear in the very wall of the veins where the other feldspars and biotite have been completely altered. These other feldspars are principally orthoclase and oligoclase-albite. In many places one of these has been much more vigorously altered than the other, and as a rule it is the orthoclase which has withstood the attack best, although here and there the situation is reversed. Even where the orthoclase has been entirely altered the microcline, though strained and cracked near the veins, remains quite clear. In cases of extreme alteration of the rock a little sericite occurs along cracks, but does not penetrate the rest of the mineral, and even in the rock actually being replaced by ore the microcline is undecomposed. Under such conditions it has been observed as being replaced by metallic minerals without alteration.[b]

Microcline has the same composition as orthoclase, and the cause of its crystallographic differences has been much discussed. It has been somewhat widely held that the microcline structure, consisting of two sets of striations, intersecting at right angles and visible under the microscope, with crossed nicols, had been developed in orthoclase by pressure. There is much microcline, however, of which this can not have been true (see p. 93); and the above-described immunity of microcline from alteration by the same waters that attack orthoclase points unmistakably to a molecular difference between the two minerals.

Epidote and marcasite were observed as alteration products in one thin section of the wall rock of the Seven-Thirty vein.

Certain of the lodes of that portion of Republican Mountain beneath which the Kelly tunnel passes show a characteristic alteration of the gneiss wall rock. This rock has acquired a peculiar bright-green color. Under the microscope it shows a thorough alteration, the products being quartz and a pale-green mineral, evidently mica, which in this case has replaced the sericite, the usual micaceous alteration product. Analyses by W. T. Schaller show the color to be due to chromium, so that the mineral is a chrome-bearing mica or fuchsite. Abundant clouded carbonates were also present.

CHANGES OF ORE IN DEPTH.

ZONE OF OXIDATION.

The zone of complete oxidation in these veins usually extends from the surface to a depth of 5 to 40 feet. The oxidized material is a brown clay, much of it stained by various other colors. It is generally rich ore and contains several hundred ounces of silver.

SUPERFICIAL SECONDARY ARGENTIFEROUS SULPHIDES.

Below this oxidized material and mixed with the lower portion of it come friable, locally powdery black sulphides and bunches or nuggets of pure secondary galena. These pulverulent

[a] Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 233.
[b] Compare the replacement of microcline by copper, in Doctor Sullivan's experiments (p. 160).

sulphides are also rich ores containing relatively high amounts of silver and lead and typically more gold than occurs at greater depth. The soft sulphides are found especially along cracks and water courses and are of secondary origin, having evidently been concentrated from the leaner ore by descending waters. They occur up to considerable depths from the surface, but in decreasing quantity. The older and typically more massive ores in which they have formed contain usually very much less silver and also less gold. For example, primary ore which contains 20 to 30 ounces of silver has yielded by this concentration process secondary sulphides which carry 200 to 300 ounces.

DEEPER SECONDARY ARGENTIFEROUS SULPHIDES.

Below the zone where soft secondary sulphides occur and irregularly overlapping the lower portion of this zone the rich ores contain polybasite, argentiferous tetrahedrite, and ruby silver, better crystallized and more massive than the pulverulent sulphides, but also subsequent in origin to the massive galena-blende ore. These richer ores diminish in quantity as depth increases, though gradually and irregularly, so that the lower portion of the veins contains relatively less silver and lead. The best ore in most veins has been found in the uppermost 500 feet, although good ore extends locally down to 700 or 800 feet, and in the Colorado Central, and to a minor extent in other veins, down to a thousand feet or more.

SECONDARY PYRITE.

The superficial portions of many of the lodes of this district are characterized by an unusually large amount of pyrite, in many places associated with and contemporaneous with abundant carbonate. The repeated evidence of the dependence of this pyrite and siderite on proximity to the surface shows that these minerals are probably due immediately to the action of descending surface waters. This deposition of pyrite by descending waters has probably taken place to a less extent up to considerable depths, since many specimens from these veins show that the pyrite, much of which on casual observation appears intergrown with the galena and blende, is really later than the sulphides and fills spaces which have been created by their having been broken or crushed.

PERSISTENCE OF VEINS OF MENDOTA TYPE IN DEPTH.

With the exception of the gradual decrease in depth of silver and lead, due to concentration effected by surface waters, and the greater proportion of pyrite and siderite close to the surface shown at many places, the primary low-grade blende-galena ores have in many of the strongest and most extensive veins proved to be fairly constant in amount and character to a depth of at least 1,250 feet, and probably much deeper. These veins, persistent in depth as well as in horizontal extent, are best represented in the group of which the Terrible and Mendota lodes are members.

PARTLY OR WHOLLY SECONDARY VEINS.

In contrast to the type just described are other veins which have usually a smaller horizontal extent and whose downward vertical extent is much less than that of the veins of the Terrible type. In the Pay Rock mine the best ore, as is usually the case with all the veins of the district, occurs within the uppermost few hundred feet, though good ore was found locally down to about 1,200 feet. The surface ores are described as having been very rich, containing large bodies of pyrite which carried gold in considerable quantity, some of it as much as 2 or 3 ounces. Within this profitable upper zone the vein is a strong one, containing much quartz, galena, blende, pyrite, calcite, and siderite, all intercrystallized and contemporaneous. Polybasite was also probably present. The calcite and siderite seem to have been more abundant near the surface than at a greater depth. The fact that calcite occurs as a gangue mineral contemporaneous with the metallic minerals, and its evident relation to the surface, together with the abundance of quartz in the gangue, marks the vein as probably belonging chiefly or entirely to the secondary period of ore deposition, during which the primary vein materials have been reworked by descending waters. On the lowest level of the mine, in the Ashby tunnel, at a depth varying from 1,000 to 1,500 feet, the zone of fractures and slips along which the ore has formed in the upper levels still persists, but this zone is usually barren and the existence of an important vein could not be suspected. There is no resemblance between the strong silicified vein above and the slightly mineralized or barren slips in the rock below.

In this case, therefore, the bottom of the enriched or reworked ore is also the bottom of the vein, and there appears to be little or no primary unworked portion below. The fact that practically the whole vein has been deposited by the descending waters is shown by its relation to a porphyry dike, which has a strike transverse to that of the vein and a dip of about 50°. The deposition of the ore has taken place most vigorously along the upper surface of this decomposed dike, and though the vein fracture passes through the dike and is reported on the other side, it was there entirely unmineralized.

There are numerous other examples of this type of silver-bearing lode which passes from the superficial region, where the character of the vein is similar to that of the superficial reworked portions of the deeper and more persistent veins, to almost or absolutely barren fracture or fault zones below. In many of these lodes the fault along which the vein has formed passes downward probably to a considerable depth, but is entirely unmineralized. Examples of this include the Boston, Beecher, and other neighboring lodes on Republican Mountain, and, so far as known, the lodes of the Democrat Mountain group. In the latter group the known ore bodies are confined to a depth of 200 to 400 feet below the surface, and the pitch of the most important ones follows that of the surface slopes.

SUMMARY.

The original ore deposition consisted of predominant blende, with galena and pyrite. The ores were deposited along fracture and fissure zones of slight displacement. Many of these veins were deposited throughout a great vertical as well as horizontal range. Some of them are known to extend at least 1,800 feet below the present surface and are probably much deeper, and considering the amount which must have been eroded from their tops it is evident that they originally occupied a vertical extent of several thousand feet. Some of the original vein deposits, however, have a very much less horizontal or vertical range, or both. Vein deposition took place probably at various depths within the general zone of mineralization, so that the upper portions of some veins were considerably higher than the tops of others, and likewise the bottoms of some were above the lower portions of others. Since the period of primary vein deposition the original surface has been lowered, so that so far as known all the veins have been exposed at the surface and have been actively attacked by erosion, while circulating ground waters, principally those which penetrated downward from the surface, have been very active in rearranging the primary ores. Probably some thousands of feet of rock, including a large part of the zone of mineralization, have been removed from the upper portion of the crust since the ores were first deposited.[a]

During this erosion the atmospheric waters have brought about a more or less complete reworking and rearrangement of the metallic minerals which were close to the surface, while

[a] It is impossible to determine accurately the thickness of superincumbent rock which has been removed by erosion since the intrusion of the porphyries. It is known, however, to be very great, and the order of the amount can be estimated. Whitman Cross (Mon. U. S. Geol. Survey, vol. 27, 1896, p. 202) has already shown from the character of the Denver (post-Laramie) formation in the Denver Basin that while its lower portion was being deposited the streams from the Colorado Range cut at no point into the pre-Cambrian rocks. The whole range was almost without doubt completely covered by lavas, surface flows of the intrusive porphyries. Formations similar to the Denver cover areas in Middle Park and in the northeastern portion of South Park. (Op. cit., p. 34.) The area of these formations flanking the Colorado Range equals that of the pre-Cambrian rocks of the range in this latitude, and since the lower half of the Denver formation (approximately 725 feet) contains no pre-Cambrian material and the upper portion considerable amounts of volcanic fragments, it may be assumed that the lava flows had an average thickness upon the range of 800 to 900 feet. It is, however, probable that the lava was thicker upon the flanks of the range than near its crest line, and in consequence the thickness of the lava in the vicinity of Silver Plume is tentatively placed at 500 feet. During the erosion which produced the old mountainous upland this lava was completely stripped off, as well as an unknown thickness of the pre-Cambrian rocks. This old surface was, however, mountainous, Mount Evans, for instance, rising 3,500 feet above the ancient valley of Clear Creek at Silver Plume. No lava remains on any of the old summits, and in consequence unless the lava was deposited upon a rugged surface with its mountains invariably where valleys now are, it is more than probable that at Silver Plume 3,500 feet or more of pre-Cambrian rocks were eroded after the land was bared of its lava flows. Since early Pleistocene time, when the streams were revived, Clear Creek has sunk its valley at Silver Plume 1,250 feet, while the present 11,000-foot contour on Brown Mountain is about 500 feet lower than the surface of the old mountainous upland. The total erosion since the intrusion of the porphyries is estimated at a minimum to be 4,500 feet and as a maximum 5,250 or more feet.—S. H. B.

their effects diminish gradually in importance with increasing depth. Much of the material originally contained in the eroded portions of veins has been carried down along the vein channels, which offered open fissures, for fracturing and fissuring resulting in reopening of the veins was continuous throughout this period. The erosion has been too active to permit the surface waters to form any impoverished zone near the surface, out of which the minerals should be leached and carried downward. In all these veins the surface portion is the richest, the result of the reworking process having been concentration of the valuable metals, lead, silver, and gold, in the superficial zone, and to a constantly less extent, dependent on the irregular distribution and strength of water courses as depth increases. These enriching effects are most marked in veins which originally contained most silver and lead and which have been laid open to the thorough searching of the waters by fissuring subsequent to the primary deposition. It is noticeable, however, to a more or less striking degree in all the veins. The result is that the upper few hundred feet of the veins has generally yielded rich lead-silver ore, especially in places, and on the very surface the gold, which in the original vein is a rare constituent, has locally been concentrated, so as to be of economic value. This zone of pay ore extends as a rule down to a depth of 300 feet, in many places to 500, in some to 700 or 800, and here and there to 1,000 feet or more, but as depth increases the amount of this ore becomes continually less and the original filling of the vein predominates more and more. This original ore encountered in the lower levels is a blende ore containing considerable galena and some pyrite, and is of low grade in respect to silver.

Many of the smaller veins, which originally had less considerable dimensions both horizontally and vertically, and especially those which formed in the upper portion of the zone of mineralization, have been eroded down so that only roots are left, as is proved by workings which pass below the vein to a practically or entirely unmineralized fracture or fault zone. The solution and downward transfer of at least a portion of the metallic minerals of the vein, which took place constantly as erosion progressed, continued until the surface was worn down almost or quite to the vein roots, with the result that all that is left of the vein is the concentrated zone, enriched from the eroded portion with respect to lead and silver and locally gold. When the bottom of the pay ore is reached, the bottom of the vein is also encountered. In some places the evidence of deposition by descending waters of the whole mass of metallic minerals and accompanying earthy minerals is so strong that it appears probable that no portion of the ore bodies in their present position is due to the primary deposition, but that the bottom of the original vein stood above the present surface. The descending waters continued to transfer the values downward as erosion progressed and finally brought the rearranged ores to what was originally the unmineralized channel, below the bottom of the original vein. These are therefore secondary veins, the barren lower portions of the fracture channels having inherited the older ores which were deposited higher up. The abundance at various altitudes of veins whose profitable surface portions pass below within a few hundred feet to barren fractures, combined with local and minor evidence that the ores are largely due to descending waters, makes it probable that these secondary veins constitute a rather common type.

RÉSUMÉ OF HISTORY OF VEIN FORMATION.

In the early Tertiary period planes of fracturing or faulting were developed in a northeastward-trending zone of weakness in the pre-Cambrian crystalline rocks. These were followed by the intrusion of monzonitic dikes, of which there were several varieties, intruded at distinct periods. Subsequent to this intrusion there was a renewal of movement within this zone of weakness, producing faulting, though usually the displacement of the faults was slight. Probably at a certain definite time many fissures were opened simultaneously in different parts of the district. For some time these fissures remained relatively dry, and gradually the walls became covered with crusts of crystalline quartz and siderite derived from the walls. At a somewhat later period the fissures became filled with circulating waters, probably hot and ascending and deriving their heat and their metallic constituents (with the exception of iron) from the subjacent monzonitic magma. These waters began active mineral deposition along faults and in all the fissures simultaneously, and deposited blende with some galena. With these minerals crystallized small amounts of silver, copper, antimony, arsenic, and a number of other metals. Pyrite and quartz crystallized at the same time, the iron and silica being probably derived from the rocks. These waters contained carbon dioxide and sulphur. The ore deposition extended over a vertical range of several thousand feet, probably at least 5,000, and some of the veins formed were of great vertical extent while others were of less, the extent depending largely on the strength of the circulation channels.

Since this primary mineralization several thousand feet of superficial rocks have been removed, exposing the veins and removing large portions of them. Descending surface waters have enriched the silver and lead in the upper portions of the veins by addition of the metals carried downward from the eroded portions to those already there, and by the removal of other materials to lower levels to make room for this addition. Many other important changes took place, so that the old veins were reworked more or less thoroughly near the surface, the relative amount of reworking depending largely on the postmineral fracturing of the primary vein. Thus the more persistent veins have an enriched upper zone a few hundred feet in depth, while the veins whose bottom was at first relatively high have been eroded downward to their roots, or even below; so that along such vein fissures there are now exposed on the surface ore deposits which either represent enriched roots or are secondary veins formed below the original roots by the transference of materials from the eroded portion to what was originally the underlying barren fracture.

FEATURES OF THE AURIFEROUS PYRITIC DEPOSITS.

COMPOSITION OF VEINS.

The characteristic and essential constituent of the auriferous pyritic deposits is pyrite, with a gangue of quartz. This pyrite contains gold, with a little copper and silver. Galena and blende may be absent, but typically are present in relatively small quantity, and some veins contain these minerals, especially the former, in considerable amounts. Where galena is an important feature of the ore this mineral usually contains considerable gold and silver.

The pyrite is cupriferous to a varying degree and locally grades into copper pyrite. Tetrahedrite is of common but rather sparing occurrence, and this is true to a greater degree of chalcocite, which usually occurs in the soft black form. In the Griffith mine small quantities of the gold and silver telluride, hessite, were found mixed with argentite and other minerals. Magyagite, a sulphotelluride of gold and silver, has been deposited at the Coming Nation mine on Soda Creek. It is reported that in one locality in the Centennial mine the ore contained platinum and iridium, having a value of $3 to the ton.

It has been demonstrated that gold occurs in the ores in native form, and free gold visible to the naked eye is sometimes encountered. Native silver is more rare.

Earthy minerals besides quartz include brown carbonates of iron, manganese, magnesia, and lime, usually to a slight extent. In the Griffith vein, however, the iron and manganese carbonates exceed in amount the contemporaneous pyrite. Barite is present in most veins in small quantity. Fluorite has been noted in a number of places in the decomposed dikes along which the veins run, but is not common as a gangue mineral. It occurs in considerable quantity in the Big Chief vein, near Georgetown, which is probably a branch of the Centennial, and also in other veins along the auriferous belt which stretches from Georgetown along the north slope of Leavenworth Mountain.

The valuable minerals in the ores consists of gold, silver, copper, and in some veins lead. Copper is usually present, but in many veins does not occur in economically important amount. A small amount of silver is uniformly present, and typically the amount is sufficient to be of importance. The relative proportion of gold and silver varies considerably. In a great many of the mines, including the Freeland, Stanley, New Era, and Centennial, the proportion of gold to silver is much the same, the ore averaging from 1 to 2 ounces of gold and 20 to 40 ounces of silver to the ton. From these ores there is a transition on the one hand to those in which the silver is contained in less proportion, as, for example, in the mines of the Empire district, where the silver is usually of slight commercial importance, and on the other hand to ores which contain relatively more silver, for example, in the Lamartine mine, where the proportion of gold to silver has been 1 to 70 (by weight), and in some other mines in which the relative value of silver is still higher. In those of the Cecil-Argo group the silver and lead form the most important metals, the value of the silver being several times that of the gold.

On the whole the auriferous gold ores of the Idaho Springs and Empire districts are to be defined mineralogically as essentially pyritic, the pyrite containing some silver and copper. Thus they are distinct from the blende-galena ores of the argentiferous veins of the Georgetown district. In these auriferous veins there is a greater range of composition than in the Georgetown argentiferous veins, which is due to the varying amounts of galena and blende.

PARAGENESIS OF VEIN MATERIALS.

In the Griffith mine the following order of deposition was noted in that portion of the vein belonging to the second or pyritic period: (1) Pyrite, brown carbonates, and quartz; (2) chalcopyrite, quartz, galena, and blende; (3) barite and kaolinite. In many places the more cupriferous pyrite and chalcopyrite which occur associated with pyrite in the mines do not show clear age relations. In the Centennial mine and those of the Empire district, however, the amount of copper in the pyrites decreases in the lower levels, suggesting that the more cupriferous pyrite and chalcopyrite are later than the relatively low grade cupriferous original pyrite and are derived from it by concentration. This is certainly true of the tetrahedrite, which was noted in both of these districts and in other mines forming along cracks in the chalcopyrite and plainly derived from it. This evident derivation makes it probable that small amounts of arsenic, antimony, etc., as well as copper, silver, and gold, are contained in the original pyrites. Chalcocite, which forms in small quantity, especially in the soft black form, near the surface and along fractures, is also plainly a later formation than the cupriferous pyrite.

Fluorite, where it occurs in the Big Chief mine near Georgetown, is later than the main period of mineralization, since it occurs coating cavites in the older sulphides, iron, lead, and zinc.

CHANGES OF VALUE IN DEPTH.

These veins are oxidized near the surface to a small extent, the amount of oxidation corresponding with that of the argentiferous veins. The zone of oxidation is especially well marked in the Donaldson-Champion Dirt group of veins, where there is a definite oxidized zone 30 to 70 feet deep, marked by the more or less complete alteration of pyrite to limonite. This zone follows the irregularities of the topography. At the Centennial partial oxidation is said to extend 15 or 20 feet down, though locally pyrite occurs at the surface. The oxidized ore of the Donaldson-Champion Dirt vein is reported to have been of unusually high grade, much of it running 6 ounces of gold. The veins of the Silver Mountain ore zone at Empire, which are oxidized completely to a depth of 40 feet or more, contain gold in a free state in amounts which seem to have been as great or greater than that in the sulphide material below.

In the Centennial mine, where the gold and silver values are associated with chalcopyrite or cupriferous pyrite, and the pyrite that contains very little copper is also of low grade with respect to gold and silver, the ores occur between the surface and a depth of about 550 feet, beneath which there is an abrupt falling off in values along a roughly horizontal line. The waters in this mine contain copper sulphate, showing that waters which follow down along the vein from the surface are actually dissolving copper from the ores. The presence of tetrahedrite, which has formed along cracks in the ore and is subsequent to the chalcopyrite, suggests that this chalcopyrite and the more cupriferous pyrites may have been altered from relatively barren pyrites by the addition of copper contained in the surface waters, in accordance with the process so frequently observed in veins containing copper.

In the mines along the Silver Mountain ore zone, at Empire, the same conditions were noted in the same class of ore. The sulphides immediately beneath the oxidized zone not only contain a large amount of copper pyrite, but along fractures in the ore black sulphides of copper, probably, in part at least, chalcocite, have formed, and these are undoubtedly of secondary origin. The best ore is said to have been of this character, and it extended from a depth of 25 feet to 150 feet below the surface. Much of this ore was high grade in gold, some of it assaying 10 ounces to the ton. The impression received by the writers was that the several veins in these mines were decidedly stronger in the upper levels than in the lowest level. In the highest workings the lodes are represented in many places by definite strong deposits of quartz and cupriferous pyrite, while in the lowest level they are characteristically only mere slips in the altered and pyritized rock, and many of these are marked by very little or no especial mineralization. It also seems probable that the proportion of chalcopyrite to pyrite is much larger on the upper than on the lower levels, and that the lowest level, that of the Aorta tunnel, is mostly below the rich cupriferous and auriferous zone. The actual difference of elevation between the outcrop of the veins and the lowest level is about 500 feet, so that the enriched sulphide zone appears to correspond in depth with that which seems to occur in the Centennial vein. In both these localities the copper is closely associated with gold and silver, so that the enriched copper pyrites are also better-grade gold and silver ores, while the slightly cupriferous varieties below are of low grade in respect to these metals.

In the mines mentioned a portion of the copper which has contributed to the enrichment of the original sulphides has been derived from the oxidized zone, but it seems unlikely that this has been the case with the gold and silver, which, like the enriched superficial portions of the argentiferous veins, must have been derived from the overlying portions of the lodes which are now eroded.

In the veins of the Freeland group it was noted that galena was more abundant in the uppermost few hundred feet, while in the deeper workings only a little of this mineral was contained in the characteristic pyritic ore. The upper workings also show more brown carbonates, consisting of siderite and rhodochrosite, and some barite. In one place observed it seems evident that the brown carbonate is secondary and has been derived from older pyrite in the ore. In these relatively superficial ores, also, tetrahedrite has formed along cracks in the chalcopyrite, and, as in the Centennial mine, is of secondary origin, and has been concentrated in this form by surface waters. The suggestion therefore arises that the relatively abundant galena near the surface may have been concentrated from the scanty galena in the original ore by the same agents.

On the whole, the strongest evidence of the reworking of the ores by surface waters is afforded by markedly cupriferous ores. Copper is a mineral which is readily attacked by descending waters, and the presence of copper sulphate in the mine waters shows that the process of solution is actually going on at present. This copper-sulphate solution seems to contain gold and silver also. Apart from this, however, and from the probable partial concentration of galena near the surface in some mines, the evidence of rearrangement of the ores by descending waters is in general not nearly so great as in the Georgetown district, and such reworking has probably taken place to a considerably less extent. The Lamartine mine, where the ore body does not reach the surface by 100 to 400 feet, affords an instance of ore which can not have been reworked by descending waters to any important extent. Yet this mine has had a very large and profitable production. Although the principal ore appears to extend less than 1,000 feet from the surface, it is probable that this has no relation to the effects of surface waters, but that the bottom of the original shoot has been reached. In the Little Mattie mine, also, the best ore is reported between the fourth and seventh levels, and although the ore in some places reached the surface, the amount was not so great as below.

POSTMINERAL MOVEMENT.

In a number of different mines in the Idaho Springs district there has been a postmineral movement along the veins, resulting in a characteristic band of breccia whose larger fragments have been rounded by attrition. This formation is in many places several feet thick and typically follows along the vein. Examples are seen in the Stanley, Freeland, and a number of other mines. Some veins are cut across by a similar postmineral breccia zone. In the Champion Dirt mine a soft breccia lode $2\frac{1}{2}$ to 4 feet thick enters the vein at an angle, turns and runs with it for several hundred feet, then cuts through it, faulting it so that it is offset 3 feet and disappearing in the foot wall. In many places where these zones occur parallel to the veins, the fact that their formation has been accompanied by displacement is also shown by striæ. In the Stanley mine striations on the walls of the breccia zone were observed dipping from 34° to 60° SW. The Little Mattie is faulted by strong but slightly mineralized cross veins, probably belonging to this period, and in places a zone of friction breccia follows along the vein itself. On one of the cross veins the striæ were observed to dip 10° from horizontal, indicating the direction of movement.

These breccia zones have usually been silicified, so that they are hard and firm. Here and there a small amount of metallic-sulphide deposition has taken place in them. They have evidently originated at a comparatively recent date, however, since the formation along a fault zone of a friction conglomerate instead of the more ordinary mass of pasty rock or gouge is a consequence of light pressure at the time of formation, such as could hardly exist at a considerable depth. Moreover, some of the detrital deposits which constitute a part of the breccia were evidently deposited in open fissures formed at the time of the fault movement.

In the Empire district movements in the rock still more recent than those which gave rise to the friction conglomerates have resulted in the formation of irregular belts of broken rock, in which the fragments are large and rather angular. These belts were noted in at least two places in the Silver Mountain ore zone, extending down to a depth of nearly 300 feet, where they are quite unconsolidated and uncemented and serve as channels for underground waters. The recent age of these belts is evident. Further movement along them and further induration would result in a formation like that of the friction breccias.

ALTERATION OF WALL ROCKS.

GENERAL DISCUSSION.

The principal products of alteration of the feldspar and biotite in the wall rocks are quartz, sericite, and various carbonates, with pyrite. In the Empire district the granitic and gneissic rocks have been altered on both sides of the vein channels for considerable though irregular distances. In many places a zone 30 to 60 feet wide on each side of the channel has been altered to quartz, sericite, and pyrite. This alteration was accomplished by the ore-depositing waters, since the pyrite is auriferous and much of it forms a low-grade ore. In the Rosecrans mine, for example, this altered granite on both sides of the main fracture is said to average $4.50 a ton in gold.

A specimen of granitic gneiss from the wall rock of one of the veins in the Silver Mountain ore zone, at Empire, was found to contain in place of the sericite a pale-brown pleochroic mica of sericitic habit, which with quartz made up the bulk of the altered rock. The quartz, zircon, and apatite of these rocks usually remain unaltered. Where the alteration is not complete some of the feldspars have been selected, while others have not been touched. A specimen from the wall rock of the Gold Dirt, at Empire, shows some of the feldspars entirely altered to sericite, while others are unaltered except for being slightly turbid from kaolinization. It is likely that this formation of kaolin is a separate and distinct process from that which has produced the alteration above described. In some cases the kaolin is cloudy and renders the feldspar turbid; in others it is a clear translucent aggregate which may entirely replace the feldspar. Interesting examples illustrating the history of rock alteration were studied in the Stanley mine.

In this mine the intrusion of a dike of bostonite porphyry has been followed by the formation of a mineral vein, subsequent to which a dike of latite porphyry was intruded along the same plane. Since this latite intrusion there has been only a trifling amount of mineralization. Besides the porphyries above mentioned, the wall rocks of the vein include gneiss and pegmatite. Fragments of the gneiss wall rock close to the vein show the feldspar entirely altered to sericite. Specimens of the bostonite show the feldspar, which includes orthoclase and anorthoclase, partly altered to kaolin, in one case to kaolin and sericite. The original pyroxene phenocrysts are completely altered to calcite, magnetite, or hematite, with abundant purple fluorite, which occurs also in cracks and in the groundmass closely associated with calcite and evidently of secondary origin. The latite as a rule is unusually hard and fresh, with fresh biotite phenocrysts. The feldspar, which includes orthoclase and calcic feldspar, is locally clear and fresh, but may be more or less altered, the calcic feldspars to calcite or here and there to brown carbonates, the orthoclase to kaolin. In one place, near subsequent veinlets of pyritiferous quartz, the feldspar is unusually altered and contains secondary quartz with some sericite and kaolin.

Some of the specimens studied show within a single slide the result of the alteration processes of different periods. A specimen of latite porphyry shows included fragments of older ore, with the adjacent gneiss wall rock. The gneiss contains relatively fresh orthoclase, singly striated feldspar which is partly sericitized, and blocks of entirely sericitized feldspar whose original nature is undeterminable. This alteration is similar to that observed in the wall rocks of the argentiferous group of veins. The inclosed porphyry in the same thin sections contains fresh biotite and feldspar which is partly fresh and partly altered to calcite. The difference in the method of alteration in the older and younger rock is striking, and it is shown that alteration of the gneiss wall rock of the veins took place before the intrusion of the porphyry.

Another specimen of latite from the same mine contains intrusive veins of arkose belonging to the period of the friction conglomerate. The arkose consists of detrital material which has been injected into fissures in the porphyry opened by the postmineral movement described elsewhere. The porphyry contains fresh biotite and orthoclase which is almost entirely altered to kaolin. The arkose is made up of granitic grains, among which is fresh or only very slightly kaolinized orthoclase. There is a striking difference in the slide between the freshness of the granitic orthoclase and the entirely altered condition of that in the porphyry. This shows that the alteration of the latite to calcite and kaolin took place before the postmineral movement that produced the friction conglomerate, and before the injection of the porphyries. The alteration, however, was probably accomplished by surface waters, since it is, as shown above, strikingly distinct from the sericitic alteration which is shown in the gneissic wall rock and which was undoubtedly accomplished by the waters which deposited the vein. The kaolinization described in the feldspar of the bostonite was probably also accomplished by the later vadose waters, while the rest of the alteration was attendant on mineralization.

Adularia was observed as an alteration product in two mines, and it is probably of relatively common occurrence. At Miller's mine, on the Lamartine road, the wall rocks are granite, which has been considerably altered near the vein, and in which the feldspar, including orthoclase, has been kaolinized and somewhat sericitized. In this rock are nests and veinlets of quartz, adularia, pyrite, and some sericite. Adularia also forms rims around the altered feldspar, including the orthoclase, or forms nests in it. It is probable that this involved the elimination of some soda, which was present in the orthoclase, adularia being practically pure potash feldspar. This rock also contains an area of clear microcline occupying an area inclosed by altered orthoclase crystals. Its clear and unaltered character suggests that it is secondary, like the adularia, but it is not closely associated with the adularia at any point, occurring only in this one locality, and the fact that in the Georgetown district the microcline, which undoubtedly belongs to the consolidation period of the granite, has remained fresh and clear where the rest of the rock was entirely altered, makes it more probable that we have here a similar case.

At the P. T. mine, on the spur separating Spring Gulch and Clear Creek, the vein has for the foot wall a dike of bostonite porphyry, and lenses of porphyry also occur surrounded by vein material. A specimen from one of the lenses shows the feldspars partly altered to kaolin and sericite. This rock contains secondary adularia, which is associated with pyrite and quartz and occurs as veinlets cutting the groundmass and as small patches in it. Pyrite also occurs in the rock, some of which may be original, while another portion is very likely secondary. The values in this mine are mostly gold, but in the other mine where adularia was found they are mostly silver, with only $1 to $2 in gold to the ton.

SUMMARY.

In summing up the effect on the wall rocks of the mineralizing waters which produced the primary vein deposition, it may be stated that the principal minerals which they formed were quartz, sericite, various carbonates, pale-brown sericitic mica, adularia, pyrite, and fluorite. This alteration corresponds with that accomplished in the walls of the argentiferous group of veins, except for the adularia, the brown sericitic mica, and the greater amount of fluorite in the auriferous veins. The alteration products of descending waters subsequent to the vein deposition are principally kaolin and calcite, with some sericite, and in the hornblende-bearing rocks a little epidote.

DERIVATION OF CERTAIN VEIN MATERIALS.

DERIVATION OF PYRITE.

The altered wall rocks in the vicinity of the veins typically contain disseminated pyrite, which the microscope shows to have been derived probably from the iron in the original biotite and other ferruginous minerals. The iron has passed into the condition of sulphide under the influence of percolating sulphureted waters. In the Aorta tunnel, on both sides of the central fissure or vein channel of the Silver Mountain ore zone, the granitic rocks have been bleached and pyritized, in places for a distance of many feet, and the disseminated pyrite is auriferous. Here the mineralizing waters have evidently contributed not only the sulphur, but also gold and a little silver to the combination with the indigenous iron of the rock. This auriferous pyrite increases in amount locally along the central vein channels, but the transition to the disseminated auriferous pyrite in the wall rock shows that all has probably a similar origin.

In the Empire tunnel further evidence was found of the derivation from the wall rock of the iron in the pyrite and even of some at least of the sulphur. In this tunnel numerous veins of pegmatite and pegmatitic quartz are associated with the large intrusive granite masses, and these pegmatitic veins contain original magnetite and contemporaneous pyrite. The granite also contains disseminated pyrite, which appears to be original and to date at least as far back as the pegmatitic stages of the granite's consolidation. These granites and associated pegmatites show on fractured surfaces secondary pyrite, which has the aspect of having been derived from re-solution and reprecipitation of that originally contained within the rock. What appears to be a further step in the segregation is the presence of small veinlets of jaspery gray quartz and pyrite, which have altered and replaced the granite along a narrow zone on either side of the central fracture. The inspection of many of these fracture zones containing quartz and pyrite and running through the fresh granite makes it seem very clear that the vein filling is derived from the adjacent rock. This example, therefore, makes it appear probable that not only the iron in the pyrite, and to a certain extent the sulphur, but also the quartz of the veins, have been, in part at least, derived from the surrounding rocks. The veinlets described are similar in appearance to the typically auriferous vein of the Empire district, although on a small scale.

Since, therefore, the pyrite, and to a certain extent the quartz, are of local origin, only the remaining metallic vein constituents, chiefly gold and copper, with a little silver, remain to be accounted for. Possibly a small proportion of these also may be derived from the neighboring rocks, since some of the pegmatitic quartz veins are reported to contain free gold. These veins are of pre-Cambrian age and represent the last stage of the consolidation of the intrusive granites. In the Grand Encampment district of Wyoming, near the northern border of Colorado and somewhat over 100 miles northwest of Empire, similar pre-Cambrian pegmatitic quartz veins contain a little gold, whose accumulation in placers has led to some prospecting and excitement. It is believed, however, that nearly all of the gold, silver, and copper has a quite extraneous origin, as is described on page 153.

DERIVATION OF BARITE, CHERTY SILICA, AND CARBONATES.

The prevailing occurrence of barite, cherty silica, and brown carbonates as crystals lining druses and representing the last stage of mineral deposition indicates that these minerals have the same origin as has been ascribed to them in the case of the argentiferous veins, where they have been regarded as having been derived from the wall rock, probably by atmospheric waters subsequent to the primary ore deposition. In some places siderite may be derived from original pyrite, as is probably the case in one instance noted in the Harrisburg mine, where a post-mineral fissure had been opened in pyritic altered rock and had become lined with siderite that was evidently due to lateral secretion. Siderite may also occur as one of the primary vein minerals, in which case, as also where it occurs among the last-formed minerals, it is usually mingled more or less with other carbonates, especially that of manganese. Where it thus has been deposited as a primary mineral it is contemporaneous with the primary pyrite, and its iron, like that of the pyrite, has probably been derived from the rocks traversed by the mineralizing solutions. This conclusion applies also to the manganese in the brown carbonates. The sulphur in these primary sulphide bodies, however, is characteristically too abundant to be readily ascribed to concentration from the rocks, and its introduction evidently accompanied that of the rare metals, such as gold, silver, copper, lead, and zinc. The abundant carbon dioxide which combined with iron and manganese to form the primary carbonates that were deposited at the same time as the sulphides is therefore probably also derived from an outside source.

DERIVATION OF RICHER CUPRIFEROUS MINERALS.

The alteration of chalcopyrite to tetrahedrite along cracks has been repeatedly noted in the different mines. This alteration is most common near the surface, where the descending waters are active, and the derivation of the tetrahedrite from the chalcopyrite is very evident. Since this is the case and there are no other known minerals from which the constituents of these secondary minerals can have been derived, the original more or less cupriferous pyritic ore and chalcopyrite must contain a small amount of arsenic and antimony. In some places at least the chalcopyrite itself is not primary, but has been derived by the concentration of copper from a lean primary cupriferous pyrite, the alteration being likewise the result of surface waters and being characteristic of the superficial zone. The subject of the derivation of both chalcopyrite and tetrahedrite from cupriferous pyrite has been considered in the description of the Centennial mine (p. 277) and that of the Silver Mountain ore zone (p. 402).

DERIVATION OF FLUORITE.

Fluorite has frequently been observed in dikes of bostonite porphyry, and along many such dikes veins have formed. Although the deposition of this mineral in the dikes appears later than the consolidation of the rock and it seems certain that it has produced rock alteration, including the destruction of the original pyroxene and the probable sericitization of some of the feldspars, it yet appears to have had a genetic relation to the intrusion, since fluorite is characteristic of this especial type of dike rock and occurs in dikes along which no vein has formed. It seems, therefore, to be evidently a product of the after action during the pneumatolytic period, when gases of magmatic origin rose along the channel of recently consolidated rock. This mineral occurs in comparatively few places as a gangue in the ore veins. Nevertheless, it is rather more common in the auriferous veins than in the silver-bearing veins of the Georgetown district, though it is present in relative abundance in the typically argentiferous veins at Argentine. Near Georgetown, however, the narrow belt of auriferous veins, which passes with a northeast-southwest trend through the town, with silver-bearing vein districts on both sides, shows fluorite in a number of places in quantity markedly greater than in the neighboring veins of the argentiferous period. Fluorite has been observed along this belt in the Big Chief mine, which is a branch of the Centennial and lies on the slope of Leavenworth Mountain overlooking Georgetown. On the north side of Clear Creek at Georgetown fluorite has been encountered in the Prudential tunnel. Here it is not associated with metallic minerals, but has formed along the fracture zone in pegmatite.

West of the Big Chief mine, near the west edge of the area mapped, on the north side of Leavenworth Mountain, considerable fluorite was found in a weak but definite lode in granite at an elevation of about 9,750 feet. This vein is reported as containing gold values but no silver. It carries a very little pyrite, and the fluorite is associated with jaspery quartz. Veinlets which are seen under the microscope contain quartz, pyrite, siderite, and fluorite. The silica and iron appear very likely of local origin. The fluorite has been characteristically the last of these minerals to be deposited. Between this vein and the Big Chief vein, also on Leavenworth Mountain and within the gold belt, is the Welsh mine, whose chief metallic mineral is pyrite. The values are reported to be gold, with very little silver. Some of the quartz from this mine is purplish and probably contains some fluorite.

To judge from the relations of the fluorite to the quartz, siderite, and pyrite, whose silica and iron may be derived from the granitic rocks through which the vein-forming solutions have circulated, the fluorite might well be believed to be of similar origin, since, as has been shown, these granites contain fluorine both in small quantities in the silicates and also in the form of fluorite. To this source a part, at least, of the fluorite found here and there in the argentiferous veins has been ascribed. The fact, however, that this belt of auriferous lodes contains fluorite to a markedly greater extent than the argentiferous lodes on each side argues for the exotic nature of at least a large part of the fluorine in this belt, and it probably was the result of the pneumatolytic period of intrusion of the feldspathic dikes. On the other hand, it is highly probable that the lime in the fluorite may have been derived from the wall rocks; and it is possible that the fluorite which forms the latest mineral in veins, as above described, may have been leached from its first position in or near the feldspathic dikes and reprecipitated.

PRESENT WORK OF DESCENDING WATERS.

In the long tunnels which run into Griffith Mountain on the Griffith vein considerable water was observed to a point about 650 feet vertically below the surface. From this point to the end of the tunnel, which is at an actual depth of about 1,050 feet, the rocks appear quite dry. The active action of atmospheric waters therefore appears in this mine to be restricted to a zone of about 650 feet below the surface; and with considerable variation, depending on the size and abundance of fractures, this general condition probably holds throughout the district. It has been observed also in several of the other long tunnels. Where these waters circulate through the copper-bearing ores the copper appears to go into solution with comparative ease. In the Centennial mine, at Georgetown, and along the similar veins of the Silver Mountain ore zone, at Empire, the superficial water encountered in the drifts contains sulphate of copper. Deposits of amorphous copper minerals were noted at several places along the Silver Mountain ore zone as having been formed since the opening of the drift. In both of these mines scales of metallic copper are sometimes deposited on iron objects, such as mine rails. In the Centennial the rust scale on the inside of a water pipe is reported to have yielded 11 per cent of copper on assay. Hydrous cupric sulphate, or chalcanthite, is reported in the old upper workings of this mine.

Iron also passes into solution in these superficial waters. A zone of unconsolidated, coarsely brecciated diorite, due to a comparatively recent movement in the rocks, has been described as occurring in the Aorta tunnel of the Silver Mountain ore zone, about 700 feet from the mouth (p. 398). The underground waters which circulated along this zone deposited considerable iron oxide on encountering the air of the tunnel, and pools of water which stand in the drift at this point are covered with a film of blood-red iron oxide. The waters in general also take up carbonate of lime, which is locally precipitated and has been noted in the Freeland mine, where sulphates of copper and iron and native copper have also been precipitated from the mine waters.

SUMMARY OF FORMATION OF AURIFEROUS VEINS.

INTRUSION AND AGE OF FELDSPATHIC DIKES.

Within the region which adjoins Idaho Springs on the south and west and also at Empire there occurred at a certain general period intrusions of numerous dikes representing different phases of a magma high in feldspathic ingredients but poor in the silicates of lime, magnesia, and iron. The dikes have a predominant northeast strike, the less important set trending in a northwesterly direction. Their directions were probably controlled by preexisting faults, which the dikes followed. This conclusion is indicated by the study of the Silver Mountain ore zone, a broad northeastward-trending belt of crushing, several hundred feet wide. The zone of fracturing and crushing contains a porphyry dike which follows the general trend of the zone but is only a few feet thick. Its coincidence in trend with that of the fracture zone suggests that it found within the zone inviting lines of weakness already existing at the time of its intrusion.

Most of these dikes are composed of bostonite and alaskitic quartz monzonite; a much smaller number consist of biotite latite with a core of alkali syenite. These are closely related rock types representing evidently a single general magma, which was distinct in its nature from the essentially monzonitic magma of the Georgetown district. From the resemblance of the Idaho Springs magmatic type to those at Cripple Creek and at the Rosita Hills, and considering the unusual character of such types, it is correlated with the magmas represented at these two volcanic centers, and the Idaho Springs dike intrusion is regarded as probably roughly contemporaneous with the volcanic and dike eruptions at these other localities, which are believed to have occurred in late Tertiary time.

MINERALIZATION CONSEQUENT ON THE INTRUSION.

General conditions.—Many of the numerous bostonite dikes contain fluorite, whose deposition followed closely the intrusion of the dikes and apparently brought about at least part of the alteration which we now find in the rock, including the destruction of the original pyroxene phenocrysts. Therefore it has been concluded that the fluorine thus represented had a genetic connection with the intrusion, and probably represented the gaseous emanations given out during the last stages of consolidation. After the intrusion of the bostonite dikes and those of alaskitic quartz monzonite, mineral veins were deposited within the same district by circulating waters. In point of time the mineralizing waters followed the intrusions closely. In many places the vein channel or fissure along which the mineralizing waters ascended, and which was due to a renewal of faulting and fracturing subsequent to the intrusion, followed along the dikes, which, occupying preexisting lines of weakness, still offered localities of least resistance. These mineralizing agents appear to have belonged to very much the same period as the fluorine emanations from which the fluorite in the bostonite dikes was formed (probably by combination with the lime liberated from the decomposed calcareous silicates), since the fact that their activity closely followed the dike intrusion has been demonstrated in the Stanley mine (p. 344).

Nature of mineralizing solutions.—The fact just mentioned shows also that the mineralizing waters were active for a restricted period, during which, however, the effects produced were very great. Therefore these agents can have been nothing else than hot waters, which were of course ascending, and the minerals deposited by them within the veins and wall rocks testify to the presence of gases such as sulphureted hydrogen, carbon dioxide, and fluorine, and metals such as gold, silver, copper, lead, and zinc, with small amounts of rarer metals, including probably bismuth and tellurium. They also contained potassium in unusually large proportion,[a] as is indicated by the formation of adularia, which has been observed in the wall rocks; and sodium was also probably present.

Effects of mineralizing solutions.—The solutions altered the wall rocks to quartz, sericite, pyrite, carbonates (especially those of iron and lime), and adularia, one of the net results being the precipitation of potash and the abstraction of soda and probably of lime, a process similar to that described by the writer at Tonopah and by Lindgren and Ransome at Cripple Creek. The biotites and other ferruginous minerals of the wall rocks were decomposed and the contained iron was reprecipitated in the form of contemporaneous sulphide and carbonate, partly in or near its original position in the rock, so that the pyrite and siderite remained disseminated, and partly in concentrated form along circulation channels, in which case these minerals assumed the form of a vein. Quartz was likewise precipitated along the circulation channels and a portion of it was probably derived from the wall rocks, though another portion, whose relation to

[a] See Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 213.

the locally derived silica is uncertain, must have been contained in the hot ascending solutions. Together with the pyrite, gold, silver, and copper were precipitated, with a variable amount of lead, zinc, and other metals. These valuable metals were deposited mainly in the pyrite along the vein channels, while that disseminated in the rock contained little or none of them. In some places, however, where the wall rock was unusually porous, the deposition of the disseminated pyrite, whose iron was derived from the ferruginous silicates, was accompanied also by that of gold, solutions bearing carbon dioxide, sulphureted hydrogen, and gold having penetrated the rock and having deposited the gold throughout, a more or less compensating amount of original rock materials being extracted.

Although siderite is very common in the altered wall rocks, and is in many places equal or superior to the pyrite in amount, the pyrite is generally greatly predominant along the main veins, which represent the principal circulation channels. Therefore sulphureted hydrogen seems to have been predominant over carbon dioxide at the time of the principal mineralization. In some veins, however, the amount of carbonate increases in proportion to pyrite, and in the Griffith mine the siderite (with rhodochrosite) equals or exceeds the contemporaneous or intercrystallized pyrite. This seems to indicate a differing condition, when the carbon dioxide equaled or predominated over the sulphureted hydrogen. It probably represents a later stage of the volcanic hot springs or solfataric history, when the waters were cooler, the surface was nearer, and the source of gases more remote.

Sequence of fumarolic activity around volcanoes.—The gases given off by cooling lavas around active volcanoes have been studied by geologists and have been found to differ according to the degree of cooling attained by the lava. In the first stage, when the lava is very hot, being about 500° C., the gases are dry, and consist of chlorides of sodium and potassium with small amounts of metallic chlorides and also fluorine, boron, and phosphorus. At a later stage, when the temperature of the lava is from 300° to 400° C., the vapors given off consist chiefly of water containing sulphurous and hydrochloric acids. At about 100° C. these water vapors contain ammonia and a little sulphureted hydrogen. Below 100° the water vapors contain some sulphureted hydrogen and carbon dioxide; while after the cessation of the expulsion of water vapor, carbon dioxide is still given off.

Comparison of volcanic fumarolic sequence with sequence of mineralizing solutions.—The mineralizing agents which have deposited the veins in the district under discussion, since their action followed so closely the intrusion of the dikes, and attended or immediately succeeded the alteration of these dikes by magmatic fluorine, bear the same relation to the igneous intrusion that fumaroles do to surface lavas.

The first period of gaseous emanation, which closely followed the intrusion and consolidation of the dikes and very likely preceded the ore deposition, is represented by the fluorine, which ascended along the dikes, partially altered the igneous rock, and combined with the calcite thus liberated to form fluorite. The fluorite found here and there in the veins is perhaps due to a solution and reprecipitation of this early fluorite. The main period of mineralization, accomplished by ascending waters having an excess of sulphureted hydrogen over carbon dioxide, and containing metals, answers to the later stages of fumarolic activity near volcanoes, when great quantities of water vapor containing considerable amounts of sulphurous gases are expelled. Finally those veins which contain more carbonates and less pyrite appear to represent a still later period, when carbon dioxide as well as sulphureted hydrogen is given off in water and gradually becomes predominant in amount. It is natural, if these conclusions are true, that the relative amounts of gold and silver should be comparatively less in these later and comparatively less efficient stages of mineralization. The Griffith vein corresponds to this conception. The carbonate-pyrite material in this vein contains less silver and gold than is usual in the auriferous veins, so that the ore is of low grade and is only in places fit for exploitation.

Magmatic origin of mineralizing waters.—The relations above outlined indicate that the waters which have accomplished the mineralization, as well as the gases contained therein, correspond with those which are expelled from surface lavas and were of magmatic origin.

If such heated waters, speeding upward toward the surface, should have encountered other water or gases permeating the rocks or flowing along circulation channels, these materials would become mixed with the volcanic supply; but the usual comparatively dry condition observed in the rocks of this region below a depth of 500 or 600 feet (see p. 138), which is similar to that observed in many other mining regions, makes it apparent that this factor was of small account.

INTRUSIONS SUBSEQUENT TO MINERALIZATION.

The less numerous dikes of the Idaho Springs magma include biotite latite and alkali syenite. In one mine (the Stanley) it has been shown that a latite dike was distinctly subsequent to the vein deposition which followed the intrusion of a bostonite dike. The latite dikes occur almost exclusively along a single narrow zone, in which the occurrence in the Stanley mine may also probably be included. The rock is typically fairly fresh, and it is likely that all of these dikes may be younger than the main mineralization. Similarly the alkali syenite which occurs in small quantities at Idaho Springs is not associated with veins. Along the contacts of this intrusive rock carbonated springs, some of them very hot, ascend. They have probably a genetic connection with the syenite intrusion, and this and the fresh condition of the rock suggest that it is not only subsequent to the main period of mineralization but is the latest of the intrusions.

MAGMATIC ORIGIN OF METALS IN BOTH GROUPS OF VEINS.

In the foregoing discussion of the process of ore deposition the origin of the mineralizing waters and gases which have deposited the auriferous group of veins has been referred to magmatic exhalation, while most of the earthy gangue, as well as the more common metals, including iron and manganese, has been referred to the wall rock. There remain the rare and more valuable metals—gold, silver, copper, lead, zinc, arsenic, antimony, etc. These metals are the distinctive features of the veins and they occur in these auriferous veins in quite different proportions from those shown in the argentiferous veins of the Georgetown district. If the evidence afforded by either of these vein groups was taken separately, the hypothesis that these rarer metals have been derived by the hot ascending magmatic waters from the rocks through which these waters ascended is as fully justified as that which supposes the metals to have been given off from the magma along with the mineralizing agents, since the crystalline igneous rocks through which the waters passed contain some, if not all, of these metals in small quantities. But additional evidence is supplied by the comparison of the two districts.

In the Georgetown district the intrusion of igneous rocks, representing variations of a monzonitic magma, was followed by the formation of argentiferous blende-galena ores containing very little gold and copper; the wall rocks were altered mainly to quartz, sericite, siderite, and pyrite, while chrome-bearing mica, or fuchsite, occurs locally in great abundance.

In the Idaho Springs district, at a later period, there were intrusions of igneous rocks representing an alkaline magma distinct from the monzonitic magma, and these intrusions were followed closely by waters and gases (probably of magmatic origin) which deposited ores containing large amounts of gold, copper, and silver, with valuable quantities of lead and zinc. There is also some evidence, though not complete, of the presence of more tellurium and fluorite in these veins than in the Georgetown veins, while the wall rocks contain adularia as well as the more common alteration products (quartz, sericite, siderite, and pyrite) of the Georgetown period. These different metallic combinations in the two districts, representing in part the different composition of aqueous solutions which followed the intrusion of different magmas, can be explained only by considering the metals to have been given off from the respective magmas, since the rocks which have been traversed by the ascending solutions are similar. This line of reasoning is the same as that which was available at Tonopah,[a] where different lavas were successively erupted and were followed by veins of different mineral composition.

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[a] Prof. Paper U. S. Geol. Survey No. 42, 1905, pp. 253-262.

ZONES OF ORE DEPOSITION.

ZONE OF PRESSURE RELIEF.

The ascending mineralizing waters must at some point in their progress have encountered a zone where relief of pressure and heat permitted a reaction between the solutions and the wall rock, including the union of the magmatic sulphur with the indigenous iron, which resulted in the deposition of pyrite and the attendant metals, including gold and silver. It is probable that this zone of deposition had definite upper and lower limits, so that the ore shoot formed had a top and bottom, above and below which the fissured or fractured zone that formed the channel for the ascending solutions still continued. If the ore bodies thus formed were deposited along a strong and persistent fissure or fracture zone, they may have more horizontal than vertical extent (as, for example, in the Lamartine mine); or where the horizontal extent of the circulation channel was slight the depth of the resultant mineralization may be relatively greater than the length.

RELATIVE ELEVATION OF GEORGETOWN AND IDAHO SPRINGS ORE-DEPOSITION ZONES.

From the conclusion that the auriferous veins of the Idaho Springs district are younger than the argentiferous veins of the Georgetown district, it follows that the former were deposited at a period when the topographic surface had been brought by erosion to a considerably lower position than it occupied at the time that the silver veins were deposited. Therefore the present surface is considerably nearer to the old surface which existed at the time of the auriferous deposition than to that which existed when the Georgetown veins were formed. If in each district the vertical zone of ore deposition occupied the same relative position with respect to the existing surface, then the argentiferous veins of Georgetown were deposited at a higher horizon than the Idaho Springs veins, and at the present day erosion has removed more of the former than of the latter. The tops of the Georgetown metalliferous veins or ore bodies were therefore exposed earlier than those of the Idaho Springs veins, by a time approximately equal to the difference in time between the two mineralizing periods, and by so much longer a time, to speak roughly, the descending surface waters have been reworking the superficial portions of the Georgetown veins.

COMPARISON OF EFFECTS OF DESCENDING WATERS IN THE TWO DISTRICTS.

The observed facts seem to bear out the inferences just stated. The effects of descending waters in reworking the primary minerals in the Idaho Springs veins seem to have been far less than in the veins of the Georgetown area, except perhaps in the veins containing cupriferous pyrite, where the easy solubility of the copper has permitted unusually rapid solution and precipitation. Therefore, while in the Georgetown district the secondary effects produced by solution and reprecipitation are of the utmost importance economically, in the Idaho Springs district they are certainly in places, of very slight importance.

NONOUTCROPPING ZONES OF ORE DEPOSITION.

Another fact indicating the probable relatively low position of the Idaho Springs veins as compared with the Georgetown veins is the occurrence of ore in the Lamartine mine, where the surface is barren and the top of the ore shoot is from 100 to 400 feet beneath it. In this case the mineralized portion of the vein had not yet been reached by erosion. No similar occurrence has been noted in the Georgetown region, where, on the other hand, evidence that the roots of veins are exposed or even that the original roots have already been removed is abundant.

Conditions like those described at the Lamartine are present at the famous mining camp of Guanajuato, Mexico, where they have been studied by the writers. In this district the veta madre, or mother lode, occurs along a great fault, which can be traced for several miles. The bonanzas which occur from place to place along this vein seem to be cut by the present surface near their original tops, so that much or all of the original depth of ore has been left. The largest mine in this district, the wonderfully productive Valenciana, had a broad outcrop of barren or very low-grade quartz which, though near active mines, remained untouched for two hundred years. When exploration was at last begun, the top of the ore body was encountered at a depth of about 300 feet and it reached from this point to a depth of about 1,300 feet. In this district also there is the even more striking Carmen-Pinguico vein, which is near the veta madre. This vein appears at the surface mainly as a crushed zone in rhyolite, or in many places only as the smooth single wall of a fault slip, with no mineralization whatever except that in one or two spots a little comb quartz outcrops. In depth this vein becomes mineralized, and a few hundred feet below the surface it becomes a well-marked and strong quartz lode, up to 8 feet in thickness, which has produced several millions in silver and gold.

In the Cripple Creek district also some shafts have been sunk for a few hundred feet without any indications of ore and have ultimately developed productive mines.[a]

LOCALIZATION OF ORES.

INITIAL CONDITIONS OF VEIN FORMATION.

The initial conditions for the formation of an important mineral vein, aside from the existence of a source whence metals may be derived and the presence of a vehicle, such as water, depend on the existence of a suitable circulation channel. Such a channel is most commonly supplied by a fault or fracture zone. The strength and width of the resulting vein depend largely on the relative openness of the zone at different places, the vein being large where the channel was open and small and "tight" in the narrow places.

ORE DEPOSITION BY MINGLING OF SOLUTIONS.

In the Georgetown quadrangle a great proportion of the important ore bodies are plainly due to the intersection of different branch veins. This is especially well shown in the Silver Plume region, where there are a number of good illustrations. In such a lode mineralization may begin at the junction of the two branches and extend from the junction along the united vein, or along the united vein and back along one of the branches, or along both of the branches. In these cases the precipitation of ore is plainly the result of mingling solutions.

According to this explanation, waters of slightly different composition circulated in these different branches, a conclusion which is corroborated by the fact that each branch now usually shows a more or less distinct character in its metallic filling, a fact which is well known to the miners in this district. For these local differences in the composition of the mineralizing solutions, if, as is probable, the solutions were all originally derived from the same source, we must look to the results of reactions with the different wall rocks encountered. Wherever such slightly different solutions have met at the junction of two branches, precipitation has taken place until the equilibrium of the mixture was restored.

ORE DEPOSITION IN FIELDS OF INTERSECTING FRACTURES.

There are, however, many ore shoots along the veins where no intersecting branches have been noted, and these shoots are also of great importance. It has been shown that the great ore bodies or bonanzas of the veins at Tonopah,[b] as well as of the similar veins in the Comstock, Pachuca, and other districts, have been caused by the intersection with the main fracture zone, along which the vein has formed, of cross fractures that have not been mineralized, but whose intersection with the main-vein zone has produced channels of maximum circulation, which approach a definite shoot-like form only where the various cross fractures become dominated by some stronger set. Inasmuch as in the Georgetown quadrangle ore bodies have been observed which have been formed not only at the intersection of two stronger branches, but also at the intersection with the main vein of some strong barren fracture or fractures, it is probable that the explanation given above applies to many of the more irregular shoots where no such intersection has actually been observed.

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[a] Prof. Paper U. S. Geol. Survey No. 54, 1906, p. 255.

[b] Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 276.

ORE DEPOSITION BY REPLACEMENT OF ROCK.

While the ore which has been deposited in open fissures has probably been precipitated largely by the mingling of solutions involving the reaction of one solution on another, and partly by the lowering of temperature and pressure at a critical depth, the important and abundant type of ore which has been formed apparently by replacement probably owes its precipitation partly, at least, to the reaction of the mineralizing solutions on the solid wall rock. Such solutions have brought about replacement of the granites, gneisses, and porphyries, in the same way that the solutions containing magnesia and silica react on limestone to form dolomite and quartz, as at Aspen.

IMPORTANCE OF RELATIVE AREA OF REACTION FACES.

A microscopic study of limestone in the process of replacement by dolomite, silica, and sulphides in the Aspen district shows that the rock was at first profoundly strained and crushed in the vicinity of faults, so that many tiny passages were opened to solutions, which finally worked through and through the strained material, replacing it. The amount of straining, which regulated the area of surface offered to the solutions, usually determined whether there would be little or much replacement.

Recent experiments of E. C. Sullivan indicate the importance of keeping in mind the consideration of how much area has been exposed to solutions in a given case. Doctor

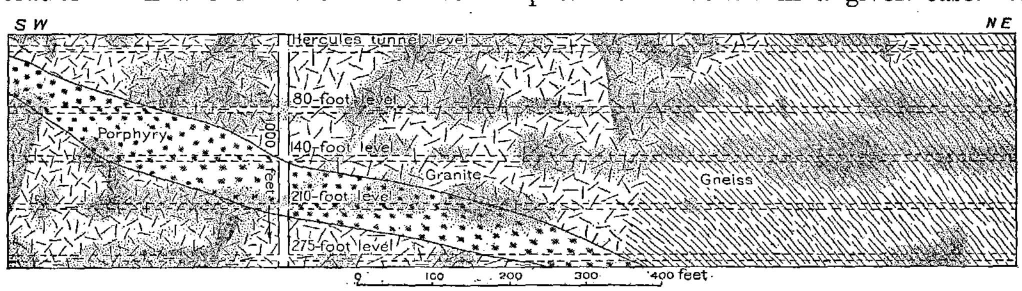


FIG. 28.—Sketch of actual plane of a portion of the Seven-Thirty vein, showing (1) relative concentration of ore (indicated by dots) along different portions of the vein and (2) the greater proportion of ore in the more rigid granite wall rocks than in the more yielding porphyry walls. The gneiss (of varying degrees of resistance) seems to be intermediate between the granite and the porphyry in point of fitness for fracturing and consequent ore deposition.

Sullivan treated various mineral materials, including kaolin, orthoclase, microcline, pyrite, and biotite, which had been ground to a fine powder, with a solution of cupric sulphate.[a] When the solution was kept in contact with the powder a few days, it was found that a reaction took place, involving chiefly a change of bases between the solution and the solids, the copper undergoing precipitation and an equivalent quantity of other bases (chiefly alkali and alkaline earth bases) entering the solution. The amount of precipitation was found to be dependent on grinding. The finer the powder the more copper was precipitated. Here, then, we have a good illustration of the influence of a large area of reaction faces in a reaction between a solid and a liquid.

LOCALIZATION OF ORE BODIES IN CRUSHED PORTIONS OF FAULT ZONES.

It was suggested to the writers from the above-described experiment that where the circulation zone along a vein is wide and is filled largely with finely ground material which is not so pasty as to prohibit free circulation through it, the replacement of earthy materials by metallic minerals as well as their accompanying gangue would go on very much more rapidly than elsewhere along the vein, where the rock is hard and is only sliced by fracture planes, and that an ore shoot would form under the former conditions, whereas during the same period the mineralization accomplished under the latter conditions would be very slight. Along veins such as those of the Georgetown quadrangle, which are all due to slight fault movement, such physical differences in different parts of the channel must exist, and being usually of fairly irregular form might give rise to irregular shoots (fig. 28).

[a] Economic Geology, vol. 1, 1905, pp. 68, 69.

The finely ground material which is found along the zone of a fault is commonly called gouge, and is abundantly encountered along the faults of the Georgetown quadrangle. With a view of testing the idea outlined above, a specimen of soft-clay gouge from the Bismarck vein was obtained and Doctor Sullivan kindly made some further experiments. This gouge contained 3.52 per cent K_2O, 0.18 per cent Na_2O, and 3.92 per cent CO_2, largely as $FeCO_3$. The gouge was already in a finely powdered state but was further ground in a mortar and allowed to stand for three days, with occasional shaking, in contact with twice its weight of a cupric-sulphate solution containing 2.978 grams of copper and 50 cm^3 of water. At the end of this period the solution contained only 2.614 grams of copper, so that 0.364 gram had been precipitated, the gouge having taken up about 1.4 per cent of its own weight in copper. The materials dissolved from the gouge and replaced by the precipitated copper are as follows:

Materials dissolved by cupric-sulphate solution from soft-clay gouge.

	Gram.
SiO_2	0.0075
Al_2O_3, etc	.0780
CaO	.0185
MgO	.0275
K_2O	.1320
Na_2O	.0075
	.2710

More than 1 per cent of the constituents of the gouge had gone into solution.

Another sample of the same gouge was kept four days in contact with twice its weight of a silver-sulphate solution containing about 0.1 gram of silver and 50 cm^3 of water. At the end of this time the silver was practically entirely removed from solution, and the solution contained the following materials, chiefly in the form of sulphates:

Materials dissolved by silver-sulphate solution from soft-clay gouge.

	Gram.
SiO_2	0.0024
Al_2O_3	.0004
CaO	.0026
MgO	.0052
K_2O	.0444
Na_2O	.0032
This total was derived from 25 grams of gouge.	.0582

Doctor Sullivan remarks that the ferrous carbonate contained in the gouge appears to take little or no part in precipitating the metals under the conditions of these experiments, which were made under ordinary temperature and pressure and were of brief duration. From the anlayses given it appears that the alkalies are about equally active in precipitation. In the gouge the proportion of Na_2O to K_2O is about 1 to 22. In the material removed from the gouge by the copper solution the proportion is 1 to 17½, and in that removed by the silver solution 1 to 14. If there is any difference, the soda has been more active than the potash. The actual replacement of alumina, which passes into solution, is highly interesting.[a]

NATURE OF FAULT MOVEMENTS.

The veins of the Georgetown quadrangle have been formed along faults of usually slight displacement. On the walls of veins movement striæ have been observed and recorded at many different localities, and the detailed notes are given in the separate mine descriptions. These striations vary in direction locally, but taken altogether are consistent and beyond doubt indicate a general direction of fault movement. Most of the veins of this region have a steep dip, but the direction of movement along these steeply dipping veins varies locally from horizontal to vertical.

[a] In these experiments the copper seems to be precipitated chiefly either as a basic cupric sulphate having the composition of brochantite or as cupric hydroxide, depending on whether the copper solution or the precipitating silicate is in excess; some cupric silicate undoubtedly forms also. The composition of the silver precipitate has not been investigated, but it is perhaps safe to assume that it is principally silver oxide.—E. C. S.

DISPLACEMENT ALONG VEIN CHANNELS OF THE ARGENTIFEROUS GROUP.

Many striations were observed on the walls of the veins of the argentiferous type, which are especially abundant near Georgetown. In the Silver Plume district, including the Lebanon group of veins, the majority of the striæ are horizontal or dip at angles ranging up to 5°, the

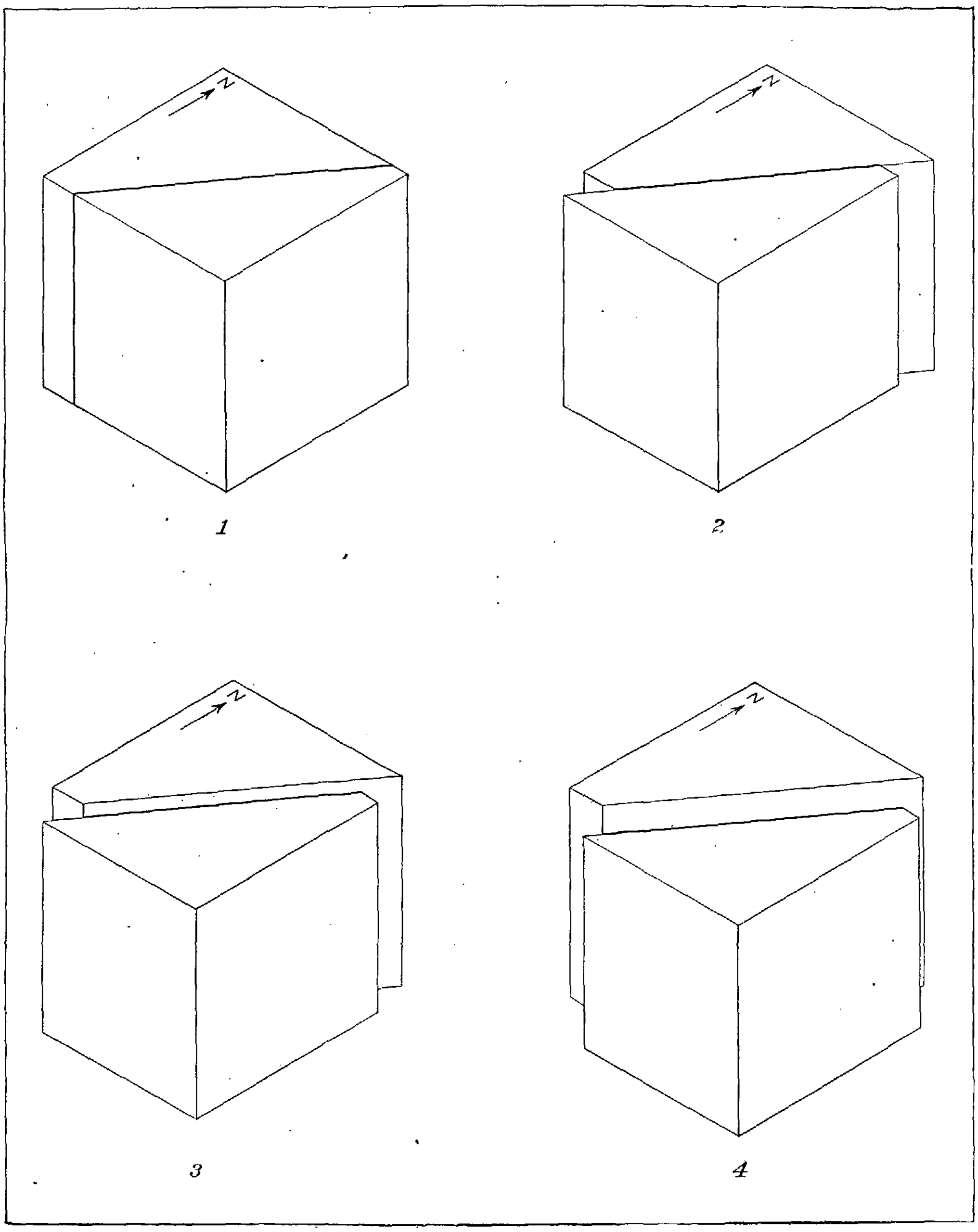


FIG. 29.—Stereogrammatic figures showing nature of displacement along faults which have later become vein channels in the Georgetown quadrangle. *1*, Unfaulted block of rock (upper side horizontal), with fracture running through it; *2*, horizontal displacement along vertical northeast fault, illustrating general type of movement in silver veins belonging to the Georgetown group; *3*, movement at an angle of about 20° from the horizontal, illustrating displacement of the Colorado Central veins; *4*, movement at an angle of 60° or so from the horizontal, illustrating typical displacement along auriferous veins of the Idaho Springs type.

angle in a smaller number of cases increasing to 30° or more and the dip in different places being in opposite directions, both to the northeast and southwest on the northeastward striking veins and to the northwest and southeast on the northwestward striking veins. On the whole the average movement in the Silver Plume group of mineralized faults has been approximately horizontal along the fault planes.

The striations observed along the Colorado Central vein, which is nearly vertical, show that one of the walls has moved southwestward past the other at a relatively small angle from the horizontal (Pl. XX, *B*). This angle has considerable local variation but averages about 20°. The maximum displacement is estimated to have been 100 feet.

In the Kelly tunnel group of veins, including the Boston and Beecher, the movement is shown to have been to the northeast along the northeastward striking vertical fault plane, at angles varying between 10° and 20° from the horizontal.

The Magnet, which is also a northeast vein, shows striæ indicating movements to the southwest at angles of 30° and 63° from the horizontal.

DISPLACEMENT ALONG VEIN CHANNELS OF THE AURIFEROUS GROUP.

Similar observations were recorded concerning the auriferous group of veins. The Centennial vein at Georgetown, which has a northeast strike, shows striæ dipping to the southwest at an angle of 32° from the horizontal. The Anglo-Saxon mine, which also has a northeast strike, records movement to the northeast at an angle of 65° from the horizontal. The auriferous veins at Empire show striæ dipping steeply at angles varying from 45° to 90° and inclined both to the northeast and to the southwest on the predominant northeastward striking lodes, the average motion recorded being to the southwest at an angle of about 65° from the horizontal. The Lamartine and Gum Tree veins, which strike northeast, show movement to the southwest at angles varying from 45° to 90°. The Stanley, also a northeast vein, shows movement to the southwest at angles of 34° and 60° from the horizontal.

The Little Mattie, a northeast vein, shows striations horizontal and dipping 5° in a northeasterly direction and 15° in a southwesterly direction, the average displacement indicated being in a direction nearly horizontal.

SUMMARY AND APPLICATION.

From the above statement it appears that in general the faults along which the veins of the argentiferous group subsequently formed, while steeply dipping or vertical, were marked by a nearly horizontal movement of one wall past the other; but in the veins of the gold group, as a rule, while the strike and dip in many cases are similar to those of the silver veins, one wall moved past the other with a strong downward plunge (fig. 29). To each of these generalizations there is a single observed exception. The Magnet, which is one of the argentiferous veins, shows movement in a direction ranging from 30° to 60° from the horizontal, more like the usual movement of the gold veins; and the Little Mattie, which contains considerable gold and belongs in the group of auriferous veins, registers a horizontal movement like that typical of the silver veins.

These observations lend further support to the conclusions already reached that the auriferous veins belong to a different period from the silver-bearing veins. It is likely that the fault fissures along which the auriferous veins were formed were opened at a date subsequent to the faulting that preceded the mineralization in the Georgetown district, and took place as a result of different stresses. Thus the horizontal fault movements were produced under a considerably greater load of overlying rocks than the plunging movements which afforded channels for the gold ores. Nevertheless, the direction of faulting is evidently not a question of load, but of local stress, since postmineral movements, roughly contemporaneous in both districts, have followed the same directions as the antemineral faults.

IDAHO SPRINGS WATERS.

ACTIVE AND EXTINCT CARBONATED SPRINGS.

The town of Idaho Springs derives its name from a number of carbonated mineral springs which are situated there. Some of these springs are hot, while others have very nearly the normal temperature for underground waters. Extinct springs are indicated in many places by mounds of yellowish-white travertine or calcareous sinter, showing that the hot-spring action dates from a considerable period back.

About a mile below Idaho Springs, on the north side of Clear Creek valley, ancient river conglomerates adhere in patches to the gneiss that forms the valley slopes. These conglomerates correspond in age and position to the conglomerates which cover the old river benches at Idaho Springs and which have in the past formed productive placers. They are of preglacial age and have been referred to the late Tertiary and provisionally called Pliocene. The remnants of these conglomerates described as adhering to the valley slopes have been cemented with banded calcite, which has filled numerous fractures and which is easily recognizable as the result of local hot-spring action. It is reported that this calcite contains some silver, but the assay of a small sample taken by the writers showed only a trace.

It therefore appears that the springs near Idaho Springs, while shifting their position repeatedly, have been active since the late Tertiary.

Mr. Waldemar Lindgren has furnished to the writers information concerning a deposit of calcareous tufa or sinter which occurs in Clear Creek valley 1 mile below Georgetown, on the lower slopes of Columbia Mountain. At this point there are rather extensive calcareous surface deposits in three places, the highest of which is about 400 feet above the valley. The largest mass covers the slope for a space perhaps 100 feet square and has been deposited upon the sloping and decomposed granitic rock. These deposits are evidently due to spring action. Mr. Lindgren remarks that the springs evidently issued 400 feet above the valley and gradually descended, keeping pace with erosion. A number of small tunnels have been driven in along the zone of veins, and low values in gold are reported common. Vestiges of thermal conditions in the form of noticeable heat are reported to have been observed in one of these tunnels.

COMPOSITION OF IDAHO SPRINGS WATERS.

The present springs near the town may be divided into three groups—the Hot Springs, which are several in number but occur close together; the Blue Ribbon Springs, which are of cold water and lie a short distance farther west; and the Cold Sulphur Springs, which are situated at a distance of several hundred yards from the other two groups and somewhat farther down Clear Creek valley. The Hot Springs issue near the contact of an intrusive body of alkali syenite with pre-Cambrian gneiss, and the Blue Ribbon Springs are situated at the contact of a smaller body of the same intrusive rock, while the Cold Sulphur Springs rise from the gravel which forms the bottom of the valley. The temperature of the hot springs varies from 98° to 108° F. or more. The water is used for bathing and also for medicinal purposes. That of the Blue Ribbon Springs is bottled and sold as a table water. Analyses of these waters follow:

Analyses of Idaho Springs waters.

	1.	2.	3.		4.[a]	5.[a]	6.[a]
	Per cent.	*Grains per pint.*	*Grains per pint.*		*Parts per million.*	*Parts per million.*	*Parts per million.*
Sodium carbonate	30.80	3.85	5.725	SiO_2	56.5	65	69.4
Magnesium carbonate	2.88	.36	.864	SO_4	317.7	352.1	391.6
Calcium carbonate	9.52	1.19	.231	HCO_3	985.3	1,320.4	1,302.7
Ferrous carbonate	4.12	.52	.061	B_4O_7[b]	Lost.	7.8	11.8
Sodium chloride	4.16	.52	.709	Cl	45.7	58.3	61.4
Magnesium chloride	Trace.	Trace.		Fe_2O_3	3	7.6	3.7
Calcium chloride	Trace.	Trace.		Al_2O_3	1.4	Trace?	.9
Sodium sulphate	29.36	3.67		Ca	109.8	128.5	145.1
Magnesium sulphate	18.72	2.34		Mg	29.2	35.1	36.0
Calcium sulphate	3.44	.43	3.441	K	54.6	59	66.1
Sodium silicate	4.08	.51		Na	343.5	457.3	447.8
Silica			.478	Li	Trace.	Trace.	Trace.
Lithia			Trace.	Sr	Trace.	Trace.	Trace.
Ammonia			None.	Cu	Trace.	None.	None.
Nitrates			None.	Zn	Trace(?)	None.	None.
Organic matter			None.				
					1,946.7	2,491.1	2,536.5
Total	107	13.39	11.509	As normal carbonates	1,446	1,820.1	1,874.5
				Residue at 180°	1,525.5	1,809.1	1,955.4
				Free CO_2	28.3	18.3	461.0

[a] Ba, Au, Ag, As, Sb, Pb, absent or not present in appreciable amounts in quantity of water examined. [b] Approximate.

1. Hot Springs. J. G. Pohle, New York, analyst. U. S. Geog. and Geol. Surveys W. 100th Mer., vol. 3, 1875, pp. 485, 486.
2. Hot Springs. J. Ohly, Denver, analyst, June 6, 1905.
3. Blue Ribbon Springs. J. Ohly, Denver, analyst.
4. Cold Sulphur Springs. W. T. Schaller, analyst.
5. Blue Ribbon Springs. W. T. Shaller, analyst.
6. Hot Springs. W. T. Schaller, analyst.

EFFECT OF WATERS ON WALL ROCK.

Specimens of the intrusive alkali syenite collected by Mr. Lindgren near the Hot Springs and forwarded to the writers show the rock riddled by small cavities which have been formed by the dissolving effect of hot waters. Many of the cavities are of such size that it is evident that their formation has been accomplished by the dissolution and removal of minerals representing all the mineral constituents of the rock, so that all the chemical constituents of the rock have passed into solution. In many of these cavities and also along cracks Mr. Lindgren found abundant crystals of barite, undoubtedly deposited by the spring waters. This occurrence is interesting, inasmuch as the alkali syenite (see p. 83) contains considerable barium, while the analyses of the waters show none. A reaction between the barium and the decomposed rock and the sulphates in the spring waters is evident, and the indigenous origin of this barite confirms the conclusions already drawn as to the origin of the barite in mineral veins. Tiny and relatively sparse quartz crystals, not so large nor abundant as the barite crystals, grow out from the sides of these cavities. Limonite has also been deposited, lining the walls.

The microscope shows that the alteration of this rock has resulted largely in the turbidity of the minerals, especially the feldspar, this clouding being caused by a very fine-grained alteration product varying in color from white to brown or yellowish brown. On the walls of small cavities limonite has been deposited. It seems probable from the inspection of the mineral which has caused the turbidity that it is chiefly carbonate, partly lime carbonate, and in part also probably iron carbonate. The limonite appears to have been formed by the oxidation of this carbonate in the cavities.

COMPARISON OF DIFFERENT SPRING WATERS.

A comparison of these waters is interesting for the reason that, while they differ somewhat in composition, they are evidently, as shown by the analyses, of allied nature. Both the Hot Springs and the Blue Ribbon Springs are carbonated and sulphureted soda springs occurring under the same geologic conditions within a few hundred yards of each other. The cold Blue Ribbon Springs, however, are evidently considerably farther removed from the focus of heat than the Hot Springs. They occur along the contact of a dike which is similar in composition to that near the Hot Springs, but whose intrusion may be of earlier date and whose cooling in its deep-seated portions may have reached a more advanced stage than in the rock whence the Hot Springs derive their heat.

As the Cold Sulphur Springs are situated at a distance of several hundred yards from the other two groups and emerge from the alluvium which floors the valley of Clear Creek, their relation to the bed-rock geology is unknown.

The analyses of the spring waters show that they now contain lime, magnesium, sodium, and potassium, chiefly in the form of carbonates and sulphates and some chlorides, and also some silica. Soda is decidedly the predominant base; lime, potash, and magnesia come next.

DISTINCT ORIGIN OF ACIDS AND BASES IN SPRING WATERS.

Since in the formation of the larger cavities mentioned above the whole rock fabric has been dissolved, the hot waters have at one time or another contained in solution all the rock-making elements, and part at least of their constituent bases at present must be derived from the rocks. The analysis of the alkali syenite, however, shows that SO_3 is present in small amounts, but that there is no CO_2 nor Cl nor compounds of boron. In the waters there are large amounts of free CO_2 and sulphur in the form of H_2S and also in the form of sulphates. A great excess of carbonic and sulphurous acids is thus indicated, and hydrochloric acid in combination as chlorides is also present. The waters also contain a notable proportion of boron. It is impossible that more than an extremely small proportion of these acids could have been derived from the adjoining rocks.

The alkali syenite along whose contact the springs ascend was probably a late Tertiary intrusion. Within this rock fluorite occurs in irregular ramifying veinlets in the groundmass or in small areas flecking the feldspar or the ægirine-augite. This mineral appears to represent the final or pneumatolytic period of consolidation. In part it may be primary, since it fills cavities between older minerals, while in part it may be considered as subsequent to the practically complete consolidation. Similar areas of analcite occur in the fresh rock. They were probably formed at the same period as the fluorite and, like it, may be considered as either original or secondary. These minerals doubtless represent not only the final stages of consolidation, but the first stages of volcanic emanations, while the great amount of sulphur and carbonic acid in the spring waters, which appear to have derived their heat directly from the volcanic rocks and which followed the intrusion, may plausibly be ascribed to the gaseous exhalations of the later stages of cooling. The boron in the waters may also be ascribed, with a high degree of probability, to the same process of gaseous exhalation.[a]

While in the rocks through which these waters pass potash is as abundant as soda, it appears that its proportion in the waters themselves is small, compared with that of soda; therefore, most of the potash dissolved is, apparently, not held in solution in the waters, but is probably directly deposited as sericite. The water analyses show that silica also is not retained in any amount at all corresponding to the proportion in the rocks, and the growth of quartz crystals on the walls of the cavities suggests that it is precipitated, after solution, practically in place; the presence of these crystals also shows that cementation of cavities and fissures by quartz is now probably going on at the proper depths. It is likely that the shifting position of the springs, recorded by the mounds of travertine in localities where no water now issues, is due to the repeated cementation of the conduits, forcing the waters to break out through new channels.

The iron shown in the analyses is likewise small in proportion to that which is contained in the rocks, and it appears that it also is precipitated soon after being taken into solution. This is indicated by the limonite mentioned above as coating the cavities near the surface and by the probable iron carbonate which occurs as an alteration product (p. 165); and it is suggested that farther below the orifice siderite and pyrite are being deposited, corresponding with the formation of these minerals which has been studied and described in the wall rocks of the mineral veins and in the vein channels, and which has also been accomplished at an earlier period by ascending hot waters.

The chief bases which are contained in the rocks and which remain in solution in the spring waters are soda, magnesia, lime, and potash, the soda being predominant in both the hot and the cold waters, while in both also the lime predominates over the potash and the potash over the magnesia.

Although some portion of these materials may be of magmatic origin and may have been given off from the cooling magma along with the gaseous or combined acids which accompany them in the waters, yet a large portion, and possibly the greater part or all of them, must have been supplied by the solution of the wall rock. The relatively insoluble rock-making materials have been deposited not far from their place of origin, the solution and precipitation involving a rearrangement, concentration, and freer crystallization of these materials, while the more soluble portions have been retained in solution. Where the spring waters come into contact with the air on emerging at the surface most of the contained lime is deposited as sinter, while the soda, magnesia, and potash are mainly carried off.

ORIGIN OF WATERS.

The conclusion has therefore been reached that the bases now contained in the spring waters, together with those deposited by them near the surface, are the result of rock leaching, and that the acids, both gaseous and combined, have been derived from the emanations of a cooling igneous magma. There remains to be considered the source of the water. The numerous deep tunnels in this region do not reveal the presence of any important amount of atmospheric water passing downward to the subterranean regions. Many of such tunnels have passed from wet into comparatively dry rock at a vertical distance of several hundred feet below the surface.

[a] Spurr, J. E., Prof. Paper U. S. Geol. Survey No. 55, 1906, p. 162.

Therefore the water is ascribed to the same source as that of the hot springs which formed the mineral veins of the region, and which are regarded as exhalations from the more deeply seated portion of the magma.

These active carbonated springs probably occupy the same relation to the alkali syenite intrusion that the hot mineralizing waters did to the bostonite and alaskitic quartz monzonite intrusions which probably antedate that of the syenite.

It is highly probable that at a certain depth, within a few thousand feet of the surface, the waters which emerge at the hot springs are depositing mineral veins at the present day.

CHARACTER OF WATERS IN DEPTH.

At a depth where ore deposition is going on the solutions have probably not the same composition as those which reach the surface, since the composition when they emerge has resulted from the interchange of some of the original chemical constituents with those of the wall rock.

This view was presented in the report on the Tonopah district in Nevada.[a] A study of the different stages of alteration in the wall rocks of the mineral veins at Tonopah resulted in the conclusion that the waters which produced the mineralization contained much silica and potash, with some carbon dioxide and sulphur, silver and gold, and relatively small amounts of other metals. After these waters had altered the wall rocks by interchange of their dissolved substances for those originally contained in the rocks, their composition became very different. It was reasoned out that at this stage they must have contained soda largely in excess of potash, important amounts of lime and magnesia, some iron, a little silica, and a very little alumina, and at best only traces of the rarer metals. These changes, it was concluded, had taken place in the waters as they penetrated laterally, from the circulation channels where the veins were deposited, farther and farther into the wall rock. It was, however, pointed out[b] that similar changes must also take place vertically along the channels of ascending waters, so that the waters which deposited mineral veins at a certain depth would emerge at the surface with the final composition stated above as the result of reactions with the wall rocks.

The composition of the spring waters at Idaho Springs corresponds to that deduced from the study of rock alteration near the mineral veins at Tonopah as the final result of these reactions.

COMPARISON WITH OTHER HOT SPRINGS.

Two other examples of hot springs in the neighborhood of mining districts and intrusive igneous rocks may be taken at random and discussed from the point of view of the foregoing conclusions. The hot springs at Glenwood, not far from the Aspen mining district,[c] contain soda as the predominant constituent, but it is in the form of chloride, no carbonate or other salt being recorded. The next most abundant element is lime, chiefly as sulphate, with a less amount of carbonate. Magnesia occurs as carbonate and chloride, the two salts being in about equal proportions. Potash is here present in the form of chloride and is roughly equal in amount to the lime and also to the magnesia. There is a small amount of bromine and traces of fluorine, iodine, and phosphorus. The temperature here is from 120° to 132° F., and therefore the waters are hotter than at Idaho Springs. The presence of the halogen elements above mentioned suggests that possibly these waters are being given off at an earlier stage of cooling or are nearer to the source of emanation than the Idaho Springs waters, and to this conclusion the predominance of chlorides over sulphates and carbonates at Glenwood as compared with the predominance of carbonates and sulphates at Idaho Springs corresponds.

A much earlier stage of cooling (or a much greater proximity to the volcanic source, or both) than that indicated at Glenwood Springs is apparently represented by the waters at Steamboat Springs, Nev. These springs have a temperature of 167° to 184° F.[d] The waters contain potash in much greater proportion relative to the soda than at Glenwood Springs, and

[a] Spurr, J. E., Prof. Paper U. S. Geol. Survey No. 42, 1905.
[b] Idem, pp. 237, 238.
[c] Mon. U. S. Geol. Survey, vol. 31, 1898, p. 213.
[d] Mon. U. S. Geol. Survey, vol. 13, 1888, p. 347.

in many times larger amount than the lime or magnesia. The Steamboat Springs waters also contain a vastly greater proportion of silica than those at Glenwood. The proportions of the constituents in solution therefore approach those which have been inferred for the mineralizing waters at Tonopah.

At Steamboat Springs also the soda is mainly in the form of chloride, as at Glenwood; and the presence of abundant borates with antimony, arsenic, and mercury, probably in the form of sodium sulphosalts, indicates a comparatively early stage of the emanations. Moreover, the sinter deposited by these springs contains various metals and other elements, including mercury, gold, silver, copper, lead, arsenic, antimony, iron, alumina, magnesia, lithia, soda, potash, silica, and sulphur.[a]

DEDUCTIONS FROM COMPARISONS.

These comparisons emphasize the conclusion already pointed out that in the case of many hot springs which emerge at the surface the mineral bases present are more the result of reactions with the wall rock than of original composition or of magmatic emanations, while the acids (both combined and free), silica, and the rarer metals, with very likely some other bases, such as potash, where this is present, may be original and magmatic.

DIFFERENT TYPES OF WALL-ROCK ALTERATION BY SIMILAR WATERS.

This fact that the formation of gangue minerals and the alteration of wall rocks by hot springs has originated largely from the reaction of the mineralizing solutions with the rocks leads to the deduction that with the same or similar solutions different wall rocks have produced by reaction different minerals. Thus in the Aspen district, if our conclusions are true, the mineralization took place at approximately the same period as in the Georgetown silver district and from similar solutions. In Georgetown the chief gangue mineral is quartz, with small amounts of other minerals, including siderite and barite. The wall rock is altered to quartz, carbonates of iron, lime, magnesia and manganese, and sericite. In Aspen the gangue minerals are chiefly quartz, crystallized dolomite, and barite, and the wall rocks are altered mainly to dolomite, and also to quartz with some iron. The hot springs at Glenwood, near Aspen, above cited, which contain a variety of constituents corresponding in a broad way to those in the Idaho Springs waters, are changing the limestones through which they rise to dolomite, silica, and some iron, the alteration being similar to that of the wall rocks in the Aspen ore bodies. Therefore these waters are probably more or less similar to those which deposited the ores.

EXTENSION OF CONCLUSIONS OUTSIDE OF THE QUADRANGLE.

If the conclusion is true that the more valuable metals in the ore deposits of the Georgetown quadrangle are of direct magmatic origin and that the mineralizing agents emanated directly from cooling magmas, it also probably applies to the districts with which the Georgetown and Idaho Springs districts have been correlated, namely, those which lie on the great northeastward-trending mineral belt and in which, as at Georgetown, the mineralization closely followed the intrusion of monzonitic rocks, and also to the veins of the isolated volcanic centers of Rosita and Cripple Creek, whence alkaline magmas have been erupted. Concerning Cripple Creek, Lindgren and Ransome in their report have concluded that the chief valuable minerals, as well as the mineralizing waters and gases, were of magmatic origin. At Rosita there is strong evidence of a similar origin for the veins. (See p. 126.) A magmatic origin for some of the mineralizing gases in that district has already been argued by Emmons, though the ultimate origin of the water was apparently considered to have been atmospheric, and it was believed that the metals and the vein materials were derived from the rocks traversed by the ascending hot springs, a justifiable conclusion when considered in the light of local evidence alone, though placed in doubt by the wider field of evidence presented in this paper.

[a] Mon. U. S. Geol. Survey, vol. 13, 1888, p. 340.

With reference to the whole group of Colorado ores whose formation followed monzonitic intrusions, the fact that the ore deposition followed closely and was dependent on the eruptions has been emphasized by separate investigators in many different localities, and the conclusion that the ores were deposited by hot ascending waters which derived their heat and dissolving power from the volcanic rocks has been reached in nearly every case. The only exception to this last statement is the Leadville district, where the early studies of Emmons led him to conclude that the ores were leached from the eruptives by circulating waters of original meteoric origin. However, an origin by hot ascending waters in that district has been advocated by a later writer (see p. 105), and in view of the developments made since the first investigation this seems probable, though the result of the subsequent work of descending atmospheric waters may be very important, as it is in the Georgetown district. The writers see no reason for separating the origin of the ores of the Leadville district from those of similar and neighboring districts.

While the explanation of deposition by hot ascending waters has been all but universally adopted by geologists, the source of these waters, in accordance with the formerly commonly accepted explanation of the origin of hot springs, has been supposed to be atmospheric, and the metals have been supposed to have been leached from the consolidated rocks, especially the igneous rocks traversed by the waters. This explanation has almost invariably been offered by different geologists for the various San Juan districts and also by Spurr for the Aspen district.[a] Purington's views concerning the ores of the Telluride quadrangle (p. 114), however, included the belief that a portion of the constituents in the mineralizing solutions had been derived from magmatic exhalations, although he conceived of the waters themselves as of atmospheric derivation.

PROGRESS OF THE MAGMATIC THEORY.[b]

In the study of the Mercur district,[c] made in the year previous to that of the Aspen district, Spurr found within a relatively small area evidence of two distinct but not widely separated periods of mineralization which were marked by quite different metallic and gangue combinations.

His conclusions were that in both these periods the mineralizing agents, including waters, gases, metals, and gangue materials, were of direct magmatic origin,[d] and the difference between the two types of mineral deposits was ascribed to different stages of fumarolic activity.[e] In this paper he dismissed the theory that the ores were deposited by hot springs whose waters were of atmospheric origin, but inasmuch as the conclusion was out of line with current geologic beliefs he hesitated even in his own mind to extend it further than local evidence warranted. In 1896 the same writer studied the gold-quartz veins of the Yukon district in Alaska[f] and concluded that the metallic and earthy minerals contained in these veins, as well as the mineralizing waters and vapors, were of direct magmatic origin, and were so slightly removed in nature and location from the main magma that the resulting veins were best considered as a consolidation phase of the granitic rock; and he suggested that the same explanation would apply to many of the gold-quartz veins in other parts of the world. This theory he has further supported by the published results of his study of the Silver Peak district, Nevada,[g] and in this publication he has argued for a world-wide distribution and eminent importance of this type.[h]

In 1901 Lindgren published an article[i] in which he collected certain literature concerning the occurrence of copper deposits in zones of contact metamorphism around intrusive bodies of monzonitic rocks. The cases cited were chiefly from the regions of the Pacific Cordilleras. These contact deposits contain chalcopyrite or bornite, with magnetite or hematite and usually a small quantity of galena and blende, with the characteristic contact-metamorphic minerals, such as garnet, pyroxene, and epidote forming a gangue. He concluded that the mineralizing

[a] Mon. U. S. Geol. Survey, vol. 31, 1898, pp. 235, 236.
[b] No attempt is made to make this outline complete.
[c] Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, pp. 343–455.
[d] Idem, p. 397.
[e] Idem, pp. 449, 451, 453.
[f] Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1898, p. 312.
[g] Prof. Paper U. S. Geol. Survey No. 55, 1906.
[h] See also Trans. Am. Inst. Min. Eng., vol. 36, pp. 372–402.
[i] Trans. Am. Inst. Min. Eng., vol. 31, 1902, p. 226.

agents, together with the ores and much of the gangue material, were of direct and immediate magmatic origin. This view he has elaborated and supported in his study of the Clifton-Morenci district, Arizona,[a] where he shows that the deposits described are due to emanations of magmatic water gas and other gases, with metallic and earthy materials, from monzonitic intrusions of late Cretaceous or early Tertiary age. These emanations replace the intruded limestone near the contact.

Spurr published in 1905 the result of studies in the Tonopah district, Nevada, a region of gold and silver bearing quartz veins in Tertiary volcanics. He came to the conclusion that these veins had been deposited by magmatic waters and gases given off from cooling volcanic rock; that the valuable metals, together with silica and some other gangue materials, had been derived from the magma, while the iron contained in the pyrites, as well as a large amount of the gangue material, had been derived from the wall rocks. He further correlated these Tonopah deposits, in point of age and origin,[b] with numerous ore deposits in Nevada, Idaho, and Mexico, and argued for the existence of a metallographic province characterized by similar veins and extending along the borders of the Pacific portion of North America; and he also showed the probability that this province is continuous further in both directions, bordering the Pacific on all sides, and so nearly encircling the world.[c]

Since the publication of the Tonopah report, its author has had opportunity to make critical studies of important ore deposits in Mexico, such as he had correlated with the Tonopah deposits, especially at El Oro, in the State of El Oro, and at Guanajuato, both of which have been very productive districts. A striking similarity in the age and composition of the volcanic rocks and of the consequent ores in these districts to the Tonopah type bears out in every respect his previous conclusions derived solely from literature. At El Oro the eruption and profound faulting of an earlier andesite has been followed by the formation of veins along the faults, and this vein formation has been succeeded by erosion. Later the veins have been followed by another flow of andesite, entirely subsequent to the mineralization, though it is of no very recent date, but is evidently Tertiary. The age relations of the rocks and ores here are strikingly similar to those at Tonopah. At Guanajuato the ores appear to be similar in age to those at El Oro, and the vein material is also similar. The principal vein (the veta madre) has formed along a heavy fault in Tertiary andesitic volcanics, corresponding to the earlier andesite at El Oro. The later andesite was not recognized at Guanajuato, although it may be present as dikes or as flows in other portions of the district. The same writer has also recently studied at several places in Mexico—for example, at Matehuala, in the State of San Luis Potosi—typical copper-bearing contact-metamorphic deposits which have formed in limestone on the borders of monzonitic intrusions, and the evidence in these places indicated that the origin of the ore was certainly magmatic, as shown by Lindgren for the similar Arizona deposits. The monzonitic magma which has produced all these contact deposits in limestone is apparently similar in composition and age to that which has been described in this report as responsible for great quantities of ores of silver, lead, and gold in Colorado. Moreover, the petrographic province seems to continue southward from Colorado through Arizona and New Mexico into Mexico, as well as westward into Utah, so that it is suggested that the Colorado silver-lead-gold veins are dependent on the same magma, intruded at the same period, as are the copper-bearing contact deposits in limestone described in Arizona, Mexico, and elsewhere.

Lindgren and Ransome,[d] in discussing the origin of the ores of Cripple Creek, in Colorado, have reached a conclusion similar to that of the senior writer concerning the Tonopah ores and believe that the waters and other mineralizing agents, with the more valuable metallic minerals, were of direct magmatic origin, while some at least of the iron and earthy gangue minerals were derived from the consolidated volcanic rocks by leaching.

[a] Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 219.
[b] Prof. Paper U. S. Geol. Survey No. 42, 1905, p. 273.
[c] Idem, p. 279.
[d] Prof. Paper U. S. Geol. Survey No. 64, 1906, p. 225.

GREAT IMPORTANCE OF WATERS OF MAGMATIC ORIGIN IN THE DEPOSITION OF ORES.

In view of these considerations it appears that the ores that are due directly to emanations from heated igneous magmas and have been deposited from a vehicle of magmatic water and gases—whether segregated within the cooling magma during the closing stages of solidification and forming, according to the best conception, a part of the resultant igneous rock (the gold-quartz veins of Silver Peak, in Nevada); or formed by the reactions of magmatic materials with immediately adjacent limestone into which the magma has been intruded (contact-metamorphic deposits); or formed in circulation channels, especially along zones of faulting, fissuring, or fracturing, at a more or less remote distance from the cooling body (the veins of Georgetown)—are not of slight importance, as was supposed a few years ago. On the contrary, these ores form a class of the very first importance.

CHAPTER II.

HISTORY AND PRODUCTION OF MINES.

HISTORY OF MINING DEVELOPMENT.

The early history of the area here considered is also the early history of Colorado and antedates the act of Congress of February 26, 1861, which organized the Territory of Colorado. A small amount of gold, claimed to have been obtained in the mountains of Colorado, was collected and exhibited by a party of civilized Cherokee Indians in 1857, on their return to the Middle West. The following year W. J. Russell headed a party of nine Georgians to what was then called the Pikes Peak country. After prospecting Platte River, Boulder and Cherry creeks, and other streams with little success, they at last found some gold in a small gulch leading into the Platte about 7 miles below the present site of Denver. The reports carried back to the States in the fall by members of this party caused many to leave for the promising new fields. The financial panic of 1857 probably had much to do with influencing many people to try their fortunes in this then little-known region.

The pioneers of the fall of 1858 founded the towns of Denver and Boulder, and also several minor settlements.

With the spring of 1859 came an influx of prospectors who not only explored the streams along the foothills of the Rockies, but also penetrated deeply into the mountains. Toward the end of January, 1859, B. F. Langley discovered some placer deposits or bar diggings on South Boulder Creek, which afterwards went under the name of the "Deadwood diggings." Before the end of March these deposits gave employment to a number of men and were producing considerable gold. Some gold had been found also on Ralston Creek, a small stream running into Clear Creek several miles below Golden.

The discovery of pay placer gold early in April, 1859, by George A. Jackson was, however, the beginning of mining work in Clear Creek County. This discovery, which was made on Chicago Creek only a short distance above its junction with Clear Creek, near the site of the present town of Idaho Springs, was also about the first really important discovery of gold made in what is now the State of Colorado, and had much to do with causing the stampede toward the new western gold fields during 1859. The discovery and location of the first gold-bearing lode on May 6, 1859, by John H. Gregory caused fully as much or possibly more excitement. This find was made on what is now claim No. 5 on the Gregory lode in Gilpin County, near the present town of Central City. Numerous other mineralized veins were found in the same vicinity shortly afterwards.

Near Georgetown, which at that time was called Elizabethtown, several lodes were discovered at about the same time, and were then worked for gold, although most of them have since been found to produce more silver than gold. Among the most prominent of the veins discovered in the neighborhood of Georgetown was one found on August 1, 1859, by George Griffith.

The Upper Union or Empire district, in which is situated the town of Empire, was located in 1860 by a number of prospectors from the old "Gregory diggings" near Central City and was the seat of great excitement for a few years during the time the surface ores of the lodes were being sluiced.

On February 26, 1861, Congress passed a bill organizing the Territory of Colorado, and Col. William Gilpin was almost immediately thereafter appointed as the first governor.

Although indications of mineral wealth had been found in Clear Creek County in 1859, the developments made during the first few years were not extensive, and most of the production of the Territory previous to 1865 was derived from the gold obtained from the placer deposits along Clear Creek for several miles above and below Idaho Springs and from the sluicing or stamping of the decomposed surface ores of the veins, mainly those in the vicinity of Empire. After about a year of successful mining of surface ores, many of the Empire miners, as their neighbors at Central City had previously been, were confronted by a serious difficulty in amalgamating the heavy sulphide ores which were encountered below the soft material at a depth of about 40 feet below the surface. In the treatment of these heavy sulphides the gold appeared to wash away, while some of the constituents of the sulphides formed a heavy but worthless amalgam with the mercury.

In 1864 Governor R. W. Steele, James Huff, and Robert Layton started out from Empire to search for silver, with the result that on September 14, 1864, the "Belmont lode," on McClellan Mountain, was discovered. This was the first important discovery of a silver-bearing lode in Colorado. The "float" and ore from the vein both gave high assays in silver. In July, previous to this discovery, silver had been found in the Cooley lode, on Glacier Mountain, in Summit County, but ore from that vein carried much lead and only small amounts of silver.

In 1865 and 1866 there was a rush of people to the silver district from all the other counties of Colorado and from other States, and as a result a large number of good silver-bearing veins were discovered on the hills about Georgetown. Little but prospecting was done during these two years, however, and it was not until 1867 that the active development of the principal lodes was commenced and the mining industry of the region began to assume a prominent position. Since the earliest days the stamp mills were the sole arbitrators of the gold product, and the returns from these were usually very unsatisfactory. In 1867, however, the first really successful attempt at smelting the ores of the district was made at Blackhawk, although several smelters had previously been running with little if any profit. The advent of smelting, by opening a new market for the ores, had a very beneficial influence.

Until 1870 great difficulties also confronted the miners from excessive transportation charges for supplies received, as well as for ore or bullion shipped, owing to the lack of railway transportation. However, on June 22, 1870, the Denver Pacific Railroad was completed from Denver to its connection with the Union Pacific at Cheyenne. On August 15 of the same year the Kansas Pacific reached Denver, thus making two through standard-gage lines to the Mississippi Valley. Moreover, by September 24, 1870, the Colorado Central Railway had been built between Denver and Golden and was opened for business, thus bringing communication with the East to the very entrance to the mountain valley of Clear Creek and affording an outlet for the products of the mines at Georgetown, Idaho Springs, and Empire, in Clear Creek County, and also of the Gilpin County mines.

The yield of ore increased wonderfully from 1870 to 1873, owing mainly to discovery after discovery of silver-bearing lodes on the hills about Georgetown and to the development of some of these lodes into extraordinarily rich mines. The development of argentiferous mines in the vicinity of Idaho Springs also helped to swell the output, so that in 1872, according to Raymond,[a] Clear Creek County "surpassed in the production of the precious metals its earlier settled and exploited neighbor, Gilpin." It was about this time also that Hall, Marture & Marshall began to buy high-grade ores and ship them to Europe, principally to Germany. Thus was established a competing market which worked much good to the miners who had ore to sell. A pronounced beneficial effect was also exerted on the mines of the area by the construction in 1872 of a narrow-gage railroad from Golden to Blackhawk, with a branch extending up Clear Creek from the mouth of North Clear Creek to the western base of Floyd Hill, 4 miles above. In the east end of the county near Idaho Springs, and also to a small extent near Georgetown, many of the mines which were formerly worked entirely for gold had been found during the preceding few years to contain much silver, and in some the main value of the ore was found to

[a] Raymond, R. W., Mineral Resources West of the Rocky Mountains, 1873, p. 267.

be in the silver constituent. This change of gold mines to silver mines was mainly due to the starting of the smelters and the obtaining of silver in the matte from ores supposed to be gold ores.

The financial panic of 1873 was a decided catastrophe to the mining industry of Clear Creek County, which consisted mainly of silver mining, for the market for ore mined became very irregular, and prices for ore, which had formerly been fair, became excessively low and only certain grades and kinds of ore were at all salable. In spite of all these drawbacks, which affected the output of the precious metals for some years, the production for 1873 fell only about $250,000 short of the yield for 1872, and that for 1874 was far greater. The reason for so slight a falling off in the output, however, lay in the amount of exceptionally high grade ore taken from the large ore bodies on a few of the newly developed lodes, which to some extent compensated for the nonproduction of some of the mines that were forced to shut down on account of the great financial disturbance.

As a result of this panic, which affected mainly the values of silver, many of the miners near Georgetown began to prospect for gold with more or less success, and since that time there has been a gradual increase in the production of gold from the county, due in part to the development of gold-bearing lodes about Georgetown as well as about Idaho Springs.

In 1872 and 1873, also, began the fierce quarrels between mine owners and the almost endless amount of litigation which for years hampered the development of many of the best properties of the district.

The change of the Territory of Colorado to a State and her admission to the Union on July 4, 1876, seemed to have a quickening influence on the mining industry; and the completion of the narrow-gage railroad from Floyd Hill to Georgetown in 1877 had a very stimulating effect, which was reflected in the great increase in production both for that same year and for 1878.

From this time until 1894, when the records show that Clear Creek County reached the climax of its production, $3,560,669, there appears to have been a fairly gradual increase in its output of precious metals. The remarkable fact is that, in spite of the panic of 1893 and the decline in the price of silver which followed, the total production for both 1893 and 1894 showed a marked increase over both the years which preceded and those which followed. In part this increase was undoubtedly due to the greater development of gold-bearing lodes in the vicinity of Idaho Springs and to some extent around Georgetown, notwithstanding the fact that the decline in silver for a time also seriously affected the production of gold, on account of the intimate association of the two metals in the ores. However, the fact remains that there was also a great increase during these same years in the yield of silver.

Although Clear Creek County is, next to Gilpin County, the oldest producer of gold in Colorado, it still has a production varying between $1,500,000 and $2,000,000 per year, and is maintaining its record as one of the most steady and reliable mining districts in the country.

STATISTICS OF PRODUCTION.

The subjoined table shows the production of the valuable metals in Clear Creek County from 1859 to 1904, inclusive.

Production of valuable metals in Clear Creek County, 1859–1904.[a]

Year.	Gold.	Silver.	Total gold and silver.	Copper.	Lead.	Zinc.	Total.
1859-1868	$2,000,000.00		$2,000,000.00				$2,000,000.00
1866-67		$40,500.00	40,500.00				40,500.00
1868			141,820.35				141,820.35
1869			400,354.00				400,354.00
1870			481,354.08				481,354.08
1871			869,046.34				869,046.34
1872			1,503,391.43				1,503,391.43
1873			1,259,761.06				1,259,761.06
1874			2,203,947.97				2,203,947.97
1875			1,928,161.74				1,928,161.74
1876	95,161.00	1,837,387.31	1,932,548.31		$50,000.00		1,982,548.31
1877	96,500.00	1,984,077.91	2,080,577.91	$3,000.00	123,000.00		2,206,577.91
1878	134,000.00	2,275,105.85	2,409,105.85	4,000.00	98,000.00		2,511,105.85
1879	175,000.00	1,695,000.00	1,870,000.00	17,000.00	80,000.00		1,967,000.00
1880	158,000.00	2,230,000.00	2,388,000.00				2,388,000.00
1881	200,000.00	2,000,000.00	2,200,000.00				2,200,000.00
1882	220,000.00	1,680,000.00	1,900,000.00				1,900,000.00
1883	250,000.00	1,580,000.00	1,830,000.00				1,830,000.00
1884	688,864.44	1,729,189.55	2,418,053.99				2,418,053.99
1885			2,000,000.00				2,000,000.00
1886	599,069.59	2,044,753.94	2,643,823.53	$81,230.00			2,725,053.53
1887	383,939.00	1,733,305.00	2,117,244.00	4,325.00	99,728.00		2,221,297.00
1888	419,820.80	1,896,517.67	2,316,338.47	28,673.02	205,242.36		2,550,253.85
1889	488,631.60	2,559,588.17	3,048,219.77	28,535.66	206,718.84		3,283,474.27
1890	427,991.00	2,496,143.00	2,924,134.00	10,066.00	550,535.00		3,484,735.00
1891	454,573.00	2,284,552.00	2,739,125.00	2,792.00	226,437.00		2,968,354.00
1892	328,205.00	2,218,715.00	2,546,920.00		277,564.00		2,824,484.00
1893	581,088.00	2,528,685.00	3,109,773.00				3,109,773.00
1894	721,181.00	2,839,488.00	3,560,669.00				3,560,669.00
1895	720,776.00	2,065,666.00	2,786,442.00	6,885.00	148,083.00		2,941,410.00
1896	803,261.00	1,977,785.00	2,781,046.00	21,208.00	130,050.00		2,932,304.00
1897	782,006.00	1,810,920.00	2,592,926.00	53,901.00	175,900.00		2,822,727.00
1898	605,528.00	2,024,024.00	2,629,552.00	35,931.00	212,057.00		2,877,540.00
1899	541,663.00	1,654,628.00	2,196,291.00	50,999.00	197,131.00		2,444,421.00
1900	466,193.00	1,737,261.00	2,203,454.00	38,031.00	204,113.00		2,445,598.00
1901	540,969.00	1,639,882.00	2,180,851.00	62,004.00	168,567.00		2,411,422.00
1902	931,671.00	1,649,996.00	2,581,667.00	56,282.00	133,588.00	$5,697.00	2,777,234.00
1903	470,011.00	1,098,622.00	1,568,633.00	40,003.00	147,946.00	35,621.00	1,792,203.00
1904	644,558.00	1,047,347.00	1,691,905.00	50,110.00	173,314.00		1,915,329.00

[a] From reports of the Director of the Mint.

The total production for the years 1859 to 1904, inclusive, is as follows:

Gold,[a] $16,110,326.48; silver,[a] $63,622,310.32; copper,[a] $530,174.68; lead,[a] $3,765,775.20; zinc, $41,318. Total, $84,069,904.68.

These results are reached from the figures in the above table, together with approximations of the product in years for which the record is faulty. The county's yield of the valuable metals prior to January, 1880, is reported to be as follows: Silver, $15,761,907.99; gold, $3,015,661.05; lead, $431,000; copper, $37,000.

[a] Approximate.

CHAPTER III.

THE SILVER PLUME MINING DISTRICT.

GEOLOGIC FORMATIONS.

GNEISSES AND SCHISTS (IDAHO SPRINGS FORMATION).

ORIGIN.

The earliest formation in the area covered by the Silver Plume special map (Pl. XXI) consists of a series of crystalline gneisses and schists, having an irregular strike and a variable but generally steep dip. These gneisses occupy about one-half of the area mapped. A study of them has suggested that they may be divided into three classes on the basis of lithologic differences. The rocks of one class (termed on the map "granitic gneiss with pebble-like inclusions") contain inclusions which are more siliceous than the matrix and which are held to represent original pebbles. It is probable, therefore, that this form of schist was originally a conglomerate. A second class (termed on the map "granitic gneiss") consists of rocks that are similar to the matrix of the first class, but contain no pebbles; many of them are highly siliceous. To follow up the ideas obtained as to the origin of the gneiss of the first class, this second gneiss may be the result of metamorphism of an impure sandstone. The rocks of a third class (termed on the map "black biotitic gneiss") differ from the siliceous gneiss of the second class in containing a very large proportion of biotite. This present mineralogical composition may be due to the rocks' having formed originally a more shaly member of the sedimentary series. The biotitic gneiss occurs at many places interbanded with the light-colored quartzose gneiss.

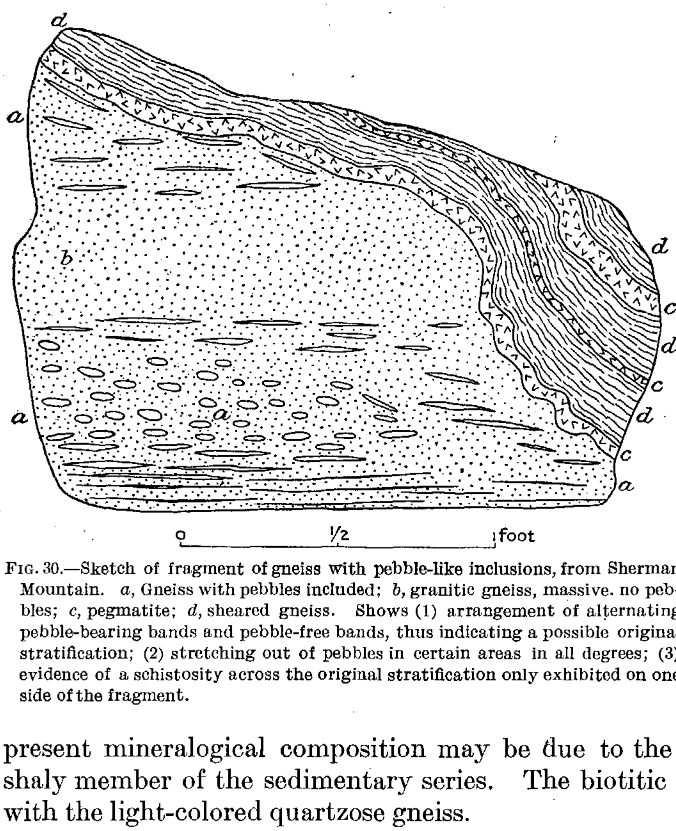


FIG. 30.—Sketch of fragment of gneiss with pebble-like inclusions, from Sherman Mountain. *a*, Gneiss with pebbles included; *b*, granitic gneiss, massive, no pebbles; *c*, pegmatite; *d*, sheared gneiss. Shows (1) arrangement of alternating pebble-bearing bands and pebble-free bands, thus indicating a possible original stratification; (2) stretching out of pebbles in certain areas in all degrees; (3) evidence of a schistosity across the original stratification only exhibited on one side of the fragment.

Some gneiss of the first class, containing probable altered pebbles, shows what are very likely the traces of original stratification, in the alternation of pebble-bearing and pebble-free bands. The gneissic structure cuts across the probable stratification without any regard to it (fig. 30). This shows that the schistosity and gneissic structure are no aids in working out the original structure, and also that the inclusions which have been interpreted as pebbles are independent of the schistosity, and originated previously to it.

U. S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

PROFESSIONAL PAPER NO. 63 PL. XXI

LEGEND
(continued)

Strike of gneissic or schistose structure

Metalliferous veins (Tertiary)

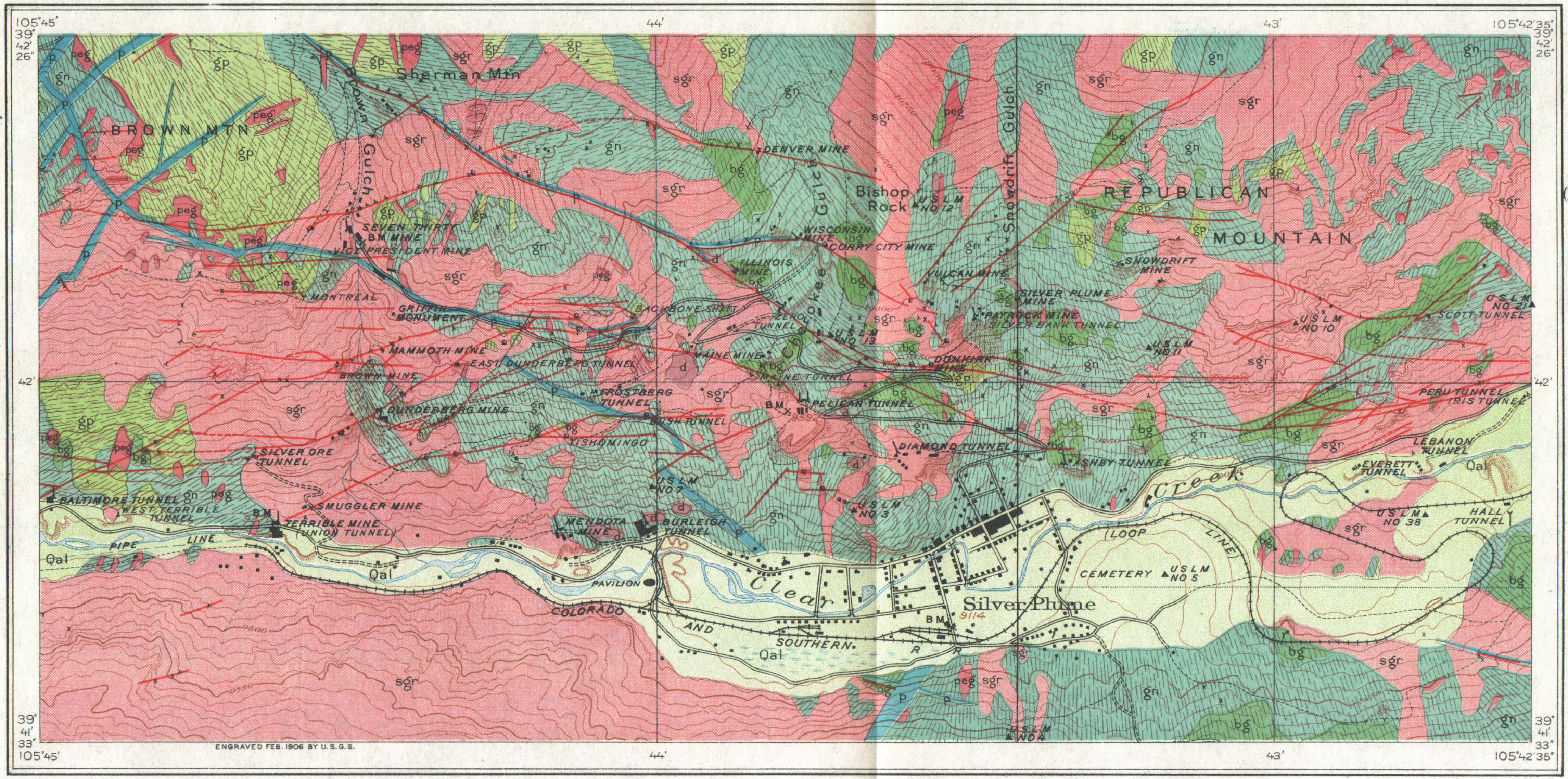
Fault

Shaft

Tunnel

Prospect

Buildings



LEGEND

SEDIMENTARY

QUATERNARY

Qal
Alluvial morainal and stream-worked glacial deposits

METAMORPHIC
(Probably metamorphosed sediments)

PRE-CAMBRIAN (IDAHO SPRINGS FORMATION)

gn
Granitic gneiss
(metamorphosed sandstone or arkose?)

gp
Granitic gneiss with pebble-like inclusions
(metamorphosed conglomerate?)

bg
Black biotitic gneiss
(metamorphosed shale?)

IGNEOUS INTRUSIVES

TERTIARY OR LATE CRETACEOUS

p
Porphyry dike rocks

PRE-CAMBRIAN

sgr
Silver Plume granite

peg
Pegmatite

d
Dioritic rocks

E. M. Douglas, Geographer.
Frank Tweedy, in charge of section.
Topography by Pearson Chapman.
Triangulation by Frank Tweedy.
Surveyed in 1904.

GEOLOGIC MAP OF THE SILVER PLUME DISTRICT, COLORADO

Geology by J. E. Spurr and G. H. Garrey

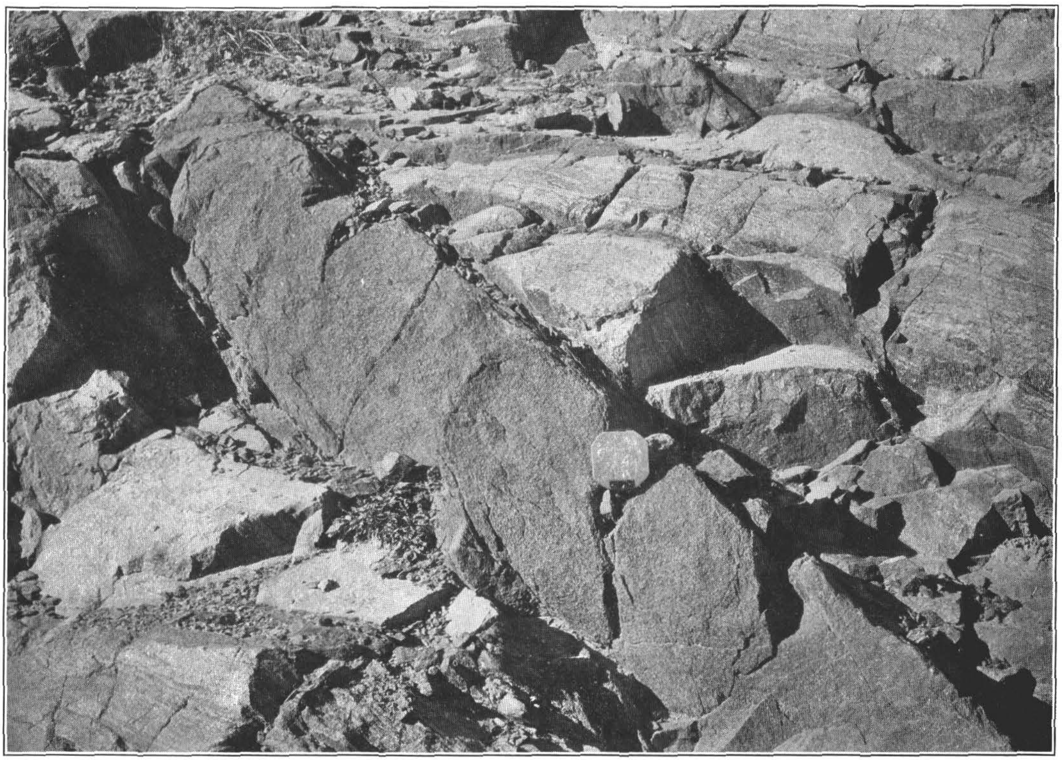
Scale $\frac{1}{12000}$

0 $\frac{1}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ $\frac{3}{4}$ 1 mile

1000 500 0 1000 2000 3000 4000 feet

200 100 0 500 1000 meters

Contour interval 50 feet.
Datum is mean sea level.
1906



A. DIORITIC DIKE (OF HORNBLENDE GNEISS) CUTTING ACROSS THE BANDING OF GRANITIC GNEISS BELONGING TO THE IDAHO SPRINGS FORMATION.

The dioritic dike also cuts across pegmatite, which has been injected into the Idaho Springs gneiss. From the roadside just east of Pelican tunnel.

B. SCHIST INJECTED BY PEGMATITE, ON ROADSIDE NEAR EMPIRE PASS, SOUTHWEST SIDE OF DOUGLAS MOUNTAIN.

PEBBLE-BEARING GNEISS.

DESCRIPTION.

In the gneiss that has been interpreted as metamorphosed conglomerate, the matrix, which is invariably biotitic, contains nonbiotitic white flat lenses, bands, or streaks, arranged like the pebbles of a conglomerate. A study of many examples shows that the original form of these was round or oval, like that of pebbles. (See Pl. VII, p. 38.) These probable pebbles, with the inclosing matrix, have been elongated by stretching, apparently while in a substantially plastic condition, so that the pebble-like forms become long, flat, and thin, and in extreme stages (see Pl. VIII, *A*, p. 40) are represented only by thin, flat, siliceous streaks, which would be no longer noteworthy or suggestive were it not for the observed transition. Such elongated pebbles are in places contorted with the inclosing matrix.

The less deformed pebble-like forms are easily detachable from the granitic gneiss matrix and can hardly be explained save as the pebbles of a conglomerate. Originally they must have consisted of impure quartzite. The conglomerate may have contained other pebbles, but only these would easily survive metamorphism and be detectable in an altered rock.

As seen under the microscope, the line between pebbles and matrix is usually sharp, though locally there is some slight overlapping of material. The granitic gneiss matrix has a fine-grained, allotriomorphic granular structure. The principal constituents are quartz, microcline, and biotite. In portions of some specimens quartz is predominant, with very little feldspar; in other specimens feldspar is subordinate and the rock consists mostly of quartz and biotite. Granules of zircon are usually abundant. Sillimanite is common, but much less so than in the pebbles. Altogether there is a decided chemical difference between the pebbles and the matrix.

The pebbles are composed almost entirely of quartz and dense fibrous sillimanite or fibrolite, the proportion of the two minerals varying, but quartz being in general decidedly preponderant. The two minerals are intergrown, or the fibrolite occurs as inclusions in quartz. Here and there some muscovite is present, apparently in process of alteration to fibrolite. Crystals of biotite, zircon, and micaceous hematite appear in some of the quartz-sillimanite areas; tiny green hornblende crystals have also been observed in the quartz.

A few of the pebble-like inclusions contain feldspar, which is disseminated throughout the pebble or forms a fringe around a more quartzose nucleus. In the locality where these feldspar-bearing pebbles were observed they are cut by stringers of pegmatite, showing that they themselves are not of pegmatitic origin. Under the microscope the feldspathic pebbles appear otherwise substantially like the nonfeldspathic ones, consisting chiefly of quartz and fibrolite. The feldspar that is associated with these minerals is fresh and comprises orthoclase and some microcline. Biotite is locally present in varying quantity, as is also muscovite.

DISTRIBUTION.

The chief occurrence of this metamorphosed conglomerate is in the northwest corner of the area represented on the Silver Plume special map (Pl. XXI). Farther south, on the west edge of this area, just north of Clear Creek, similar rock is present, though extremely stretched and intricately injected by pegmatite. The principal localities of this phase of the gneiss, within the area shown on the special map, occupy a rough belt trending northeast and southwest across the western part of the area. Farther southwest, along the extension of this belt, other occurrences of this variety of the gneiss have been noted by Mr. Ball. It is probable that this belt represents the strike of an original heavy conglomerate series. The schistosity does not conform with this strike, and indeed has no relation to it. In the northwest corner of the area the schistosity is perpendicular to the strike and in other localities cuts across it at a lesser angle.

GNEISS WITHOUT PEBBLE-LIKE INCLUSIONS.

The second and third varieties of gneiss, which have been interpreted respectively as altered impure sandstone and altered shaly sediments, are intimately mingled within the area here discussed, but the dark-colored, highly biotitic gneiss is most abundant in the southeastern portion, covering a rough northeast-southwest trending zone, which is parallel to the zone of conglomeratic gneiss.

Under the microscope the gneiss of the second class, which does not contain pebble-like inclusions, is shown to have a general composition varying from that of granite to that approaching an impure quartzite. Quartz is usually predominant, in some cases making up four-fifths of the entire section. The feldspar is microcline and oligoclase (including oligoclase-andesine and oligoclase-albite). Biotite, muscovite, magnetite, and zircon occur in much less quantity.

The dark-colored biotitic gneiss which represents the third class differs from the last-described variety in the much greater proportion of biotite and the subordinate amount of feldspar and quartz.

INJECTION OF GNEISS BY PEGMATITE.

The gneisses and schists of the region have been intricately intruded by a siliceous pegmatite, which has taken the form of pegmatite, alaskite, muscovite granite, and pegmatitic quartz,

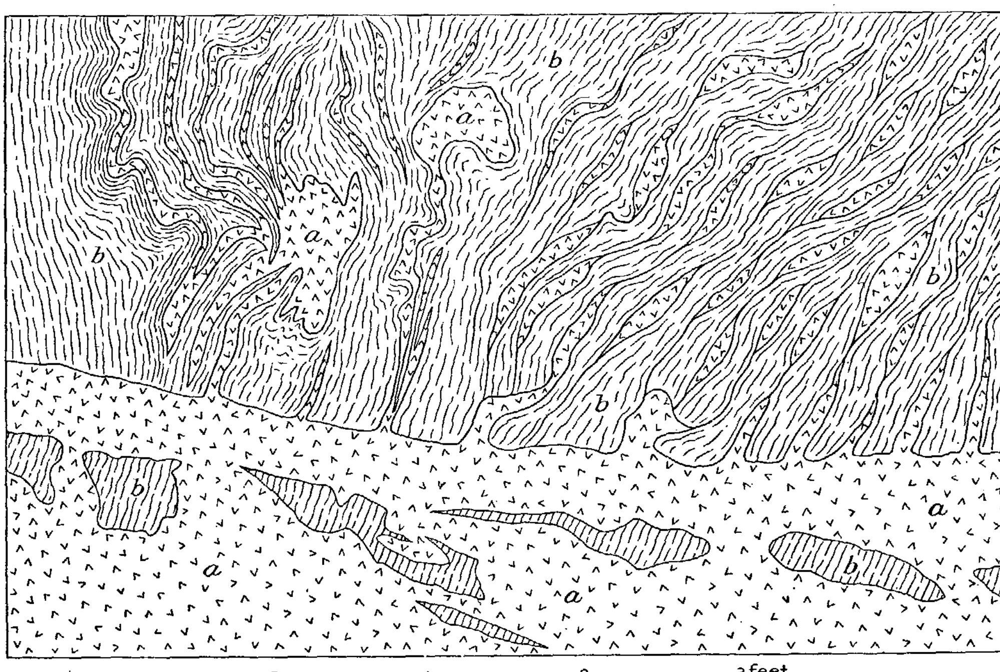


FIG. 31.—Sketch of vertical outcrop at extreme northwest corner of area shown in Pl. XXI, showing schist intruded by crosscutting pegmatite dike (*a*) which sends out tongues and lenses between the laminæ of gneiss (*b*).

one variety passing into another within a very short distance (fig. 31). As a rule the injections of pegmatite have found their way along the laminæ of the schistosity, but in numerous places there are also crosscutting dikes. Many of the intercalations of pegmatite between the laminæ of the schist are convoluted, and on superficial observation appear to have been folded, and thus to be older than the crosscutting dikes. In places, however, such dikes send out tongues between the laminæ, showing that the folding of the schist was in the main previous to the injection, and that the injected pegmatitic material has simply followed the curves of the folding. This pegmatitic material has been injected into the schist in all proportions, so that in different parts of a single outcrop the schist and the pegmatite are alternately predominant. An extreme phase shows pegmatite with only shreds of gneiss remaining.

In one place noted in the northwest corner of the Silver Plume special area the gneiss, which is intruded by the pegmatite, proves under the microscope to be of the ordinary variety, consisting principally of quartz with numerous small grains of biotite, microcline, and oligoclase, all sparse in relation to the quartz. Another specimen of the same rock appears to have been altered by the pegmatitic injection; the biotite is partly bleached and the feldspar is entirely altered to what at first seems a sericitic product. The highest power of the microscope, however, shows for this alteration product a pale-green color, faint pleochroism, and complete extinction, indicating probably a fibrous variety of amphibole. In this rock there are some small pink garnets and considerable epidote.

DIORITIC ROCKS.

HORNBLENDE GNEISS OR SHEARED DIORITE.

Hornblende gneiss or sheared diorite occurs only in a few narrow bands within the area shown on the Silver Plume special map. The localities are also widely separated. This rock is younger than the gneisses and schists which have been described, whose schistosity they traverse at an angle in many places, although in others they conform to it. In one locality the sheared dioritic gneiss was noted as cutting across and through the pegmatite intercalated in the gneiss as well as the gneiss itself (Pl. XXII, *B*). At another locality, however, pegmatite which was believed to be of the same age as that just noted was observed cutting through the hornblende gneiss (Pl. XXII, *A*). These two occurrences, indicating that the pegmatite is found locally older, as well as younger, than the hornblende gneiss, would suggest that both rocks are in general contemporaneous, and this accords with the studies made over the whole Georgetown quadrangle by Mr. Ball.

Under the microscope the hornblende gneiss shows a fine allotriomorphic granular gneissic structure. The constituents are feldspar, hornblende, quartz, and biotite, in some specimens all nearly equally abundant. The feldspar is chiefly oligoclase and andesine, with labradorite here and there. Ilmenite and zoisite are also abundant, the latter in long prisms in quartz, feldspar, biotite, etc. Titanite is present, and in much of the rock abundant, usually surrounding ilmenite. In one specimen original pyrite takes the place of the ilmenite.

The feldspar in these rocks is in places partly or completely altered to sericite or coarser muscovite, with a little chlorite and secondary biotite, or to sericite and quartz.

MASSIVE DIORITIC ROCKS.

DISTRIBUTION AND AGE.

Massive dioritic rocks occur within the territory covered by the Silver Plume special map chiefly in one or two areas of small extent in the vicinity of the Wisconsin and Maine workings. The amount of these rocks is considerably greater than that of the hornblende gneiss just described. This massive diorite appears to be equivalent to a fairly regular coarse diorite studied by Mr. Ball in other portions of the quadrangle, where much of it shows a tendency toward segregation of its constituent minerals. The rocks within the Silver Plume area show this tendency carried to an extreme.

This massive diorite is certainly older than the porphyritic granite, which cuts and includes it. Within this special area its age relation to the hornblende gneiss is uncertain, both being younger than the ordinary gneiss and schist formation and older than the porphyritic granite. Mr. Ball, however, has collected from other parts of the quadrangle evidence which shows a quite distinct age of the two formations, the sheared gneiss being the older of the two.

RESULTS OF DIFFERENTIATION.

Large outcrops of the massive diorite formation near the Wisconsin and upper Maine workings are streaked and blotched in many places with light-colored acidic material, and contain nests and seams of pegmatite, commonly consisting of quartz, feldspar, and mica. This pegmatite locally changes to nearly pure feldspar or to pure pegmatitic quartz. The dark-colored rock in which the pegmatitic streaks lie is an irregular coarse diorite which varies to a hornblendite. Close observation and study show that the pegmatite, diorite, and hornblendite are contemporaneous, the result of a thorough differentiation of the material in place.

Every transition is observed between pegmatite, quartz, and hornblendite, at many places within a few inches or feet. The smaller pegmatitic blotches or seams may contain hornblende, but the larger ones contain mica instead, and the hornblendite itself near the point of passing into pegmatite contains mica. Characteristically the pegmatite in large bodies is slightly younger than the black hornblendite and cuts across it, showing that the acidic materials of the magma consolidated later than the hornblende, according to the well-known rule. Many large bunches of pegmatite and even pegmatitic quartz, however, are simply nests segregated in the hornblendite. and the smaller seams almost invariably show contemporaneity and the continuation of crystallization from the basic to the acidic extremes. The process of differentiation has been singularly perfect and complete within a small rock mass, and all the different varieties must have formed practically in place during a very long period of consolidation. The banding and streaking which the outcrop shows is not a structure induced in the consolidated rock. The internal structure of the rock in these streaks is the same as where the rock is massive. The banding is due to flow while the material was still plastic and may have been brought about by pressure.

Within a distance of 50 to 75 feet specimens were collected which show numerous stages of transition from hornblendite to pegmatite, with the intervening dioritic phases. All these phases are equally common, the normal diorite being not more abundant than the extremes.

Microscopic examination of these specimens shows the constituent minerals mixed together in all proportions, indicating a very irregular segregation. The essential constituents of the rock are andesine-oligoclase, hornblende, augite, ilmenite, titanite, and probably rutile and zircon. Certain specimens illustrating extreme segregation are of pure feldspar rock; others are of pure hornblende rock with or without augite. In some rocks augite is predominant. In one section the usually very scanty apatite was found to be present in numerous large grains, making up about 5 per cent of the whole field.

The augite is green, and much of it is intergrown with green hornblende. It is altered in many places along the margins and locally along the cleavages to green hornblende, and the two relations are often found to occur in the same slide. The alteration of augite to hornblende is in some specimens accompanied by its partial alteration to golden-brown serpentine, with a little calcite. In other specimens the continuation of this process is shown by pseudomorphs after pyroxene, consisting of serpentine, calcite, and green hornblende.

Locally the hornblende is considerably altered to chlorite. Sometimes it is found included in tremolite. An intermediate rim of glaucophane has been noted around the hornblende, separating it from the inclosing tremolite. Colorless diopside is in places associated with the hornblende of the hornblendite. Brown biotite is an essential constituent in some phases. Quartz is rare and in irregular grains. Calcite is usually in small grains and is of uncertain derivation. One specimen examined consists of about 60 per cent hornblende, 20 per cent ilmenite, and 20 per cent calcite, all crystallized and apparently contemporaneous.

The feldspar is andesine-oligoclase. Some of the crystals of feldspar include small crystals of idiomorphic augite and hornblende. Feldspar occurs partly or completely altered to sericite and fine muscovite, or to sericite and epidote, or entirely altered to a fine mat of tremolite, also to broad plates of tremolite.

Tremolite occurs in many large crystals. In one section it was noted as containing large grains of calcite, epidote, titanite, and green hornblende. The green hornblende in one section seems to fade into the tremolite, with an intermediate rim of glaucophane at many points; in some portions of the same section subordinate fresh feldspar is present. Tremolite also occurs in blades penetrating the rock, filling cracks in feldspar, etc.; also replacing feldspar, as noted in the preceding paragraph.

Ilmenite is characteristically surrounded by relatively more abundant titanite, which probably represents a later crystallization. Locally the ilmenite is without this border. The ilmenite is in general closely associated with and is included in hornblende. In one rock noted, ilmenite and calcite are associated and seem contemporaneous.

The titanite generally forms borders around the ilmenite, and also occurs in separate grains. It is generally included in the hornblende.

Epidote is rather common in the form of grains, and in some places is clearly one of the alteration products of the feldspar, occurring with sericite.

ORDER OF CRYSTALLIZATION OF ROCK-MAKING MINERALS.

The general order of crystallization of the rock-making minerals may be stated as follows, with more or less reservation: (1) Green augite; (2) hornblende (largely due to the alteration of augite) with diopside, titanite, and probable rutile; (3) biotite, feldspar, and quartz; (4) in the last stage of consolidation or after practical consolidation muscovite (sericite), calcite, epidote, tremolite (and glaucophane).

PEGMATITES.

Pegmatites are very abundant in the region shown on the Silver Plume special map. They belong to three different groups, which are distinct in age.

EARLY PEGMATITE INJECTION.

The pegmatite of the oldest group is by far the most abundant and forms intricate intrusions and injections in the gneiss and schist series throughout the area; it also occurs at many places in considerable masses. This pegmatite has muscovite granitic phases and alaskitic phases, but the different varieties change into one another within short distances. This pegmatite is distinctly older than the ordinary granite of the region, and, as before stated, is probably about the same age as the sheared diorite or hornblende gneiss.

The constituent minerals of the pegmatite are quartz, microcline, orthoclase, and in many places coarse muscovite. Accessory biotite occurs locally. Small scattered needles of sillimanite occur in much of the quartz and also in the feldspar. A specimen of the alaskitic pegmatite, taken from the contact of the gneiss into which it is intrusive, showed considerable fibrolite in large and small bunches, practically confined to the muscovite crystals in the rock. This fibrolite is characteristic of all the muscovite in the rock, and the mode of occurrence suggests that it has arisen from the alteration of the muscovite.

PEGMATITIC PHASES OF MASSIVE DIORITIC ROCKS.

Pegmatites of the second class are those derived from the coarse diorite already described as a highly siliceous differentiation product. The dioritic masses in the vicinity of the Wisconsin and upper Maine workings contain seams of pegmatite, in part hornblendic, which are segregated from and in general are contemporaneous with the black hornblende-bearing part of the rock, though many of them are slightly later than this part, showing a relatively later crystallization. This pegmatite, together with the other phases of the coarse diorite here, is distinctly older than the Silver Plume granite, which cuts through it. Further characteristics of this pegmatite are mentioned under the heading "Massive dioritic rocks" (p. 179). It is doubtful if it occurs except in close connection with the diorite as above described.

PEGMATITIC PHASE OF SILVER PLUME GRANITE.

Connected with the eruption and consolidation of the typical granite of the region is a pegmatitic phase. Pegmatite of this class is much less abundant than that of the older period first described, but probably considerably more abundant than the pegmatitic phase of the diorite. The pegmatite connected with the granite represents the closing stages of consolidation of that rock.

GENERAL COMPOSITION.

The principal minerals of this pegmatite are quartz and feldspar. In much of the pegmatite that consists chiefly of these two minerals the feldspar is mostly on the edges and the quartz in the center, a distribution which has been previously noted in pegmatites in other regions. A large part of the pegmatite consists of quartz alone. In addition to quartz and feldspar, muscovite is very abundant and characteristic.

OCCURRENCE AND RELATIVE AGE OF MAGNETITE, MUSCOVITE, AND ZIRCON.

Some specimens of pegmatite show nearly as much magnetite as quartz and feldspar. The granite itself contains considerable magnetite, and where it becomes coarse granite and approaches a pegmatitic structure, even though it is not pegmatite properly speaking, much of it contains considerable lumps of this mineral.

A specimen of coarse pegmatitic granite from Leavenworth Mountain contains a lump of magnetite 1½ inches long and half an inch thick. A thin section of this rock shows an allotriomorphic granular structure, with a texture varying from medium fine to medium coarse. Feldspar (microcline and orthoclase) is predominant, with subordinate quartz and here and there small muscovite. Magnetite is present in crystals not larger than usual; but more numerous, and in many places bunched together.

Near the same locality a pegmatitic vein in granite is made up entirely of quartz and magnetite. This vein is very regular and straight and from one-half to two-thirds of an inch in diameter. In part it consists mainly of magnetite and in part mainly of quartz, the magnetite on the whole being predominant. The vein contains no feldspar. One tiny crystal of biotite was observed. While this vein is undoubtedly of pegmatitic origin, this fact would hardly be recognized without a general study of the pegmatites of the region. Near by this vein magnetite of pegmatitic origin occurs without quartz as a facing on a bowlder, representing a vein whose other wall has been broken off.

Microscopic examination of the specimen of granite containing the quartz-magnetite vein above referred to shows that the structure of the granite is pegmatoid. The chief mineral is fresh microcline with large crystals of oligoclase-andesine, which include small areas of muscovite. There is a little zircon. Magnetite is present in small crystals. Near the quartz-magnetite veinlet the scattered crystals unite to form a solid vein, intergrown with coarse crystalline quartz. There is no sharp dividing line between the granite and the pegmatitic vein, but the outline of the magnetite in the vein against the granite wall consists of an aggregate of idiomorphic magnetite crystals, in contact with the feldspar, muscovite, etc., of the granite. The magnetite and quartz of this pegmatitic vein have been the last minerals of the granite to crystallize. Some, at least, if not all of the isolated idiomorphic magnetite crystals in the rock away from the pegmatitic vein are of similar origin to the magnetite in the vein, as is shown by their clustering together in the proximity of the vein.

This observation shows the futility of the ordinary criterion, by which magnetite is judged to be one of the first minerals to crystallize from a magma. The fact that magnetite typically occurs in idiomorphic crystals included in the quartz, feldspar, biotite, etc., of granites, has led to this conclusion; but the present observation shows that magnetite may have this habit and nevertheless be one of the last minerals to crystallize, as is shown by its occurrence in large amounts in the pegmatite. This occurrence indicates that the magnetite has the property of being diffused through the already consolidated minerals and crystallizing as isolated individuals in them, without necessarily obtaining access through any definite channels.

Microscopic examination was also made of the wall rock of the magnetite vein on the granite bowlder above mentioned. The granite here is semipegmatitic and contains quartz and feldspar with sparse biotite and more muscovite. The feldspar is about one-third microcline and about two-thirds striated feldspar, probably in part oligoclase-andesine. The striated feldspar contains numerous inclusions of calcite and muscovite. The muscovite varies from grains of a very tiny size, such as would usually be called sericite, to coarse ordinary granitic muscovite. The calcite grains show the same variation in size. These numerous fine inclusions give the feldspar a typically altered appearance. The coarser muscovite blades in the rock are undoubtedly of the same origin as the fine ones, and many of them follow cleavages in the feldspar. The microcline is fresh; some muscovite of the coarser type is here and there intergrown with it. Muscovite occurs also intergrown with quartz. Small rounded zircon grains are present. Ordinary magnetite in single crystals or bunches of crystals, not different in appearance from the magnetite of ordinary granites, is scattered here and there. Yet magnetite occurs on the face of this specimen as a mineral of the pegmatitic phase and the last mineral to crystallize. All of the magnetite, moreover, is probably of the same age here.

The intergrowth of microcline and muscovite suggests that the older feldspar has been altered to muscovite before or during the crystallization of the microcline. The fact of this intergrowth is against the explanation that there has been selective alteration of the feldspars to muscovite, affecting the older striated feldspar and not affecting the clear unaltered microcline. The order of crystallization in this rock is as follows: (1) Feldspar (andesine-oligoclase?); (2) muscovite and calcite; (3) quartz and microcline; (4) magnetite (and zircon?).

The relative age of zircon is not plainly shown in this specimen. In a specimen of magnetite-bearing pegmatite obtained near Freeland, however, described on page 62, large crystals of zircon occur as one of the pegmatitic minerals, constituting with magnetite and quartz the last of the granitic minerals to crystallize. Zircon has usually been supposed to be one of the first minerals to consolidate from a granitic magma,[a] the conclusion being based on the fact that, like magnetite, it occurs in idiomorphic crystals inclosed in all the more essential rock constituents, like quartz, feldspar, and biotite. The observation previously made concerning the magnetite, however, shows that this criterion is not reliable, and suggests that later-formed minerals may crystallize in the midst of earlier-formed ones by some process of molecular diffusion.

A pegmatite vein containing quartz and muscovite observed near the magnetite-bearing pegmatites on Leavenworth Mountain shows pure quartz on both sides and muscovite filling up the center in a regular band (fig. 32). This occurrence seems to indicate the filling of an opening in the solidified granite by the successive deposition of pegmatitic materials.

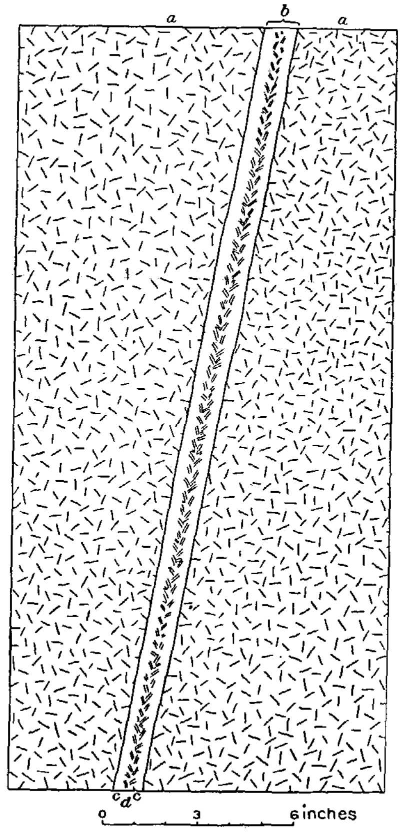


FIG. 32.—Pegmatite vein (showing banding) in granite. *a*, Granite wall rock; *b*, pegmatite vein; *c*, pure quartz with occasionally a fleck of uncrystallized muscovite; *d*, solid muscovite, very regular.

SILVER PLUME GRANITE.

Granite of nearly uniform structure and texture occupies about one-half of the area shown on the Silver Plume special map. This granite is younger than all the other rock formation previously described except the latest pegmatite, which represents the final stage of its consolidation. The other rock formations are intruded by the granite. The older gneiss, which except the granite is the most widely distributed rock formation, is intricately cut by the granite, as is well shown on the geologic map, and where the contact is observed on a smaller scale the intrusion is still very intricate. On the extreme west edge of the mapped area, north of Clear Creek, immense bowlders of gneiss occur in the granite, forming a gigantic breccia.

As a rule the granite, though massive, has a porphyritic habit, marked by the more or less completely idiomorphic feldspars. The increase in size and number of these feldspars produced a highly porphyritic type known to the miners as "corn rock."

[a] See, for example, Rosenbusch, H., and Iddings, J. P., Microscopical Physiography of the Rock-Making Minerals, 4th ed., p. 154. W. C. Brögger, however (Mineralien der Syenitpegmatitgänge: Zeitschr. für Kyrst., vol. 16, 1890, p. 164), regards it as probable that zircon is formed by the action of mineralizers, probably fluorine, and notes that while it is formed during the ordinary magmatic consolidation, it is also formed during the pegmatite period. A. La Croix (Nouvelles archives du Muséum, Paris, 1902, vol. 4, p. 86) has described an alkaline granite from Madagascar, in which zircon is later than all the minerals except quartz. The present writer, in a study of the alaskites of Silver Peak, Nevada (Prof. Paper U. S. Geol. Survey No. 55, 1906, p. 105; also Trans. Am. Inst. Min. Eng., vol. 36, 1906, p. 391), found that zircon was one of the last minerals to crystallize, and was especially associated with the quartz.—J. E. S.

The constituent minerals of the granite are feldspar, quartz, biotite, muscovite, and magnetite. The feldspar consists of microcline, orthoclase, and oligoclase. Ordinarily the feldspars are more or less altered, chiefly to sericite. In the process of alteration the oligoclase seems to be most easily attacked, and the orthoclase next, while the microcline is invariably fresh. Original pyrite is present here and there.

PORPHYRIES.

The youngest of the rock formations in the Silver Plume area consists of dikes of porphyry. These are not very abundant and usually are of relatively small size. In the northwestern part of the area the porphyry is more abundant than elsewhere. The longest dike shown on the map is traceable from the northwest corner southeastward to Clear Creek near the Burleigh tunnel. Most of the dikes trend northwest and southeast; a number of others trend northeast and southwest, nearly at right angles to the first set. These dikes were not all intruded at the same time, but nevertheless seem to represent a single general period of igneous intrusion. They are all younger than all the other rock formations described, and are all, so far as known, older than the veins of the district. As a rule no determinations as to relative age have been possible; the only exception is in the case of the porphyry encountered in the Baltimore tunnel. This tunnel follows a dike of white porphyry with glassy borders, which is intrusive into the gneiss. This light-colored porphyry is found to be intrusive into a brownish porphyry which is exposed for a short distance only in the walls of the tunnel. The two porphyries are mainly fresh. As a rule the dikes of the district are thoroughly altered, so that no fine distinctions as to original composition can be made. All, however, seem to be either alaskite porphyries, granite porphyries, or quartz monzonite porphyries, and in most cases it is not possible to tell, on account of their thoroughly altered condition, into which class a given dike falls.

The white porphyry of the Baltimore tunnel is an alaskite porphyry containing scattered phenocrysts of quartz and orthoclase in a glassy to microgranular groundmass. The brown porphyry has a fine microlitic groundmass and contains numerous phenocrysts of biotite, andesine, some orthoclase, and quartz. In the hand specimen certain altered dark phenocrysts suggest pyroxene.

The other dikes of the region, such as the dike through which the Seven-Thirty and other veins cut transversely, and the dikes along which the Bismarck, Pelican, and Corry City lodes have formed, are in a high state of alteration. Microscopic examination shows scattered quartz phenocrysts and abundant alteration pseudomorphs after biotite. The presence of calcite among the alteration products indicates as a rule a certain amount of lime-bearing feldspars. Apatite is a constant accessory in all these dikes and is unaltered.

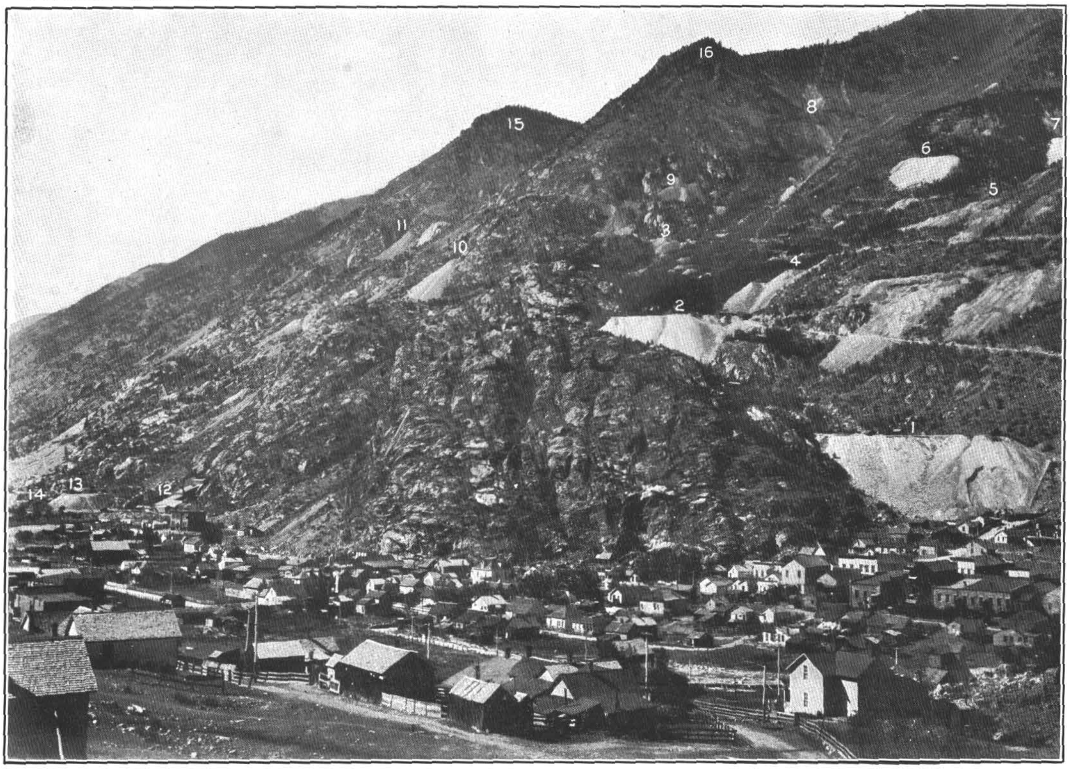
DISPLACEMENT OF ROCKS.

PREPORPHYRY MOVEMENTS.

This region seems to have suffered during a considerable period under the effects of dynamic stress. The porphyry dikes described above are part of a more extensive zone of similar dikes which extends in a northeast-southwest direction. The dikes themselves have either a northeast-southwest or a northwest-southeast extension. The general trend of these dikes, and the fact of their location in a definite belt extending through the ancient rocks of the region, suggest that the intrusion took place along this belt on account of its being a zone of weakness, and that the porphyry rose through the planes of weakness produced by the stress.

POSTPORPHYRY MOVEMENTS.

It is at least certain that the porphyry dikes subsequent to consolidation were themselves zones of weakness, and that general dynamic stresses continued to be felt in the rocks of the region. In many places these stresses found relief most easily along the dikes, producing faulting parallel to their strike and dip. The actual amount of displacement produced by this faulting was generally small. Numerous examples have been noted where it amounted to a move-

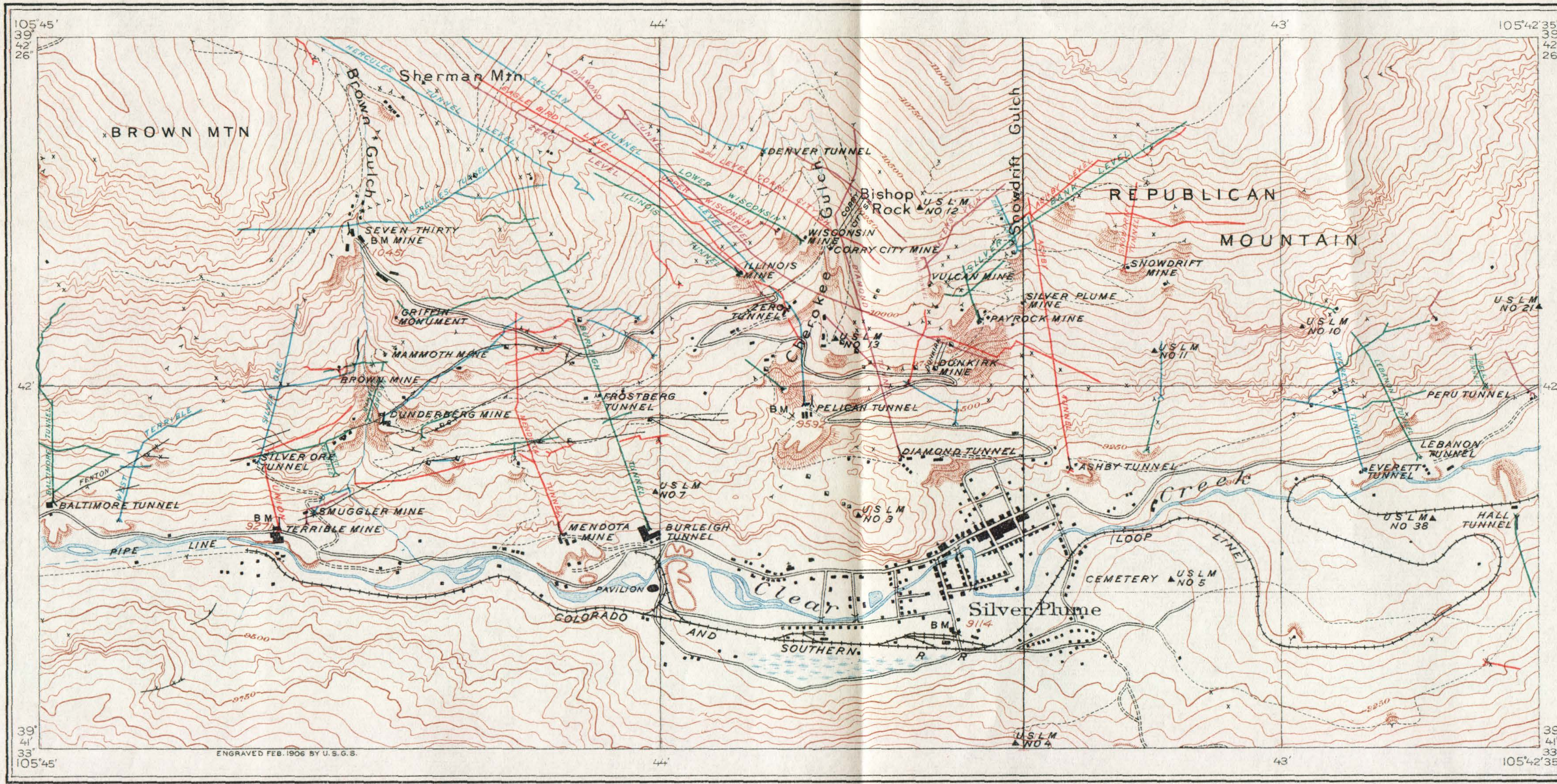


A. SHERMAN AND BROWN MOUNTAINS, FROM CEMETERY HILL.

1, Diamond tunnel; 2, Pelican tunnel; 3, Maine mine shaft; 4, Eagle Bird tunnel; 5, Dives vein, old workings; 6, Illinois tunnel; 7, Wisconsin mine, upper tunnel; 8, Bismarck vein, upper workings; 9, Backbone tunnel; 10, Frostberg tunnel; 11, Montreal mine; 12, Burleigh tunnel and Dives-Pelican-Seven-Thirty mill; 13, Victoria tunnel, Mendota mine; 14, Mendota mill; 15, Brown Mountain; 16, Sherman Mountain.

B. MINES NORTH OF SILVER PLUME, FROM SLOPE OF LEAVENWORTH MOUNTAIN.

1, Diamond tunnel; 2, old workings on Dives vein; 3, Illinois mine; 4, Dunkirk shaft; 5, Silver Bank tunnel, Pay Rock mine; 6, Silver Plume mine; 7, Vulcan mine.



E. M. Douglas, Geographer.
Frank Tweedy, in charge of section.
Topography by Pearson Chapman.
Triangulation by Frank Tweedy.
Surveyed in 1904.

MAP OF THE SILVER PLUME MINING DISTRICT, COLORADO
SHOWING SKELETON OF PRINCIPAL UNDERGROUND WORKINGS

Mine workings compiled from mine maps by H. F. Clarke.

Scale $\frac{1}{12000}$

0 $\frac{1}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ $\frac{3}{4}$ 1 mile

1000 500 0 1000 2000 3000 4000 feet

200 100 0 500 1000 meters

Contour interval 50 feet.

Datum is mean sea level.

1906

ment ranging from only a few inches to a few feet, while in many other places it probably did not exceed a score of feet. Here and there, however, the displacement was probably greater, though no well-proved cases can be cited.

The direction of movement in these postporphyry displacements was in general horizontal, as is proved by numerous observations on the striæ which mark the fault planes. These show that the movement was slightly variable in different places, but that practically the maximum deviation from the horizontal direction was 30°, while the greater majority of striæ show angles between this amount and the absolute horizontal, a set of fault slips of a given strike generally pitching in both directions from the horizontal, which therefore represents a fair average.

Here and there some of the faults are not parallel to the preexisting dikes. The best known of these transverse faults are at right angles to the dikes and are detected by the fact that they have displaced the dikes. The northeast faults which displace the largest dike shown on the map, on the south side of Sherman Mountain, north of Clear Creek, are the best examples of these.

The openings produced by these postporphyry fault movements became the sites of ore deposition, so that many of the veins run along porphyry dikes, at least for part of their course.

POSTMINERAL MOVEMENTS.

Subsequent to the main period of ore deposition there has been some slight renewal of the movement, indicating that the inciting stress has not yet been satisfied. This disturbance is evidenced by postmineral movement parallel to the veins and in a few places across them. Like the premineral faulting, this relatively slight postmineral faulting has been in an approximately horizontal direction. It has not, however, been of any great amount.

MINES.

PELICAN-BISMARCK VEIN SYSTEM.

HISTORY.

The Bismarck lode was discovered in June, 1866, by a party of prospectors from Central City.[a] The Pelican (see Pl. XXIII, *A*) was discovered in 1868 and located December 19, 1869, by E. S. Streeter.[b] The claim was 1,400 feet in length and 50 feet in width, being located under the law of 1866. The narrow claims of both the Pelican and the Dives companies failed to cover the lodes and led to almost interminable litigation. It was not until early in 1871 that the mine began producing ore. In 1872 began the fierce quarrels between the owners of the Pelican and the Dives claims which culminated in May, 1875, in the death of Jacob Snyder, one of the heavy stockholders of the Pelican mine, at the hands of Jackson C. Bishop, a lessee on the Dives. The litigation, which also started in 1872 and included suits and counter suits, injunctions and counter injunctions, finally came to an end with the consolidation of the two properties in March, 1880, when both came into the possession of the Pelican and Dives Mining Company.[c] This company then began buying up neighboring properties, among which were the Bismarck and Seven-Thirty, the latter being purchased in 1896.

DESCRIPTION.

The Pelican-Bismarck vein system, consisting of a main trunk vein giving off important branches at both ends, is perhaps the strongest vein system in the Silver Plume region. (See Pl. XXIV.) On account of the complexity of the trunk vein, which consists in large part of overlapping, splitting, and reuniting, or parallel veins occupying a relatively narrow zone rather than a single well-defined vein, and on account of the fact that the relations of the branches to the trunk vein are not everywhere clear, there has been a great deal of confusion in the nomenclature. The trunk vein has been variously called the Dives-Pelican, the Eagle Bird, and the Bismarck. From the northwestern portion of this vein splits off the Seven-

[a] Burchard, H. C., Rept. Director of Mint for 1883, p. 270.
[b] Georgetown Courier, February 6, 1904.
[c] Fossett, Frank, Colorado, 1880, p. 392.

Thirty vein. The southeastern portion of the trunk vein gives off as a branch the Wisconsin-Corry City vein, and farther southeast splits into the Dives and Baxter veins, of which the former is stronger, its eastern extension going under the name of the Dunkirk vein. For the sake of simplicity the trunk vein between the branches will be called the Pelican; the same vein northwest of the intersection with the Seven-Thirty will be called the Bismarck. The trunk vein as here defined and its northwesterly extension past the intersection with the Seven-Thirty have a northwesterly strike and a dip to the northeast at a variable angle, averaging about 65°. The principal mine which has exploited this trunk vein has long been well known by the name of the Dives-Pelican. This mine is said to comprise about 13 miles of underground workings.[a]

PELICAN-BISMARCK LODE.

NATURE OF VEIN.

The Pelican-Bismarck vein has formed along a strong fault zone, whose course was determined by a preexisting dike of rhyolite porphyry (fig. 33). Evidence of this movement is afforded here and there by discordance of the walls on the two sides of the vein, and throughout the underground workings (Pl. XXV) by zones of brecciation and trituration, by slickensided walls, and by surfaces striated by differential movement. The direction of these striæ indicates that the movement was nearly horizontal.

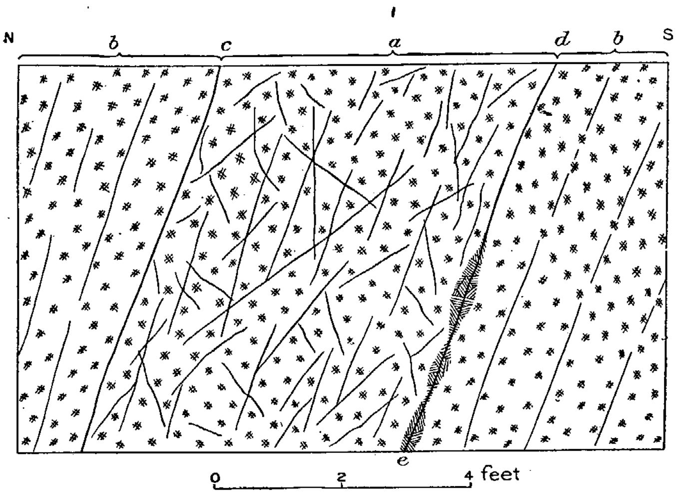


FIG. 33.—Sketch of Pelican tunnel, showing strong portion of Pelican lead. *a*, Zone of very much crushed and jointed porphyry, bounded by two definite walls, *c* and *d*; *b*, porphyry sheeted parallel to lode; *e* argentiferous galena and blende (100 ounces silver to the ton) along foot wall. When the sketch was made this ore was being worked, sorted, and shipped.

The fault along which the vein subsequently formed has followed the porphyry dike for a maximum distance of half a mile, as measured in the Pelican tunnel. Along this portion the vein has been most productive. This section of the vein underlies the summit of Sherman Mountain and the slope running down to Cherokee Gulch. Northwest of this portion, as seen in all the underground workings, the vein passes out of porphyry into granite with some gneiss in the region lying under the western slope of Sherman Mountain going down to Brown Gulch. The same lack of porphyry is characteristic also of the surface at this point, but farther northwest the porphyry reappears at the surface along the fault zone and passes beyond the limits of the area mapped. Along the southeastern portion of the vein also the porphyry virtually comes to an end in the ground underlying the southeastern slope of Sherman Mountain. Before Cherokee Gulch is reached the vein passes southeastward into gneiss and granite, containing only nonpersistent and untraceable streaks of porphyry.

Workings have not been pushed very far beyond the porphyry to the northwest, since beyond this point, so far as investigated, the vein has grown poorer and, finally, has contained little ore. This portion of the vein has been opened chiefly in the Hercules, Zero, and Pelican levels (Pl. XXVI). The Pelican level goes nearly 600 feet beyond the limits of the area shown on the map. The portion farthest in is now inaccessible, but it is reported that near the end of the level a drift following the Bismarck lode[b] encountered a porphyry dike at right angles to the vein, or nearly so, and that at this point the vein was practically lost. This dike is probably that shown on the map as running northeastward across the saddle of Brown Mountain and is the second northeastward-trending dike counting from the northwest corner.

[a] Proc. Colorado Sci. Soc., vol. 6, 1897, p. 43.

[b] To be distinguished from Bismarck vein, p. 367.

Southeast of the portion of the Pelican-Bismarck lode which lies in or alongside the porphyry the vein, on passing into granite and gneiss, divides up into different branches, many of which are traceable for considerable distances and have yielded a considerable mass of ore. The junction of the different branches which belong to this vein system is characteristically inconspicuous. It is certain, for example, that the Seven-Thirty unites with the Pelican-Bismarck, as is shown

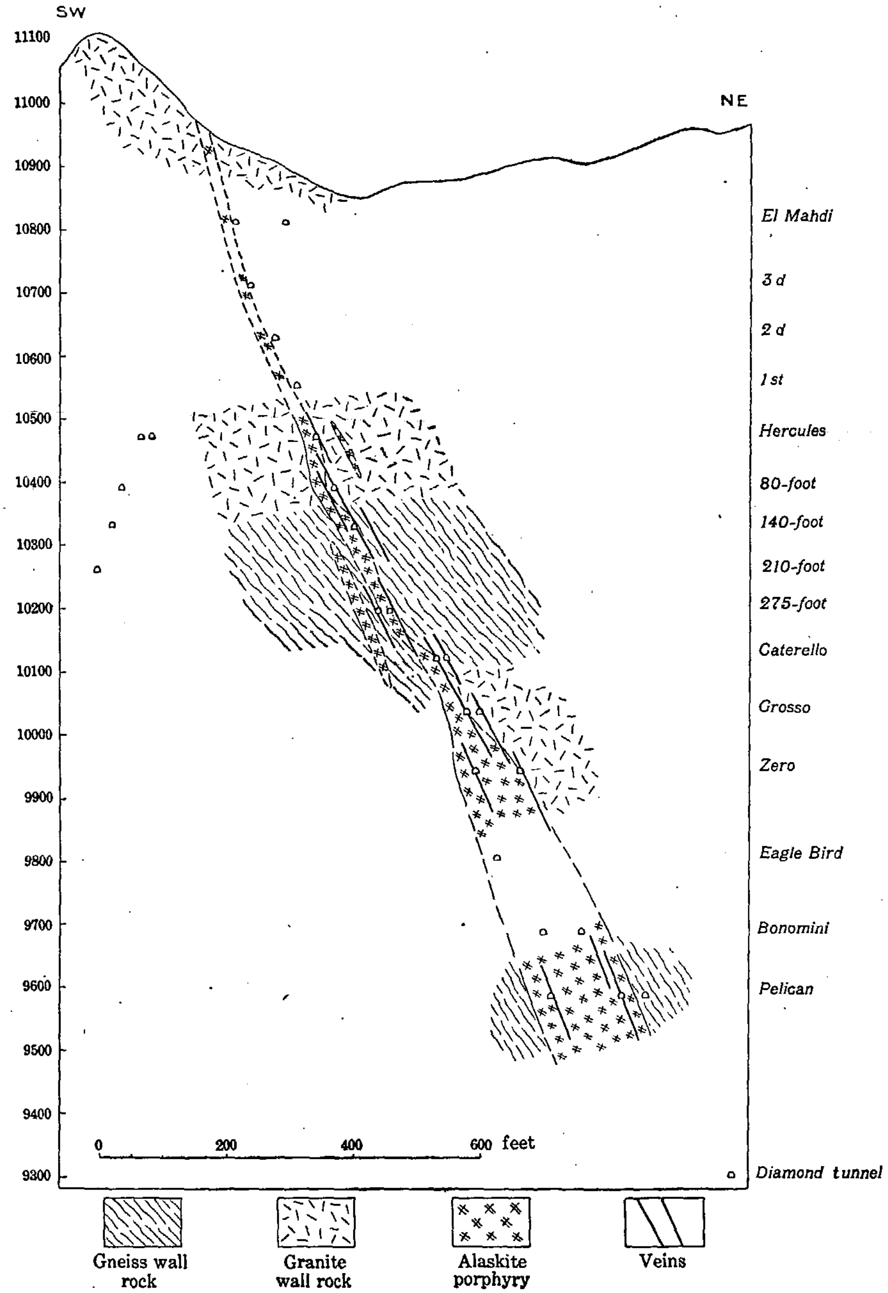


FIG. 34.—Vertical cross section of Bismarck lode, Sherman Mountain.

on several of the levels of the Seven-Thirty mine, but the actual junction is at many points difficult to locate.

On approaching the trunk vein the Seven-Thirty diverges from its normal trend and tends to become parallel with the stronger lode, and finally it becomes lost in the several parallel streaks which make up the zone of the Pelican-Bismarck. Similar characteristics attend the branching of the vein on the southeast to form the Dives and Baxter veins, and, so far as can be learned, the same is true of the junction of the Wisconsin and Pelican lodes, which is now inaccessible.

The distribution of the porphyry along the vein is very irregular. At some places the porphyry is thick and at others thin; at still others it is wanting entirely. It may occur in irregular bunches or in streaks or slices inclosed between movement planes. The relations of these different masses of porphyry to each other and to the vein shows that the horizontal fault movement along the porphyry dike has resulted in shredding the dike, so that in some places along the fault there is no porphyry, while in others the faulted portions overlap and increase largely the original thickness.

Inasmuch as the whole of the porphyry dike, being a weaker zone included between stronger gneiss and granite walls, has been crushed by the faulting, there are numerous fault planes running through it or along it, and along any or all of these ore has formed (fig. 34). Thus veins may occur on either contact of the porphyry or on neither, or it may occur in parallel streaks with porphyry on both walls. These veins may overlap without connection, they may split and reunite, or they may run parallel to one another. Inspection of the various levels shows that the relation of these veins to one another and to the porphyry is constantly changing and that a vein may be at one point entirely in porphyry, but may change along the strike or dip, or both, to the porphyry contact with the granite or gneiss.

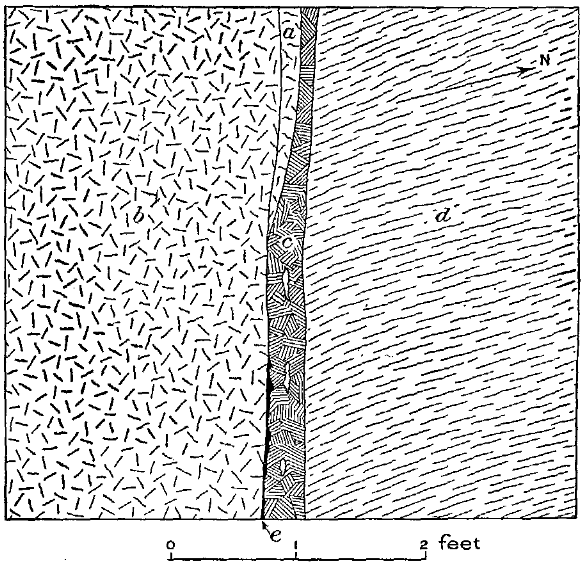
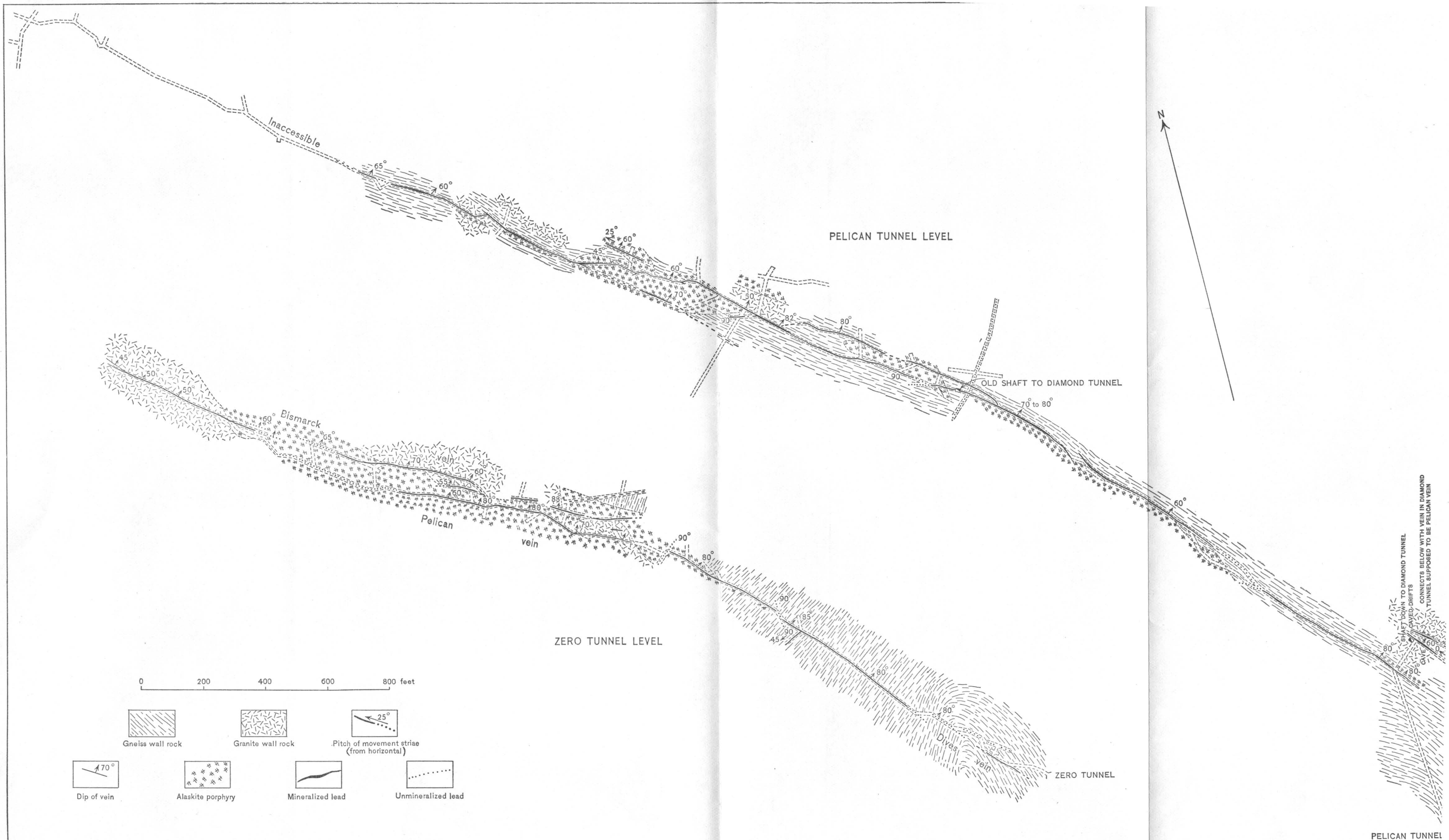


FIG. 35.—Horizontal sketch of branch of Pelican vein, Pelican tunnel level, showing fault nature of vein channel. *a*, Quartz (gangue); *b*, granite; *c*, blende; *d*, gneiss; *e*, pyrite. In the center of the vein are vugs.

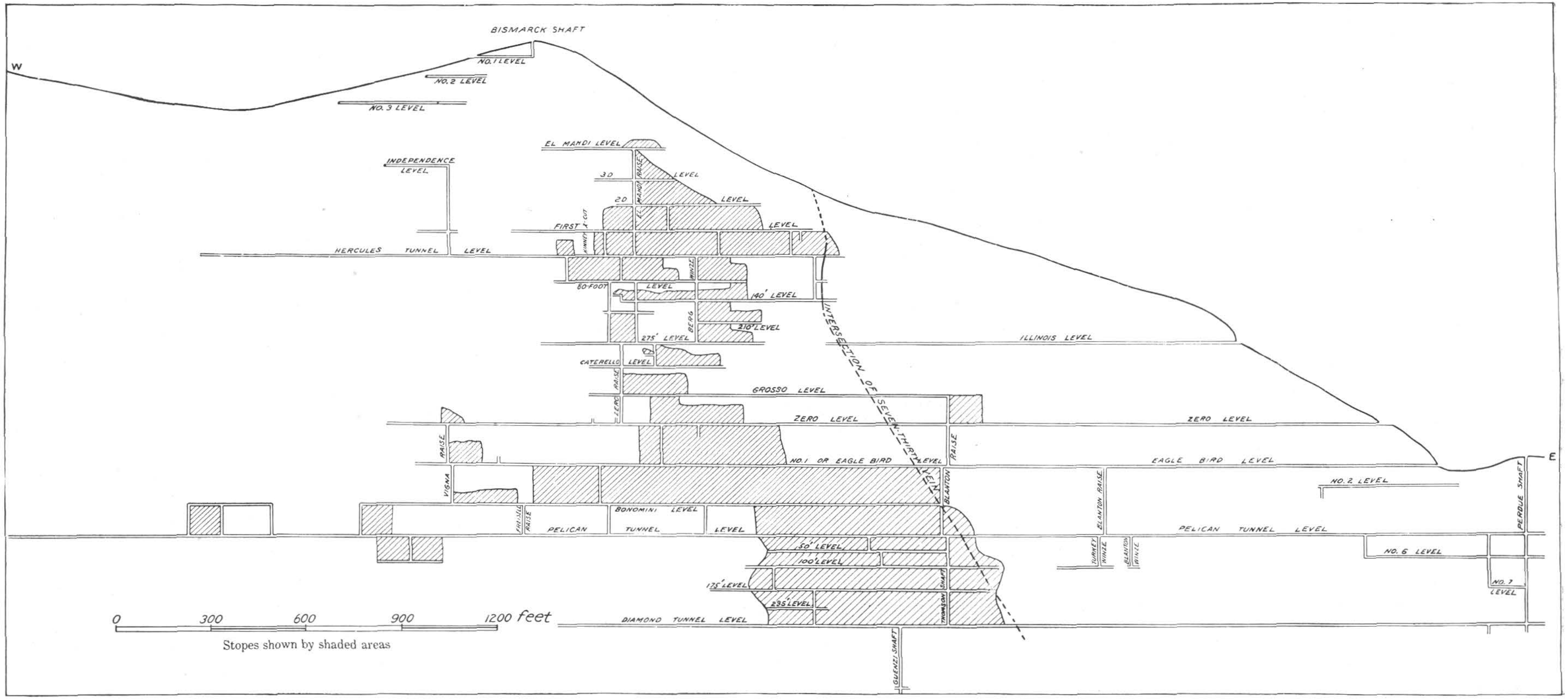
On account of the nonpersistence of these separate veins the whole dike has in the past been frequently considered as forming a single vein. While this is hardly true, yet it essentially forms or coincides with the relatively narrow vein zone, the different veins in which are generally too intimately related to be separated. These peculiarities are seen in the geologic maps of the separate mine levels. In places only the different veins within the porphyry dike remain separate and distinct for a considerable distance. Thus on the Zero level two parallel veins, both in porphyry on both walls, and lying about 70 feet apart, run alongside each other for a distance of approximately 1,200 feet. In this case the northeast vein has been called the Bismarck, the southwest one the Pelican. On this level, where these two veins leave the porphyry dike and pass into granite and gneiss on the northwest and on the southeast, they seem to have resolved themselves into a single lode.

STRUCTURE OF VEIN.

Zones or planes of fault movement constitute the "lead" in these mines, and these fault zones may or may not be mineralized, the occurrence of ore being irregular (fig. 35). Where ore does occur the general structure is similar to that of the barren portions of the lode. In general the veins have a single good wall representing the main slip. On one side of this, generally above it, there is a rather indefinite zone several feet wide, consisting of fractured, broken, or completely crushed rock, usually decomposed and silicified. The best and the most continuous ore is to be looked for along the main wall or slip, and the adjacent zone of broken rock may be barren or it may be seamed or reticulated with ore. The opposite side of this zone is usually indistinct.



N
Inaccessible
PELICAN TUNNEL LEVEL
OLD SHAFT TO DIAMOND TUNNEL
Bismarck
vein
Pelican
vein
ZERO TUNNEL LEVEL
Dives
vein
ZERO TUNNEL
SHAFT DOWN TO DIAMOND TUNNEL
CAVED DRIFTS
CAVE
CONNECTS BELOW WITH VEIN IN DIAMOND TUNNEL SUPPOSED TO BE PELICAN VEIN
PELICAN TUNNEL
0
200
400
600
800 feet
Gneiss wall rock
Granite wall rock
Pitch of movement striae (from horizontal)
Dip of vein
Alaskite porphyry
Mineralized lead
Unmineralized lead



VERTICAL LONGITUDINAL PROJECTION OF PELICAN-BISMARCK VEIN.

Adapted from a projection by O. O. McReynolds, June, 1903.

As a rule the ore appears to have formed mostly by replacement near cracks, as is shown both by field and by microscopic study (fig. 36). There are, however, numerous places where irregular cavities or druses have been filled with sulphides and gangue.

COMPOSITION OF VEIN.

The principal metallic minerals of the vein are blende and galena, with locally considerable pyrite. The chief gangue mineral is quartz, with some barite, calcite, and, especially near the surface, siderite. The galena and blende are both argentiferous, and the ore contains a little gold. In 1896 the average value of the ore shipped from the mine was $75 per ton. This ore contained 150 ounces of silver, 0.1 ounce of gold, 14 per cent of lead, and 20 per cent of zinc, the remainder being mostly silica and iron.[a] Sulphides of silver, including argentite, polybasite, and pyrargyrite, also occur, especially in the upper levels. Native silver was common near the surface. A specimen of this ore from 100 feet above the Pelican level, about

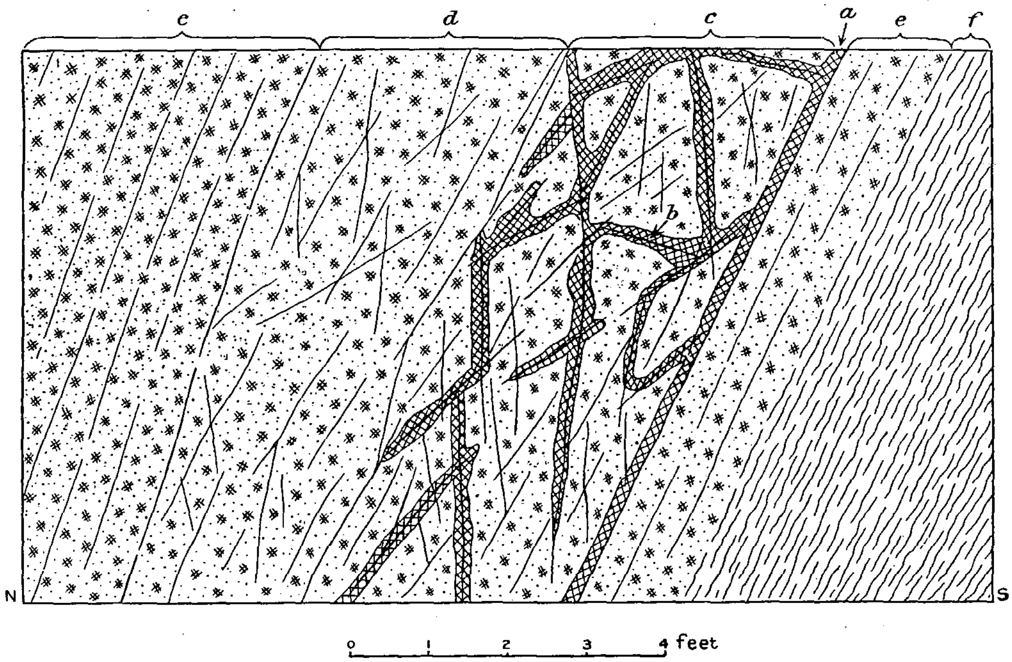


FIG. 36.—Sketch of Pelican vein, Pelican tunnel level. *a*, Main lead; *b*, ore, chiefly blende; *c*, ore zone of brecciated, highly silicified alaskite porphyry; *d*, highly fractured silicified alaskite porphyry; *e*, sheeted silicified alaskite porphyry; *f*, altered granitic gneiss.

4,000 feet in, and at a depth of 1,550 feet below the surface, shows predominating blende, with coarse galena, some polybasite or tetrahedrite, and a little dark-red ruby silver. The polybasite and pyrargyrite do not show any different origin from the galena or blende, but seem to be contemporaneous with them, so far as one can judge.

LOCATION OF ORE BODIES.

It is plain from a study of the stope projection (Pl. XXVII), combined with inspection of the available underground workings, that the ores lie chiefly in a definite shoot. The whole length of the vein, including branches, which has been developed underground is about 7,200 feet from the northwest end of the Pelican tunnel to the Ashby tunnel. Most of the ore, however, came from a shoot that extended from 500 to 800 feet along the vein and was continuous from the surface vertically down to the Bonomini level, and from that level with an offset to the southeast developed down to the lowest workings below the Diamond tunnel. The upper part of this shoot coincides with the junction of the main vein with the Seven-Thirty vein.

[a] Lawrence, B. B., Proc. Colorado Sci. Soc., vol. 6, 1897, p. 44.

At the surface this junction comes approximately at the outcrop of the shoot. On the Hercules tunnel level of the Seven-Thirty mine the shoot extends from the branching point for over 800 feet northwestward along the Bismarck lode. On the 80-foot level of the Seven-Thirty mine a shoot also begins at the junction and extends toward the northwest, and the same thing is seen in the 140-foot level. On the 210-foot and 275-foot levels of the Seven-Thirty the general relation of the junction to the ore shoot is to all appearances practically the same, although the actual intersection has not been proved. Below the 275-foot level the junction of the Seven-Thirty with the Bismarck has not been detected, and the Seven-Thirty levels have not been driven so as to approach anywhere near the main vein. However, the Seven-Thirty is known to extend in depth probably as far down at least as the lowest workings on the Pelican-Bismarck lode, and its almost perpendicular attitude renders it easy to project the approximate point of its intersection with the main lode. On account of the steep southerly dip of the Seven-Thirty this intersection would pitch southeastward on the Bismarck, corresponding in general to the pitch of the main ore shoot. (See Pl. XXVII.)

It seems from this coincidence that the junction of the Seven-Thirty with the main Pelican-Bismarck lode bears a causal relation to the principal ore shoot on this lode, since the shoot on the Bismarck reaches from the intersection 500 to 800 feet farther northwest. Yet the Seven-Thirty vein is not enriched near the junction; on the contrary, this junction is very weak, and the exact point is hardly recognizable even on those levels where it is best developed. It is best shown on the 80-foot level of the Seven-Thirty. On all the Seven-Thirty levels the vein appears near the intersection with the Pelican-Bismarck as a weak fracture zone or succession of fractures more or less mineralized but containing as a rule no notable quantity of ore. Therefore it is quite natural that the junction has not been observed on the lower levels.

According to report the intersection of the Wisconsin lode with the Pelican-Bismarck had a similar effect, producing there an important and rich ore body. Neither the intersection nor the extension of the ore body, however, seems to have been identified for any considerable distance downward.

A similar relation may be detected in many places at the junction of branches along other portions of the vein system. On the Diamond tunnel level, for example, where the main vein splits up into the Dives and Baxter veins, the exact junction appears not to have been detected, yet the Dives vein is enriched for about 500 feet southeast of the probable branching point.

RELATION OF ORES TO DEPTH FROM SURFACE.

At the surface, as reported, the ore of the principal Bismarck shoot consisted largely of rich soft black silver sulphides with much wire silver. The old workings also show considerable blende, galena, pyrite, and siderite. At the very surface and extending down about 40 feet oxidized ores having the appearance of brown clay are reported. These ores are said to have been the richest in the vein, containing several hundred ounces of silver. Mixed with the oxidized ores and extending downward for 200 to 300 feet, especially along water courses, are the soft black sulphide ores, plainly of secondary origin. These ores consist chiefly of galena and blende and contain several hundred ounces of silver. The ordinary ore of the vein consists of intercrystallized coarse blende and galena, the blende being especially predominant. There is also some pyrite. In many localities, as, for example, in the Zero and Eagle Bird levels (at a depth of, say, 500 to 800 feet), pyrite is scattered through the entirely altered porphyry near the vein and seems to be secondary from original iron in the rock. Coatings of pyrite on joint faces in the same rock have a very recent aspect. The suggestion arises that the scanty (except near the surface) pyrtie in the vein is derived from the wall rock. The best ore bodies are said to have been found at a depth of 300 feet, but good ore is also reported to have been encountered to a depth of 1,800 feet.[a]

The general appearance of the coarse blende and galena ore is much the same from the top to the bottom of the mine, except that in the lowest levels the blende seems to become relatively

[a] Lawrence, B. B., Proc. Colorado Sci. Soc., vol. 6, p. 44, 1897.

GEOLOGICAL PLAN OF DIAMOND AND ASHBY TUNNELS.

more abundant. It also appears probable that the amount of silver decreases gradually with depth. In the upper levels much of the blende is argentiferous, but in the lower levels this appears to be not the case. A large part of the argentiferous blende appears to owe its silver content to intergrown particles of polybasite or tetrahedrite. The lowest workings are in the Diamond tunnel level, at a depth of about 1,800 feet.

NATURE OF WALL ROCK.

The granite and gneiss which constitute the wall rock of a considerable portion of the vein are similar to the rocks displayed at the surface and in the neighboring mines of the region. The porphyry, though almost invariably decomposed, was evidently originally a rhyolitic or alaskitic variety containing phenocrysts of quartz, feldspar, some biotite, and probably hornblende in a glassy or microlitic groundmass. Apatite is almost always present.

ALTERATION OF WALL ROCK.

By alteration the porphyry has become white and soft. Under the microscope it is shown to be invariably almost entirely decomposed. The feldspar is altered to sericite and fine quartz, the biotite to semistite and iron carbonate. Near veins the wall rock is highly silicified. Small veinlets and oval cavities are common, lined with quartz and filled with a clear, faintly spherulitic or apparently isotropic material which appears to be kaolin. (See p. 142.) Small grains of probable fluorite have also been detected in these veinlets. The kaolinic alteration product has been detected at various depths, at least as far down as the Pelican level.

POSTMINERAL FAULTING.

Usually, as is the case with all veins of this region, the amount of postmineral movement, except in some places along the plane of the vein itself, has been slight. Here and there, however, small transverse faults, in general involving an offset of only a few feet, have been noted. On the Zero tunnel level such faults were noted in two places, in one the fault being at right angles to the vein and in the other diagonal.

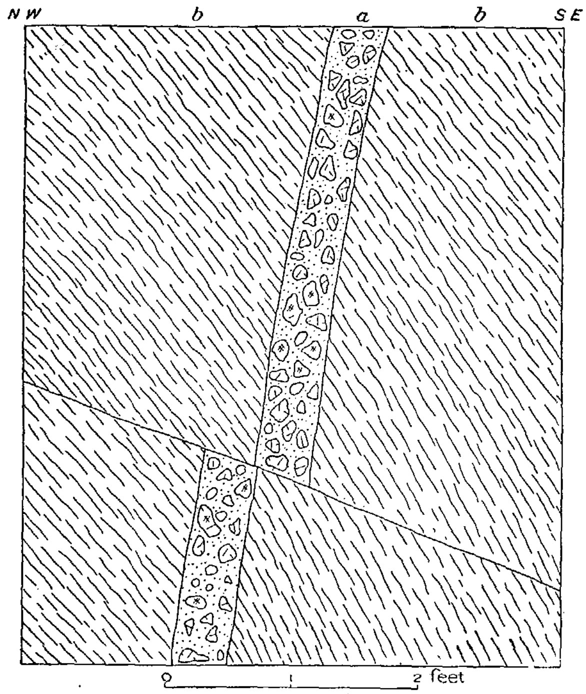


FIG. 37.—Sketch of wall of Pelican vein, Pelican tunnel level. Shows in gneiss, (b) a zone of fragmental material (a) consisting of a compact hard gray matrix containing angular or subrounded fragments of alaskite and granite. This zone has been displaced by a fault.

RUBBLE ZONE IN GNEISS.

In a single locality in the mine an interesting occurrence was noted. This is represented by fig. 37, a sketch of the wall of the stoped-out Pelican vein, on the Pelican tunnel level. A straight zone in the gneiss, 5 inches wide, and bounded by smooth parallel walls, consists of a compact, hard gray fragmental matrix, containing angular or subrounded fragments of granitic rocks. The nearest granite noted on this level is nearly a thousand feet northwest of this locality.

This zone has been slightly faulted, as shown in the sketch. Its relation to the lode faulting is obscure, though its occurrence in the wall of the lode would suggest that it represents a fissuring of greater age.

DIVES-DUNKIRK LODE.

DESCRIPTION.

In the neighborhood of Cherokee Gulch the trunk vein known as the Pelican splits into the Dives and Baxter veins. Of these the Baxter is more nearly in a direct line, but is the weaker of the two. The two branches are exposed underground on the Pelican tunnel level and more clearly on the Diamond tunnel level, though the exact junction is not seen in either place. Farther southeast both of these principal branches split repeatedly, no porphyry dike being present to localize and control the zone of faulting and fracturing.

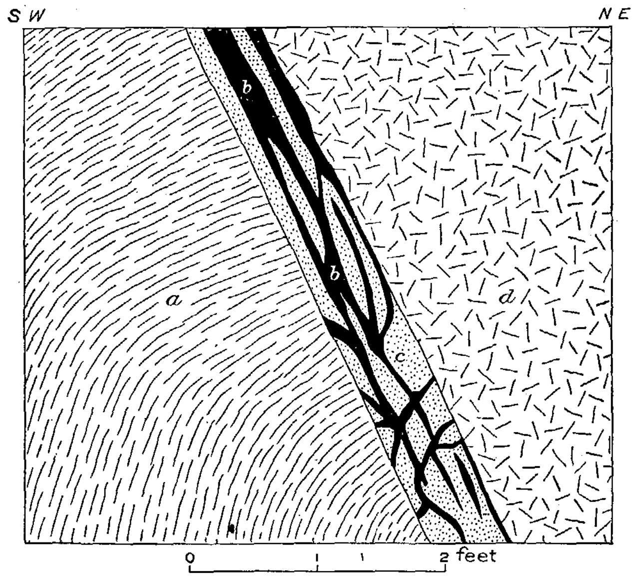


FIG. 38.—Vertical cross section of Dives vein and Diamond tunnel level near tunnel. *a*, Gneiss; *b*, seams of crystalline blende with some pyrite; *c*, zone of crushed granite; *d*, granite. Shows fault nature of vein channel and the formation of a vein in the fault zone. Depth below surface 650 feet.

On the Diamond tunnel (Pl. XXVIII) the Baxter vein is seen to dip almost perpendicularly, while the Dives has a dip of about 60° NE. Therefore the two branches tend to approach each other as distance from the surface is decreased. The Dives vein has been followed continuously from its junction with the Pelican to the workings of the Dunkirk mine, where it is known as the Dunkirk vein. The same Dunkirk vein has been drifted on at a lower level, in the Ashby tunnel. On this level, at a point west of the main tunnel, the vein is overlapped by a parallel vein 100 feet farther northeast. This vein also goes by the name of the Dunkirk vein, and has been followed to a point about 450 feet southeast of the tunnel. It may be a branch of the main Dunkirk vein, the probable point of junction being just west of the Dunkirk shaft on the Ashby tunnel level. If so, it is considerably the stronger of the two branches, for the southern branch, where the tunnel crosscuts it, is marked only by a slip in the gneiss with no mineralization.

For about a thousand feet southeast of the southeast end of the Ashby tunnel workings on the Dunkirk vein this vein has not been traced underground or at the surface. Beyond this point comes the Lebanon group of veins, of which the Morning Star and the Alhambra are the principal branches. The Morning Star lode, to judge from its trend and position, may perhaps be the continuation of the Dunkirk lode, though this surmise lacks confirmation. At the east end of the Dunkirk workings, however, the lode is still fairly strong. The Alhambra lode, as shown on the map, is a branch of the Morning Star.

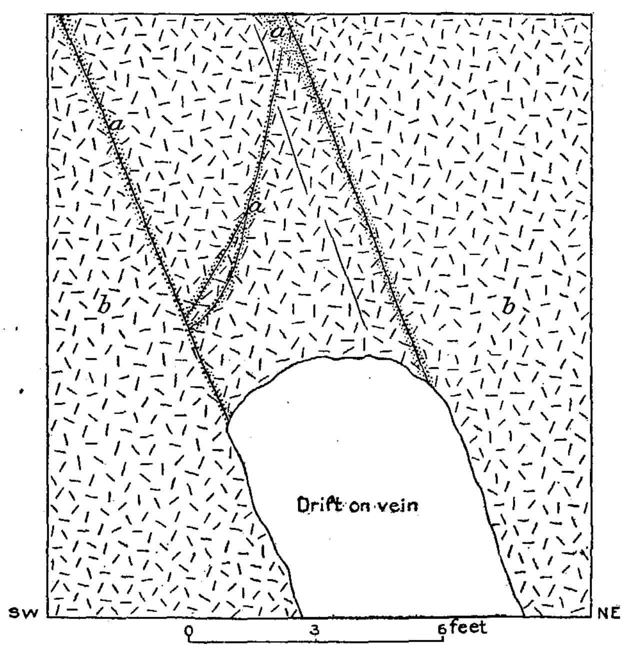


FIG. 39.—Vertical section of Dives vein in Diamond tunnel level near the tunnel, showing vein as two parallel seams (*a*) of blende and pyrite in granite (*b*). The granite between the seams is like that on either side.

NATURE OF VEIN.

The Dives-Dunkirk vein has formed along a strong fault slip which has a general northwest or west-northwest trend and a northeast dip varying from 50° to 80°. That the fracture zone along which the vein has formed is actually a zone of faulting is shown by polished and striated slip walls, the striæ on which have usually a very moderate dip from the horizontal, not exceeding 30° in any case noted. This indicates an approximately horizontal movement. Faulting is also shown locally by discordance of the walls (fig. 38). In many places there is only one strong slip along the zone, but in other places there is a well-defined zone bounded by two good walls (fig. 39). These peculiarities of course apply also to the vein, which has formed along the circulation channels thus offered. The mineralization is somewhat irregular, having little to do with the importance of the fault movement or with the presence of one or two movement walls. Some portions of the fault zone are quite unmineralized, containing neither metallic minerals nor gangue. At intervals, however, all along the explored portion of the vein, ore is found. The ore consists of blende, galena, and pyrite in various proportions; and the silver content ranges up to about 300 ounces. As a rule the mineralization evidently grows gradually less with the increasing distance from the Pelican vein. The upper portion of the vein nearer the surface seems to have produced more ore in proportion than the lower portions. The Diamond tunnel level is approximately 500 feet below the outcrop

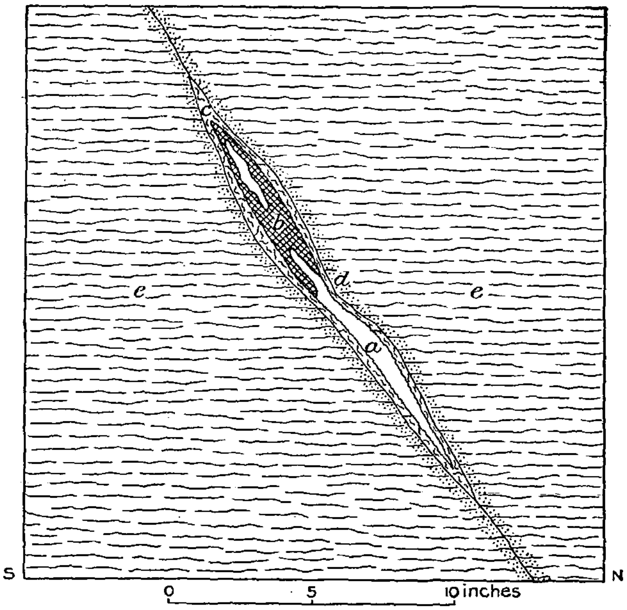


FIG. 40.—Vertical cross section of veinlet in gneiss, Diamond tunnel near Dives vein. Depth about 650 feet. Shows successive deposition of quartz and pyriferous carbonate. *a*, Empty vug; *b*, pyriferous carbonate; *c*, quartz; *d*, silicified gneiss; *e*, gneiss.

On the Diamond tunnel level near the Dives vein a few small veinlets were noted, which are interesting from the point of view of the paragenesis of the vein-forming minerals (figs. 40, 41). One shows a small gash vein which has formed along one portion of a slight fault slip in gneiss. A cavity at this point has been partly filled by a succession of minerals, comprising quartz, siderite, pyrite, and galena. The filling has been accomplished by successive crystallization from the walls inward, though part of the original opening still remains in the form of central druses. The general succession of the deposition of minerals is (1) quartz, (2) pyrite, (3) blende, and (4) siderite; but the periods of deposition of all the minerals overlap. Pyrite occurs here and there embedded in siderite, both being fresh and original, although as a rule siderite is a later formation. A thin section of another veinlet from the same vicinity as the one above described shows the vein to be chiefly a replaced and silicified rock, possibly porphyry, although the walls show only gneiss. At present the gangue is a mixture of predominant sericite with fine granular quartz and numerous small crystals of apatite. There is some kaolin. In this material a veinlet made up of carbonates is present. The larger part of the carbonates have the optical properties of calcite; a

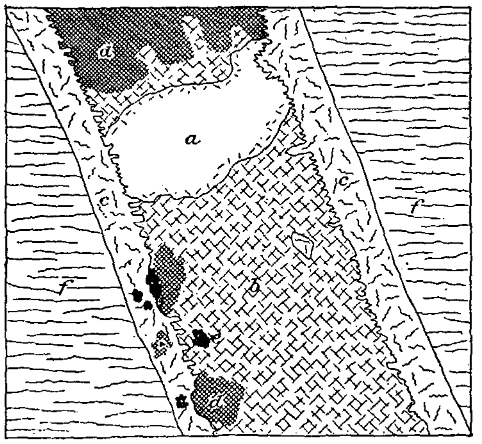


FIG. 41.—Detail of portion of vein shown in fig. 40, showing the relations of different vein materials. *a*, Vug lined with pyriferous carbonate crystals; *b*, pyriferous carbonate; *c*, comb quartz; *d*, zinc blende; *e*, pyrite; *f*, gneiss (wall rock).

minor part, especially near the edges of the veinlet, consists of single crystals having an elongated rhombic form and curving extinction, probably siderite. Another veinlet in the same slide consists of quartz, blende, and galena.

NATURE OF WALL ROCKS.

No porphyry was actually detected in the wall material of the Dives-Dunkirk vein. The wall rock is characteristically gneiss, with some granite. As a rule, the strike of the schistosity is oblique to the lode, the angle between the two approximating 70°. Evidently, however, the attitude of the gneiss did not control the direction of the lode, but the lode fracture is a continuation of the main fracture controlled by the Pelican porphyry dike.

A specimen of the gneiss in the Diamond tunnel, about 100 feet north of the Dives vein, shows on microscopic examination a moderately fine granular structure. This gneiss contains predominant quartz, with areas of sericite nearly as abundant. The sericite is secondary after feldspar. Subordinate primary muscovite is present, and in many places altered biotite. Parallel thick wavy zones of fibrolite (sillimanite) seem to determine the parting planes of the schist. Sillimanite in isolated crystals is also included in the quartz, as are a few small unaltered biotite flakes. Small zircon crystals are present in the quartz and in the sericite areas.

HISTORY AND PRODUCTION.

The Dives property was located May 27, 1869, by Thomas Burr. It produced but little until 1871, when a large body of ore was encountered. From this time until 1880 the Dives was involved in the litigation with the Pelican mine, which was terminated only by the consolidation of the two properties.

According to C. H. Morris "the yield or production from the Dunkirk group since the discovery and location of the Dunkirk claim in 1868 has been some 200,000 ounces fine silver." This, however, does not include the returns from large amounts of ore claimed to have been extracted by other parties from the west end of the vein between 1870 and 1880.

BAXTER LODE.

The Baxter lode, which is the direct southeast continuation of the Pelican lode and has the same trend, is best shown in the Diamond tunnel, which it crosses at something more than 600 feet from the mouth. It trends northwestward and either dips very steeply to the northeast or is perpendicular. Just west of the Diamond tunnel a branch diverges, opening out to the west. The drift on the main vein has caved about 100 feet northwest of this branch, but is said to have been opened for several feet farther. The diverging branch is exposed by a drift 500 or 600 feet long. Both branches are along strong fault slips. The main vein is a strong mineralized lead in granite, marked by seams of galena and blende. Ore has been taken out also from the branch vein. A very considerable stope shows that ore has been taken out on the main vein for about 50 feet east of the junction. The location of this ore body seems to have been dependent on intersection. East of the Diamond tunnel workings the lode becomes practically barren. It has been traced for a considerable distance by drift tunnels. One tunnel, starting in just above the road which runs above the Diamond tunnel, follows this lode for 500 feet, overlapping and continuing the drift on the Diamond tunnel level lower down. The smaller tunnel shows the lead as a strong single-wall fault, accompanied by a crushed zone from 3 inches to a foot thick. On the wall, striæ pitch 15° NW., indicating a nearly horizontal movement. In this tunnel a branch leaves the vein, opening out from it toward the east. This branch is also a strong fault lead, with very slight indications of mineral.

Still farther southeast the Baxter lode is probably represented by a strong barren fault zone in the Ashby tunnel, about 130 feet in from the mouth. This fault shows striæ pitching 5° E. There are no signs of mineralization—only a little pyrite, which may or may not be connected with the ore deposition. Beyond this point the lode has not been traced. (See Pl. XXIX.)

According to Fossett[a] the total yield of this mine to 1880 was about $360,000. During the latter year the lessees are reported to have employed forty or fifty men.

[a] Fossett, Frank, Colorado, 1880, p. 394.

E. M. Douglas, Geographer.
Frank Tweedy, in charge of section.
Topography by Pearson Chapman.
Triangulation by Frank Tweedy.
Surveyed in 1904.

MAP SHOWING VEINS AND PORPHYRY DIKES IN THE SILVER PLUME REGION, COLORADO

Geology by J. E. Spurr and G. H. Garrey.

Scale $\frac{1}{12000}$

0 $\frac{1}{8}$ $\frac{1}{4}$ $\frac{1}{2}$ $\frac{3}{4}$ 1 mile

1000 500 0 1000 2000 3000 4000 feet

200 100 0 500 1000 meters

Contour interval 50 feet.

Datum is mean sea level

Mineral veins

Porphyry dikes

WISCONSIN-CORRY CITY LODE.

RELATIONS TO PELICAN-BISMARCK TRUNK VEIN.

The ores developed in the workings of the Wisconsin and Corry City mines appear to have been obtained from the same lode, which is apparently a branch of the main Pelican lode. The point of separation lies at the surface approximately in the gulch east of Sherman Mountain. The main lode, the Pelican, here has a northwest strike, while the diverging Wisconsin lode has a west-northwest strike, so that farther east the distance between the outcrops of the two branches continually increases. The difference in strike amounts to about 25°. There is also a difference in dip, the Wisconsin-Corry City lode, with an inclination of 50° to 60°, being considerably flatter than the Bismarck, which dips at about 75°. Owing to this difference of strike and dip of the two branches the junction pitches very flatly, and with increasing depth travels very rapidly to the northwest. On the upper levels the junction of the two veins was encountered. The Illinois level, running in on the Bismarck lode, and the Wisconsin level, running in on the Wisconsin lode, came together in a large body of ore which had formed near

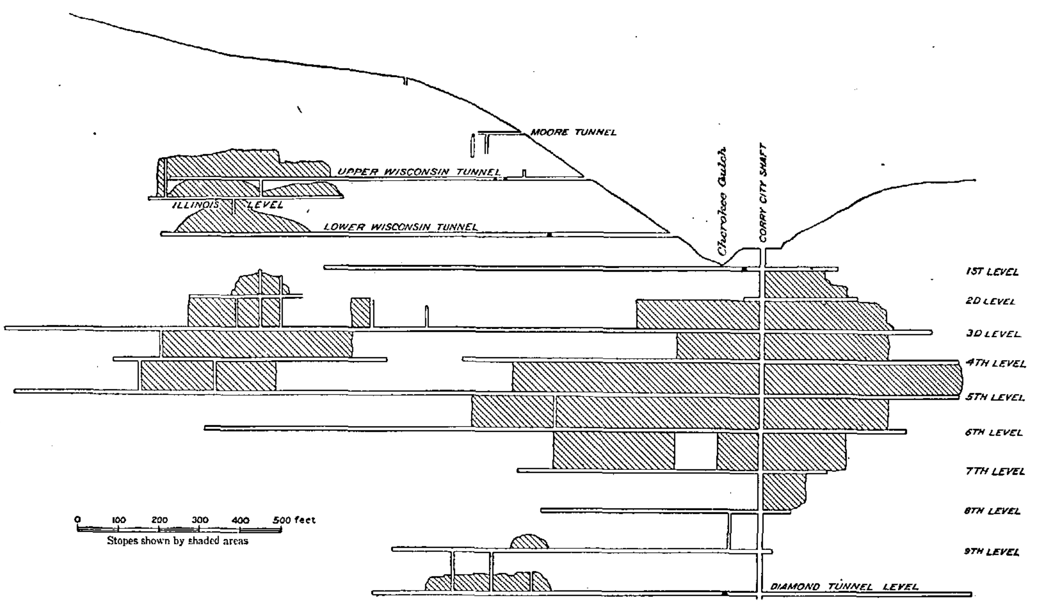


FIG. 42.—Vertical longitudinal projection of the Wisconsin-Corry City mine workings.

their junction, a fact which caused prolonged conflict and litigation. In the relatively lower levels, however, the junction either has not been encountered or has not been recognized. Even on the Zero level, which runs in on the Bismarck lode about 250 feet below the Illinois level, the projected junction with the Wisconsin lode would come somewhere under Sherman Mountain, at a depth of about 1,200 feet, a distance from the surface which in most of the mines of this district has proved to be unfavorable for extensive ore deposition. In the still lower levels the junction of the two lodes would extend northwestward beyond the ore-bearing zone of the district and would be at still greater depths.

NATURE OF VEIN.

In the upper levels of the workings which run along the Wisconsin-Corry City lode (fig. 42), especially in the Wisconsin mine, which exposes the portion relatively near the junction with the Bismarck, the vein follows a very strong fault zone, in many places several feet wide and marked by brecciation and slickensided surfaces. On these surfaces striæ caused by movement are abundant and are nearly horizontal or flatly pitching, the variation measured from the horizontal being ordinarily not more than 20°. Thus the movement is shown to have been approximately horizontal. The fault zone is associated with a dike of light-colored porphyry, which may lie on one side of the fault or locally on both sides. The porphyry dike seems to be continuous to the Bismarck vein and to unite with the dike along which the Bismarck has formed. It terminates on the east, however, within a relatively short distance, near the line of the gulch which separates the Wisconsin and Corry City mines and underground in a corresponding position, as may be seen by the maps of the different mine levels. Plainly the location of the fault movement has been determined by the preexisting porphyry dike, which has been weaker than the inclosing rocks and has offered a zone of weakness along which slipping took place. The lode extends eastward beyond the termination of the dike, with gneiss and granite as its walls, but after leaving the dike becomes weaker, branches repeatedly, and is at length virtually lost. The slips or leads followed in the gneiss or granite by this lode are also faults whose movements have had a pronounced horizontal direction, but these faults appear to have split up and scattered, distributing throughout the rock the movement which farther west was taken up along the relatively narrow zone of the porphyry dike.

STRUCTURE OF VEIN.

The ore has formed along thin seams in the fault zone, here on one wall, there on the other, and elsewhere along two or more parallel slips. It is in many places irregular, shooting across and reticulating the fault zone, and much of it occurs in blotches. As a rule the dimensions of the veinlets are small, not more than a few inches. There are no traces of mineral along many parts of the lead, but again in favorable localities mineralization has occurred. The vertical longitudinal projection of the vein (fig. 42) shows two distinct ore shoots, one on the Corry City, beneath Cherokee Gulch, and one on the Wisconsin, near or at the junction with the Bismarck vein.

COMPOSITION OF VEIN.

The ores contain lead and zinc in the form of intercrystallized galena, blende, and pyrite, with some tetrahedrite or polybasite. They run well in silver, the best ores containing several hundred ounces.

NATURE OF WALL ROCK.

The wall rock consists of porphyry, gneiss, and granite. The porphyry was originally siliceous and rhyolitic or alaskitic, containing phenocrysts of feldspar, biotite, and in places quartz, in a fine-grained groundmass. Accessory apatite is present. The rock was essentially like the porphyry accompanying the Bismarck vein, from which it is probably a branch. It is at present entirely altered.

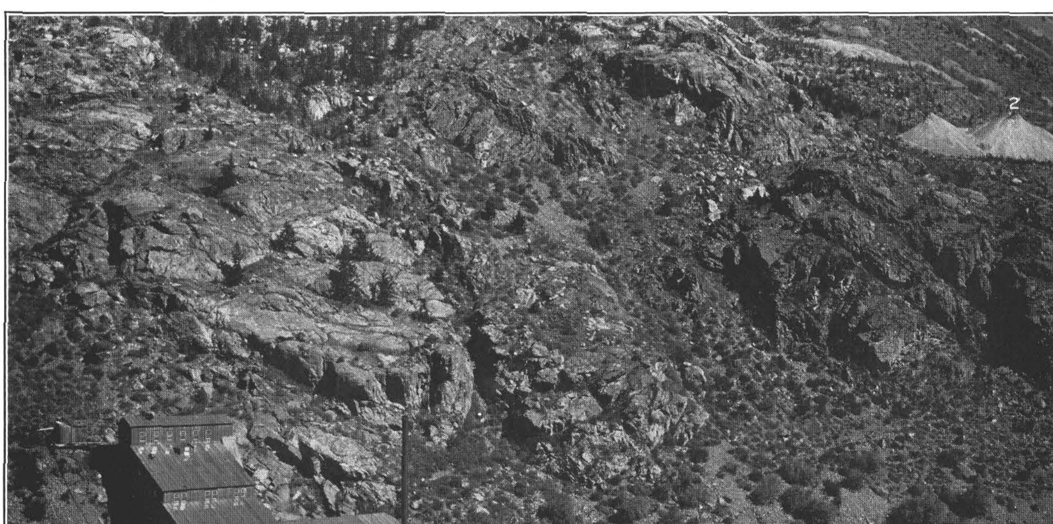
ALTERATION OF WALL ROCK.

The wall rocks are everywhere thoroughly altered. The porphyry in the hand specimen is white and soft, or where more thoroughly mineralized is gray and siliceous. Under the microscope the feldspar phenocrysts are found to have been entirely decomposed to fine quartz and sericite; the biotite phenocrysts to quartz, sericite, cloudy carbonates, and pyrite. The groundmass of the porphyry has been altered to quartz, sericite, and fine crystalline carbonates. These carbonates do not effervesce with dilute hydrochloric acid, and are therefore not calcite.

INFLUENCE OF WALL ROCK.

As stated above, the best part of the vein is that which accompanies the porphyry dike, or is not far removed from it, the reason appearing to be that the whole fault movement has been united where it runs along this dike, but has been separated into different parts where it passes into a more homogeneous mass of granite or of gneiss. In detail the different wall rocks seem to exercise some influence on the character of the lode here, as in other lodes of the district, the influence depending apparently on the relative rigidity of the different rocks. Along this lode there is no definite rule. In the upper Wisconsin tunnel the lode contains ore at the contact of porphyry and gneiss, but becomes barren on passing into porphyry

A. SEVEN-THIRTY MINE, IN BROWN GULCH, LOOKING NORTH-NORTHEAST FROM GRIFFIN MONUMENT.



B. BURLEIGH TUNNEL AND DIVES-PELICAN MILL.

1, Burleigh tunnel; 2, Pelican tunnel.

entirely. In the lower Wisconsin tunnel, however, the reverse is the case, as the maps show. It is probable that in the upper tunnel the porphyry was locally decomposed, and thus relatively plastic and impervious at the time of the ore deposition; and that in the lower tunnel the rock was locally more rigid and so capable of maintaining open fractures for the mineralizing solutions. The general order of events in this and the neighboring mines seems to have been (1) fracturing and slight faulting, producing circulating channels; (2) alteration of wall rock and partial softening of the porphyry; (3) ore deposition.

CHANGES OF ORE IN DEPTH.

The greater portion of the ore taken from this lode has been obtained from the surface down to a depth of 300 to 500 feet. Below this depth there was very little. At the very surface dumps show probable rhodochrosite and other carbonates with very little sulphides. In the lower Wisconsin tunnel, 300 feet below the surface, the ore for the most part appears primary, consisting of coarse intercrystallized galena and blende with some pyrite. This ore contains a fair amount of silver. Some of the ore, however, shows along abundant crevices dull-black soft secondary sulphides, characteristic of the recent work of descending waters. This constitutes some of the best ore, and is very apt to occur in wet places in the mine. In the upper Wisconsin tunnel the deposition of ore which apparently constitutes the main vein on top of the flatly dipping dike of impervious altered porphyry, suggests that the original deposition may also have been due to descending waters. In connection with these observations it is interesting to note the position of the Corry City ore body beneath Cherokee Gulch (fig. 42). The belief that the best ores occur where there is water and that the position of a vein directly beneath a gulch is especially favorable to good ore is common among Georgetown miners. The lowest level of the vein is in the Diamond tunnel, which is about 750 feet below the lower Wisconsin tunnel. Here the lode is very poorly mineralized, containing practically no filling whatever for considerable distances. In places, however, it contains a relatively large quantity of pyrite with some blende. This pyrite carries no values. The fact that the porphyry has been thoroughly altered throughout and the original iron which it contained leached out of it, together with the presence of this barren pyrite, suggests that the pyrite may have been derived from the porphyry.

SEVEN-THIRTY LODE.

LOCATION AND HISTORY.

The Seven-Thirty mine, which is one of the group of mines owned by the Dives-Pelican and Seven-Thirty Mining Company, is on an approximately east-west vein which crosses Brown Gulch at a point about 10,500 feet above sea level (Pl. XXX, *A*). The vein makes a junction with the Bismarck vein just east of the summit of Sherman Mountain; it then runs down the southwest slope of Sherman Mountain, crosses Brown Gulch, and runs westward along Brown Mountain.

The Seven-Thirty mine was first located about 1870 as a single claim. Numerous other claims were acquired by the owners, who, in 1896, transferred the entire group to the owners of the Dives-Pelican mine. The purchasers immediately pulled up the pumps and allowed the property to fill with water to the 275-foot level, from which level the water runs through the Dives-Pelican workings. This property, which has always been worked on the leasing system, has at various times in its history given employment to a force ranging from 50 to 80 men.

DEVELOPMENT.

At the present time the Seven-Thirty vein is worked entirely through the Hercules tunnel, which runs about 150 feet due north from Brown Gulch before it intersects the vein. Above the Hercules tunnel level five tunnels or drifts are driven east on the vein and three west. Work in these upper levels, however, was long ago discontinued. Below the Hercules level drifts have been driven on eleven levels both east and west of the Seven-Thirty shaft, which is sunk from the Hercules tunnel level to a depth of 975 feet. This shaft, which is on the vein, has a general dip of about 80° S. Near the end of the Burleigh tunnel what is probably the Seven-Thirty vein has been cut, at a depth of 290 feet below the bottom of the shaft.

The development in the lowest levels of the Seven-Thirty vein is not nearly as great as above, owing probably as much to the greater leanness of the ores at that depth as to the greater cost of production and the later period at which the development was undertaken.

The aggregate length of the workings on this vein, not including numerous raises and winzes, is between 5 and 6 miles. These figures represent the total amount of the original workings. Many hundreds of feet of workings, however, have subsequently been closed by caving. The owners are at present driving a crosscut from the Burleigh tunnel (Pl. XXX, *B*) to come under the Seven-Thirty shaft and join a continuation of that shaft. The Burleigh tunnel is located on a level only a little above Clear Creek, and by connecting with the Seven-Thirty shaft the workings below the 275-foot level will be drained of water, and the cost of ore transportation will possibly be diminished to such an extent that the low-grade ore bodies can be worked with profit.

PRODUCTION.

The yield of the vein from January 1, 1887, to January 1, 1896, was as follows:

Production of Seven-Thirty mine, 1887–1895.[a]

Year.	Ore mined.	Silver produced.	Lead produced.	Average assay.		Value.
				Silver.	Lead.	
	Tons.	*Ounces.*	*Tons.*	*Ounces.*	*Per cent.*	
1887	763.46	105,717.00	72.44	138	9.6	$83,642.91
1888	981.39	134,718.47	85.43	151	9.5	103,277.56
1889	711.87	106,197.08	98.00	149	13.0	81,614.39
1890	1,303.81	185,047.89	180.40	141	13.8	165,554.66
1891	1,849.76	304,930.40	183.19	164	10.0	248,659.42
1892	1,168.45	111,806.63	31.25	95	11.0	74,218.25
1893	341.70	72,962.84	49.07	214	14.0	46,788.67
1894	485.65	92,337.95	71.37	190	14.0	41,902.75
1895	560.48	120,654.26	71.27	215	13.0	68,420.82
	8,076.57	1,234,372.52	942.42	154	11.5	914,079.43

[a] From report on the mine by O. O. McReynolds.

The following approximation was made by O. O. McReynolds in a report on the mine drawn up in 1903:

Approximate total production of Seven-Thirty mine.

Prior to 1879	$151,617.00
From 1879 to 1887	743,024.54
From 1887 to 1896	914,079.43
During 1896	60,000.00
	1,868,720.97

From 1896 until recently practically no active work was done on the Seven-Thirty vein.

NATURE OF WALL ROCK.

Granite, gneiss, pegmatite, and porphyry form the wall rocks. Of these granite is predominant.

Granite.—The western part of the developed vein lies almost entirely in granite, which also occurs irregularly along the eastern portion. This granite (Silver Plume granite, pp. 58–60) is a medium-grained rock containing considerable biotite and usually showing small feldspar phenocrysts. In some places this porphyritic structure is more strongly developed by an increase in size of the phenocrysts and a diminution in size of the individual crystals of the groundmass, forming the "corn rock" of the miners.

Wherever seen in the mine workings this granite is more or less decomposed. The freshest specimen examined microscopically contained original feldspar, biotite, muscovite, magnetite, apatite, and pyrite. Microcline is abundant and very fresh. Another variety of feldspar is mainly altered to sericite; undecomposed portions show twinning striations and possess optical properties indicating andesine-oligoclase or oligoclase. Small idiomorphic crystals of largely sericitized feldspar, inclosed in microcline, probably belong to the same species. The biotite is nearly fresh, with some developments of sideritic material. The magnetite and pyrite are associated together.

Gneiss.—The eastern part of the vein passes through gneiss, which varies considerably in structure and composition. Some portions are firm and siliceous; others are fissile and biotitic. Many of the schist laminæ are crumpled, but the average strike is N. 40° W. and the average dip 65° NW. The gneisses inclose seams of pegmatite, porphyritic granite, and (in one place) graphic granite.

A specimen of firm, biotitic gneiss, examined microscopically, proved to consist of primary quartz, biotite, sillimanite, feldspar, pyrite, and muscovite. The feldspar is partly fresh microcline and partly another feldspar which has been almost entirely altered to sericite.

Porphyry.—The vein cuts diagonally across a porphyry dike in the vicinity of the Seven-Thirty shaft. This dike is 50 to 80 feet wide and dips flatly east-northeast, so that it lies between 200 and 300 feet west of the shaft on the 80-foot level below the Hercules tunnel and between 225 and 375 feet east of the shaft on the 275-foot level below the tunnel. The unaltered rock of this dike is a grayish quartz monzonite porphyry, containing phenocrysts of feldspar, quartz, and biotite.

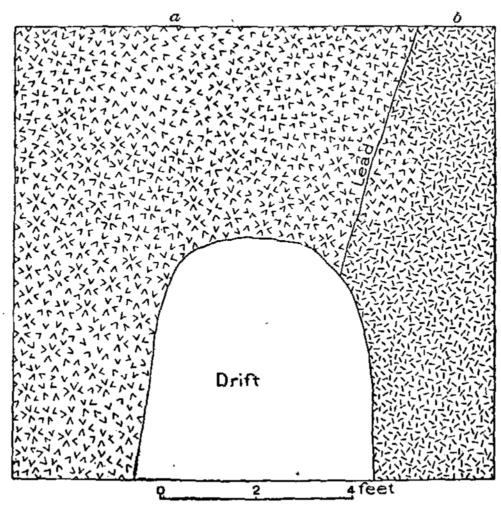


FIG. 43.—Sketch of barren lead (slip) on Hercules tunnel level, Seven-Thirty mine. *a*, Pegmatite; *b*, diorite. The discordance of the rocks on the two sides of the lead shows faulting.

NATURE OF VEIN.

The Seven-Thirty vein is a branch of the Bismarck, and although its junction with the Bismarck is inconspicuous, in many places obscure and attended by no well-marked effect on ore deposition, yet the productive portion of the Bismarck does not extend far to the northwest beyond the point where the Seven-Thirty leaves it. The last ore body of importance on the Bismarck is about 800 feet northwest of the split, but ore was found in the Seven-Thirty for 2,500 to 3,000 feet west of the branching point. Farther west the mineralization becomes obscure. It would therefore seem that the mineralizing solutions which circulated along the Bismarck lode openings were principally deflected into the Seven-Thirty lode openings at the branching.

The vein follows a line of movement in the rocks. The amount of movement is small, even though the openings created were sufficient to form a channel for mineralizing solutions for a horizontal distance of over half a mile. It was not sufficient to form a definite and continuous single fault or fracture zone, however, but resulted in a series of minor east-west fractures which run into and tie on to one another to form the general vein channel. Similar fractures branch off from the vein channel, but as they were not in the main string or line of openings these were but slightly mineralized or not at all (fig. 43).

Inasmuch as the veins lie along a composite fracture zone the strike and dip vary much locally. The strike ranges from east to northeast and the dip, while everywhere steep, changes repeatedly from south to north, the angle varying from 80° N. to 55° S., although the average is about 80° S. The weakness of the movements which produced the fractures is also shown by the constant deflection of strike and dip, due to the nature of the rocks which the fractures traverse and to the changing of the vein from one fracture to another (fig. 44). There is, however, some slight faulting along the fractures, shown by discordances of the wall rock on either side. Slickensides and movement striæ are also numerous and their trend varies from horizontal to a maximum pitch of 25° E.

On account of the nature of the vein channels above described and the lack of definite and regular movement zones the vein which has formed does not possess definite walls. The circulation openings were, wherever observed, mere cracks, and from these cracks the mineralizing solutions penetrated the wall rock for a certain distance on each side, this distance depending on the amount of circulation at each point. The first result was a bleaching and alteration of the wall rock on both sides of the crack, and this effect is found along practically all fracture planes in the mine (fig. 45). The next step was the impregnation of the altered country rock with metallic sulphides, and finally the more or less complete replacement of the rock by vein materials. As a rule the effects of this alteration extend to a regular distance on each side of the crack which has supplied the solutions, and so a definite band of altered granite, or (in the first stage) of ore, results, with, however, no definite division plane between it and the country rock. Veins of this type are numerous and important in the Georgetown region. In the Seven-Thirty mine the feeder crack is usually in the center of the resulting vein, but in other mines, described elsewhere, the alteration has been mainly on one side of the feeder only, producing a vein with a single side wall. Veins of this type may be called single-wall veins, to distinguish them from the more familiar double-wall veins, which consist of a definite vein zone bounded by hanging and foot walls; and these single-wall veins may be defined as single center-wall veins or single side-wall veins, according to the position of the feeder crack.

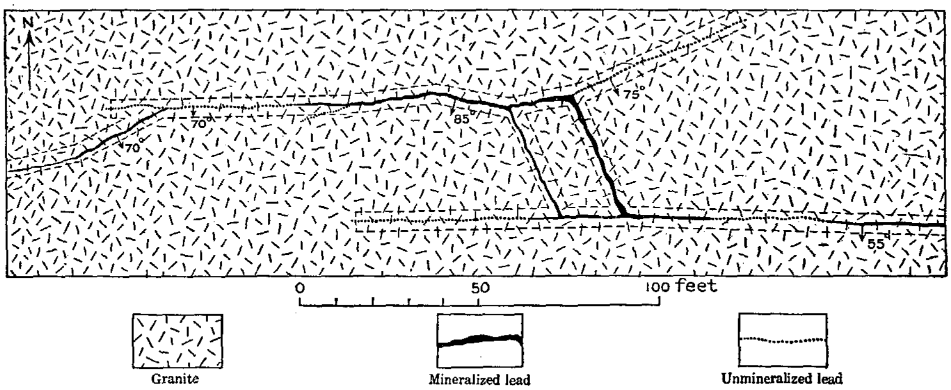


FIG. 44.—Plan of portion of Seven-Thirty vein, 80-foot level, showing deflection of mineralizing solutions by different fracture channels.

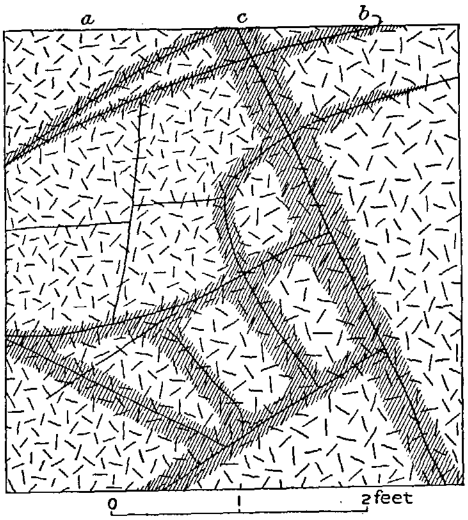
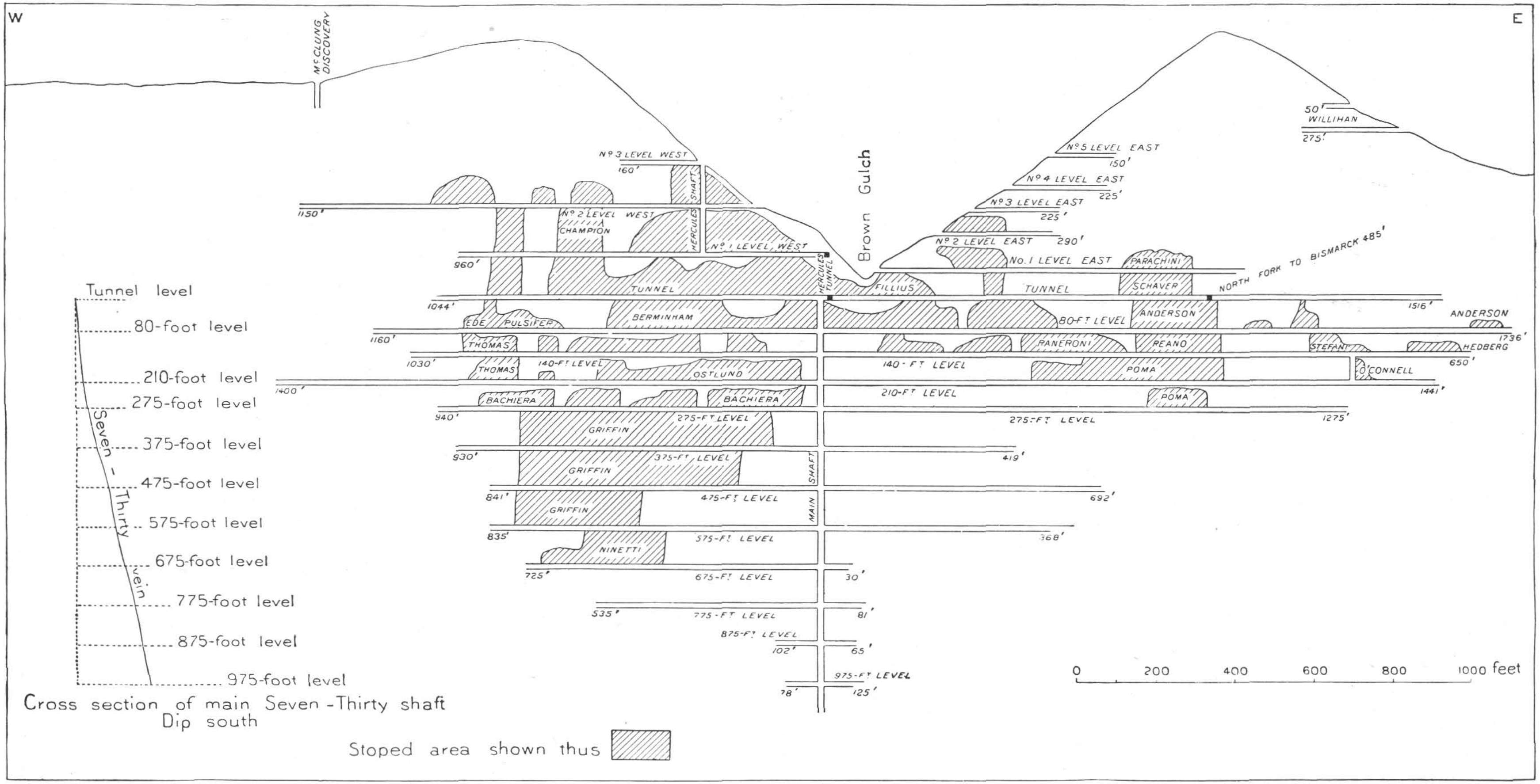


FIG. 45.—Vertical sketch on wall of stope, Hercules level, Seven-Thirty mine, showing joints (b), in dark biotite granite (a), bordered on each side by a regular band of bleached and silicified granite (c). These bands form definite veins (single center wall veins). The increase in thickness of these veins causes them to unite to form a larger mass.

STRUCTURE OF VEIN.

The detailed structure of the vein depends on the method of its formation, just described. In considerable portions of the underground workings the miners have followed rather poor "leads" consisting of strong fractures with or without considerable mineralization (fig. 46). These fractures may become mineralized, and the mineralized belt on each side may increase in thickness sufficiently to form an ore body. As a rule, however, an ore body is due to a bunching of mineralized fractures. Such a bunching is frequently seen at the intersection of two or more principal fractures, or it may take place along a single strong fracture by the local thickening



VERTICAL PROJECTION SHOWING WORKINGS ON SEVEN-THIRTY VEIN.

Adapted from a section by O. O. McRevnolds, June, 1903.

up of the fracture field. The latter condition produces a lenticular ore body. In such a field of close-set fractures the altered and mineralized zones bordering the individual cracks may broaden till they unite.

The ore is thus almost entirely due to replacement of the granite (fig. 47). In such ore, seen under the microscope, the quartz has the retiform structure characteristic of replacement quartz.[a]

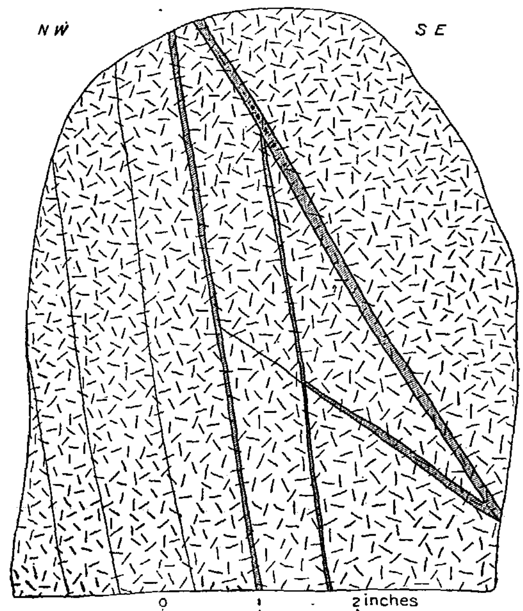


FIG. 46.—Sketch of breast of drift, Hercules level, Seven-Thirty mine, showing joints in granite, of which some have broadened into thin zones inclosing a few inches of unmineralized crushed granite. The walls of the zones usually show evidences of horizontal movement. These zones constitute the barren leads followed by miners.

COMPOSITION OF VEIN.

The gangue material is chiefly quartz with local barite. Calcite veinings occur, but it is doubtful if they form part of the original gangue.

The metallic minerals consist usually of galena, blende, polybasite, and tetrahedrite, with a little pyrite, some of it cupriferous. These ores contain a relatively large amount of silver and a small amount of gold (0.1 ounce to the ton). As shown by the table on page 198, the average value of all the ore shipped during the nine years between 1887 and 1895 was $113.17 per ton, and each ton carried an average of 154 ounces of silver and 11.5 per cent of lead. Several mill runs have also yielded between 1,400 and 1,500 ounces of silver to the ton. The blende is mainly dark brown, but some of it is yellowish or light-brown "resin blende." It is held by the miners that where the blende is light colored, the silver content of the ore is greater.

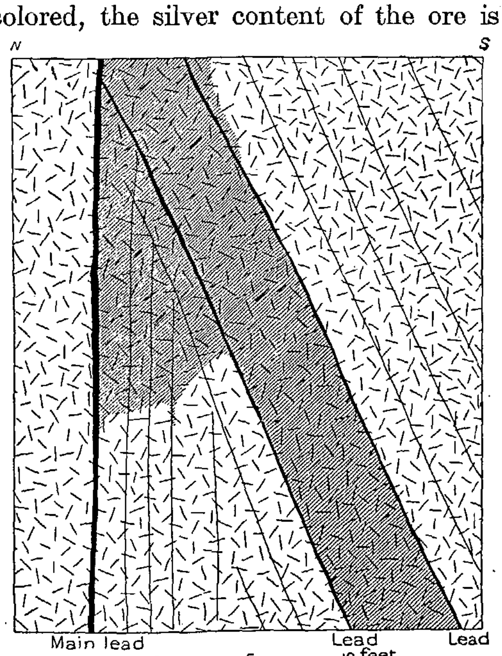


FIG. 47.—Vertical section of wall of stope, Hercules level, Seven-Thirty mine, showing formation of ore body by replacement of fractured granite at junction of main lead with minor leads.

Native silver in flakes is occasionally found. Argentite and pyrargyrite have also been reported.

INFLUENCE OF DIFFERENT WALL ROCKS.

The different wall rocks through which the vein passes influence the character of the vein, but, so far as noted, on account of their physical and not their chemical peculiarities.

Granite.—The comparatively fresh and rigid granite has evidently afforded the plainest and most persistent fractures, as a result of the applied pressure. In the granite (fig. 47) the vein runs due east and west, is usually well marked, and contains considerable ore.

Gneiss.—Where the vein openings cross gneiss, they have been deflected from an easterly to a northeasterly trend. That this deflection is due to the gneiss is evident, for if the vein reaches granite again, after passing through gneiss, it resumes its normal east-west course. As the prevalent strike of the gneiss is northwest, the result of the deflection seems to have been to make the trend of the vein fractures more nearly normal to this strike.

The fissile character of the gneisses seems to have been unfavorable to the strength and persistence of the movement fractures, the movement having a continual tendency to be deflected

[a] Spurr, J. E., Mon. U. S. Geol. Survey, vol. 31, 1898, p. 218.

and to be taken up in part along the schistosity planes. This action, of course, depended in large part on the relative rigidity of the gneiss, which varies very widely in different portions. In the softer schistose gneisses the fractures were poor and veins are apt to be small and to split up continually; while in the hard gneisses the conditions were as favorable as in the granites. The miners of this mine as a rule regard the schistose gneiss with disfavor.

Porphyry.—The porphyry dike which the vein cuts across, near the Seven-Thirty shaft, has no connection with the origin of the vein. The vein, as before stated, is a branch of the northwestward-trending Bismarck vein, whose direction is controlled by another porphyry dike. The dike which the Seven-Thirty crosses has also a northwest strike, so that the east-west vein crosses it obliquely. The effect of the dike has been to tend to deflect the vein fracture in a direction normal to the dike walls—a tendency especially shown on the 275-foot level (fig. 49).

As a rule the fractures in the porphyry have not been so strong as in the granite and hard gneiss, and the vein is poorer (fig. 48).

ALTERATION OF WALL ROCK.

The bleaching and alteration of the wall rock, noticeable along the fractures in the granite gneiss, or porphyry, is especially marked to the naked eye by the bleaching of the biotites and the alteration of the feldspars. This alteration was especially studied microscopically in the

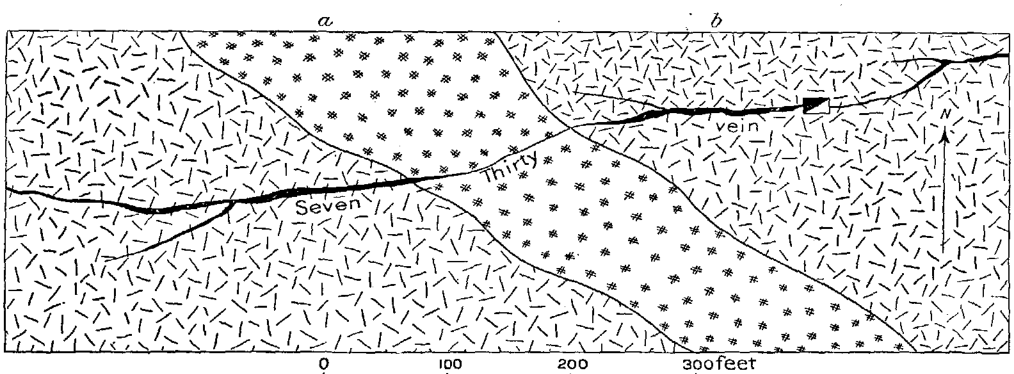


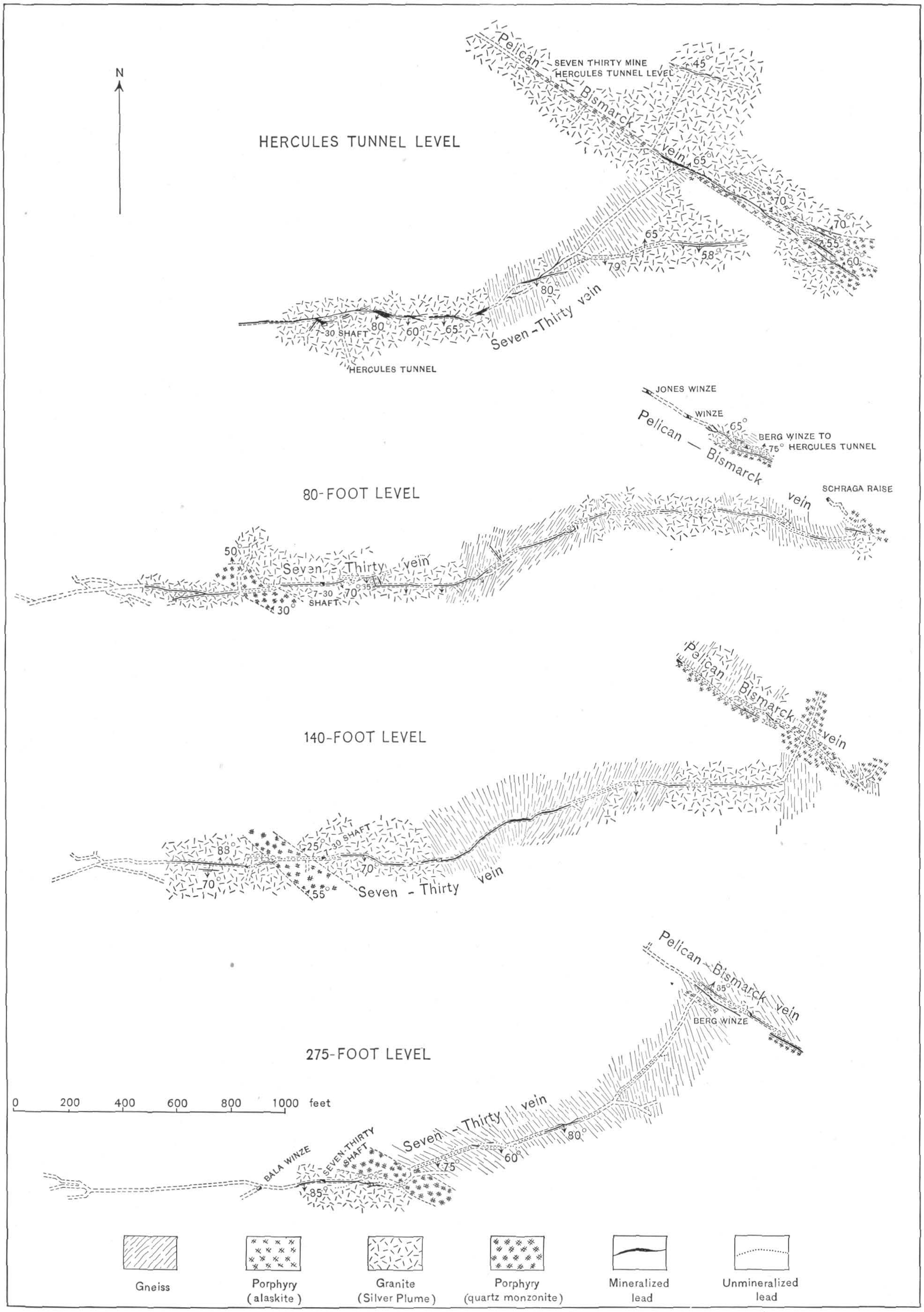
FIG. 48.—Horizontal plan of portion of 80-foot level, Seven-Thirty mine, showing diminution of vein on passing through porphyry. *a*, Quartz monzonite porphyry; *b*, granite.

case of the granite. Of the original minerals of the granite, quartz, microcline, and muscovite are invariably unaltered. Other feldspars and biotite have been more or less completely altered. Andesine-oligoclase and oligoclase are often found largely altered, and in much of the rock are undoubtedly entirely altered; and orthoclase appears to have been entirely altered in all cases. The decomposition products are chiefly sericite, with some fine quartz, kaolin, ferriferous carbonates, and epidote. In these masses of alteration products fluorite crystals were detected and in one specimen a speck of native gold. Fluorite was also detected in other parts of the rock, among other places filling cracks in fresh microcline, and extending from the veinlet into the microcline as single isolated crystals; also filling cracks in quartz. Although some of this fluorite simulates the habit of an original mineral, its general relations leave no doubt as to its secondary nature. Marcasite and probable pyrite also occur as secondary minerals. The biotite is in general almost completely altered to sericite and a brown carbonate, in part, at least, siderite.

A specimen of the porphyry near the vein also proved to be entirely decomposed. Of the phenocrysts, quartz, feldspar, and biotite, the last two were entirely altered. The feldspar was altered to sericite, kaolin, carbonates, kaolinic matter, quartz, etc.

CHANGES OF ORE IN DEPTH.

The oxidation of the ores extends down about 40 feet below the surface. (See Pl. XXXI.) The oxidized material looks like brown clay, much of it strained reddish, yellowish, or greenish. It occurs along cracks and watercourses, and is by far the richest ore of the mine, containing several



GEOLOGICAL PLANS OF SEPARATE LEVELS, SEVEN-THIRTY MINE.

hundred ounces of silver. Below this oxidized material, and in many places mixed with it, come sulphides, typically easily broken, powdery, and black. This material is also rich, and contains several hundred ounces of silver. A sample taken from the Bismarck vein on the Hercules tunnel level (see Pl. XXXII) of the Seven-Thirty, at a point not far below the surface, was examined by Doctor Hillebrand. It was found that the metallic minerals were almost wholly if not altogether in the sulphide condition. "The chief mineral is sphalerite, the next may be galena, though its distinctive features are not recognizable. There is a silver-antimony mineral which may be tetrahedrite, though possibly these elements belong with the lead in a complex sulph-antimony mineral. The only detectable oxidized mineral is a little lead sulphate. There is no silver chloride and no phosphate."

Below these soft crumbling sulphides (called "sulphurets" by the miners), the solid sulphides continue to the bottom of the mine. From the surface down the amount of lead and silver in the ore is said to decrease and the zinc to increase.

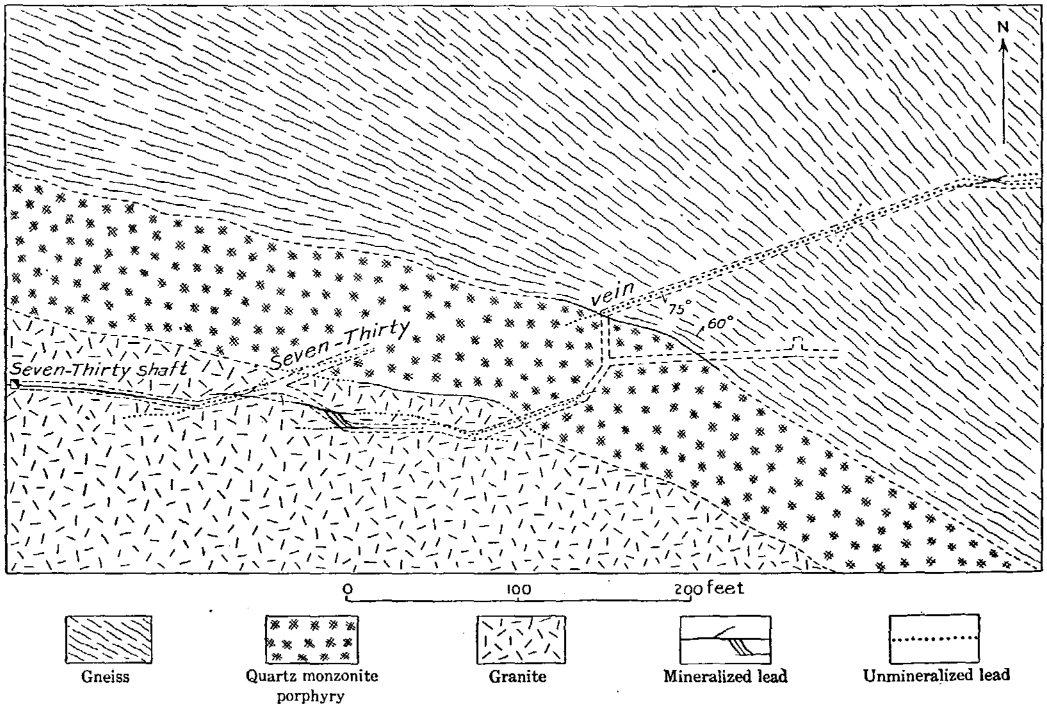


FIG. 49.—Horizontal plan of portion of 275-foot level, Seven-Thirty mine, showing the effect of softened porphyry dike on vein. Vein is deflected by dike and is impoverished, the dike having been a less rigid medium for fracturing than either the hard gneiss on the northeast or the granite on the southwest.

The ore was said to have been good down to the sixth or seventh level. Below those levels it consisted of zinc-blende and pyrite ores, poor in lead and silver. The lowest level in the Seven-Thirty workings proper is 975 feet below the Hercules tunnel, and this is also practically the bottom of the shaft. About 920 feet lower, or 1,800 feet below the Hercules tunnel, the vein, where cut in the Burleigh tunnel, shows only a seam of blende three-fourths of an inch thick. The lead here is in hard gneiss, with patches of pegmatite and granite. An unsuccessful attempt was made to follow it along the strike, but it becomes unmineralized and splits repeatedly into fractures passing into the gneiss. (See Burleigh tunnel plan, Pl. XXXVII, p. 220.)

DENVER LODE.

The principal outcrop of the Denver lode lies 500 or 600 feet north of the Wisconsin–Corry City lode, with which it has a general parallelism. It is developed chiefly by a tunnel which follows the lode for a distance of 800 feet. The lode is traceable on the surface for the same distance that it is followed in the tunnel, and also is recognizable on the opposite or east side of Cherokee Gulch, making a total distance of nearly 2,000 feet. On the west the outcrop of the lode passes into the broad depression filled with glacial drift which lies east of Sherman Mountain. On the opposite side of this depression, on the side of the mountain, appears a lead or a series of leads going up the slope in the direction of the Bismarck lode. While no connection of these leads with the Denver lode exists, nothing corresponding to an extension of the Denver is found elsewhere, and it is possible that the leads in the two localities belong in one and the same zone.

In the Denver tunnel drift the lode strikes west-northwest and dips to the north at an angle ranging from 55° to 75°. The vein is along a fault lead on whose walls striæ dip 5° W. The rock is mostly gneiss with a little porphyritic granite. The lode for the most part seems to cut across the laminæ of the gneiss at right angles. In general the lode is a strong one and still appears strong at both ends of the tunnel (fig. 50). The filling is largely quartz, which coats the walls of fissures in the lead, but is principally massive—the result of replacement along the fault zone. The metallic minerals are chiefly blende, pyrite, and galena, which are in general later than the quartz and occur in many places as crystals lining druses and coating the earlier quartz crystals. In other places seams of massive ore traverse granite with no signs of crustification. Locally the ore has been raised on somewhat, but probably no great amount has been extracted.

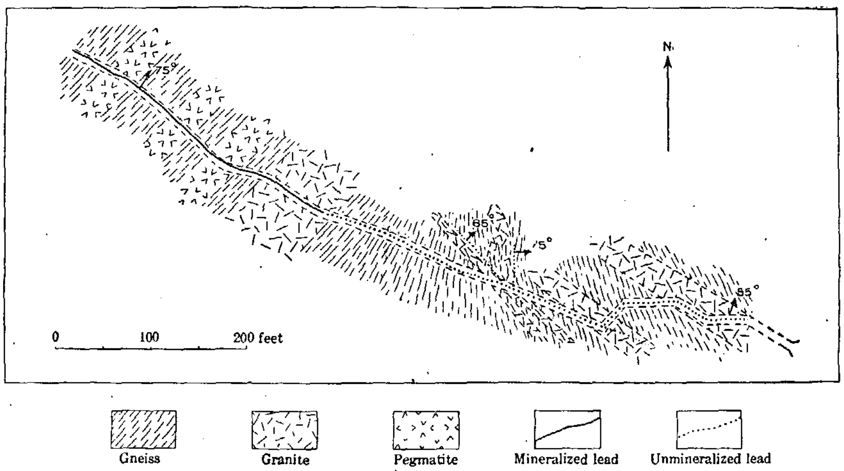


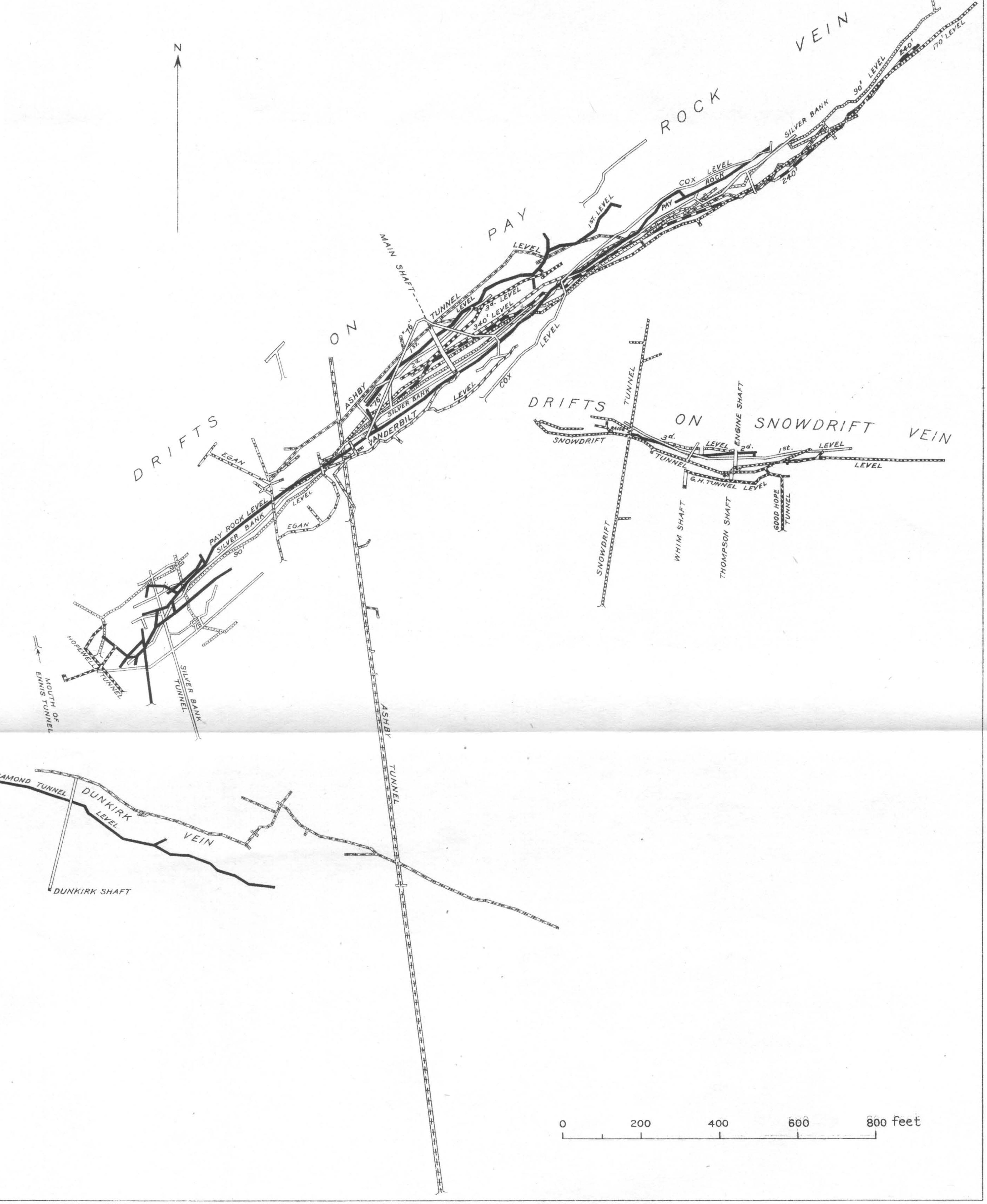
FIG. 50.—Plan of tunnel on Denver lode, showing geology.

On the Hercules tunnel level of the Seven-Thirty and Bismarck mines the Kinney crosscut runs northeastward from the Hercules drift on the Bismarck lode and cuts what is known as the New vein, or New North vein, at a distance of 344 feet. This point is about 600 feet below the surface. The New vein strikes a little north of east and dips 45° N. It is entirely in granite It was drifted on along this level for about 300 feet. It resembles the Seven-Thirty vein in consisting of a connected string of branching veins, many of them running into one another at an angle. These slips show movement striæ, which were noted in one place dipping 15° to 25° E. on the fault plane. Scattered sulphides and some stringers of blende and galena occur along these slips. A shipment of 4,260 pounds of ore from a raise on this drift is recorded (May, 1903) as yielding 261 ounces of silver, 14 per cent of lead, and 16 per cent of zinc. The position of this vein renders it possible that it may be the same as the Denver lode, on the one hand, and as the series of leads above noted which run up the east side of Sherman Mountain toward the Bismarck vein, on the other. This vein has not been encountered in any of the other workings of the Dives-Pelican mine, and indeed on the lower levels its relatively flat dip would carry it rapidly farther and farther away from the Bismarck-Pelican vein.

PAY ROCK LODE.

HISTORY AND PRODUCTION.

The Pay Rock lode (Pl. XXXIII), which was discovered in 1872, was one of the active producers for years and all through the early eighties gave work to sixty or seventy men. In 1884 a bucket tramway was used to convey many tons of low-grade material from the dump to



HORIZONTAL PLAN OF WORKINGS IN THE PAY ROCK AND SNOWDRIFT MINES, INCLUDING ASHBY TUNNEL WORKINGS the mill which had been constructed at the edge of Clear Creek. But little work has been done in this mine for years.

Fossett[a] states that the Pay Rock mine yielded about $60.000 in 1878 and "produced altogether some $450,000 up to 1880, or more than any other excepting the Dives and Pelican." E. O. Leech, Director of the Mint, reported the production during three years as follows:

Production of Pay Rock mine, 1889, 1890, and 1892.

	Silver.	Lead.	Total.
1889	$135,757.56	$3,952.00	$139,709.56
1890	35,203.00	517.00	35,720.00
1892	217,479.00	6,107.00	223,586.00

The total production of the Pay Rock vein is estimated by E. F. Kendall, the superintendent, at about $2,000,000.

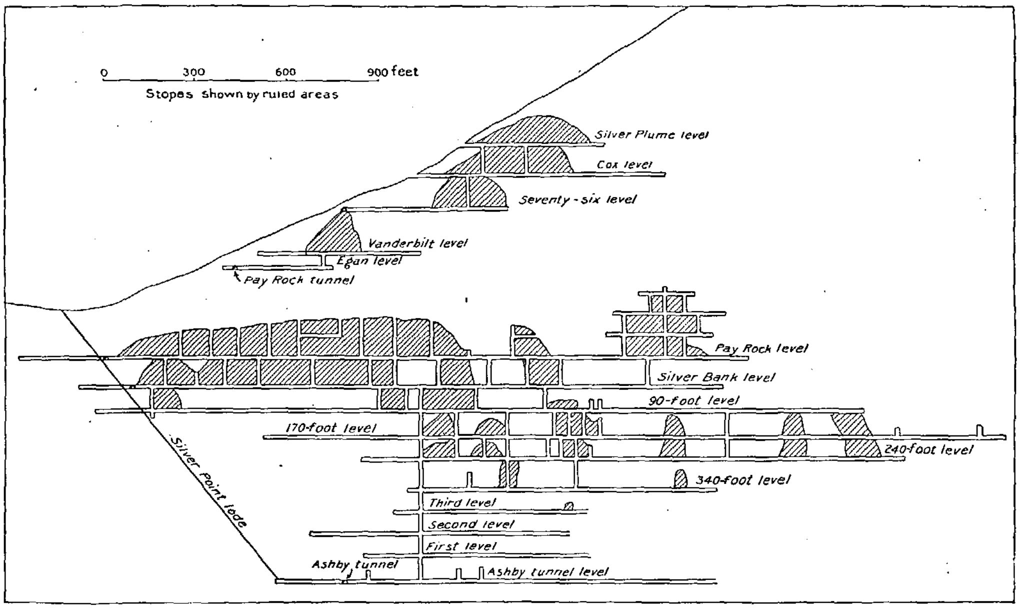


FIG. 51.—Vertical longitudinal projection of Pay Rock mine.

DESCRIPTION.

The Pay Rock (or Silver Plume) lode may possibly have some connection with the Pelican-Bismarck vein system, as a branch of the Corry City lode. This relation, however, is not well established, and the productive portions of the two lodes are widely separated. The Pay Rock is a nearly perpendicular vein striking due northeast. At the southwest end of the developed portion the dip is northwest, at an angle of about 80°; but farther northeast it becomes perpendicular, or even steeply inclined to the southeast. The length of the vein as developed by underground workings is about 2,700 feet, and the aggregate amount of developed work done in the Pay Rock mine is approximately 5 miles. The lowest tunnel, that from the Ashby tunnel, ranges in depth from 1,000 feet below the surface at its southwest end to 1,500 feet at its northeast end (fig. 51).

NATURE OF THE INCLOSING ROCK.

The country rock is mostly hard gneiss, with some pegmatite and some porphyritic granite. The general trend of the schistosity and the angle of the vein to it are fairly constant, as seen in the Ashby and Silver Bank tunnel levels. The gneiss strikes north and south, so that the vein cuts across it at an angle of 45°.

[a] Fossett, Frank, Colorado, 1880, p. 394.

The productive portion of the vein ends on the west at the contact with a transverse dike of porphyry, which has a northwest strike and a dip of about 50° NE. This dike was seen in the Ashby tunnel, where it has a thickness of 20 feet or more, and in the Silver Bank tunnel, where it has been disturbed by movement parallel with its course, resulting in considerable shredding of the porphyry, and the diminishing of the porphyry zone to about 6 feet. The same dike is reported as having been encountered at the southwest end of other levels of the mine, between the two above mentioned.

In the field this porphyry was noted to be of the Corry City type. The microscope shows it to be entirely altered. Large phenocrysts of feldspar are altered to calcite, sericite, and kaolinic products (the latter in the Silver Bank tunnel); phenocrysts of biotite are completely changed to silica, sericite, and cloudy carbonates. Apatite is frequently seen. Characteristic areas of cloudy siderite, rhombic or square in outline, probably represent altered pyrite. Many of these areas are fringed by hematite. The groundmass is a devitrified glass, now containing secondary carbonates, etc.

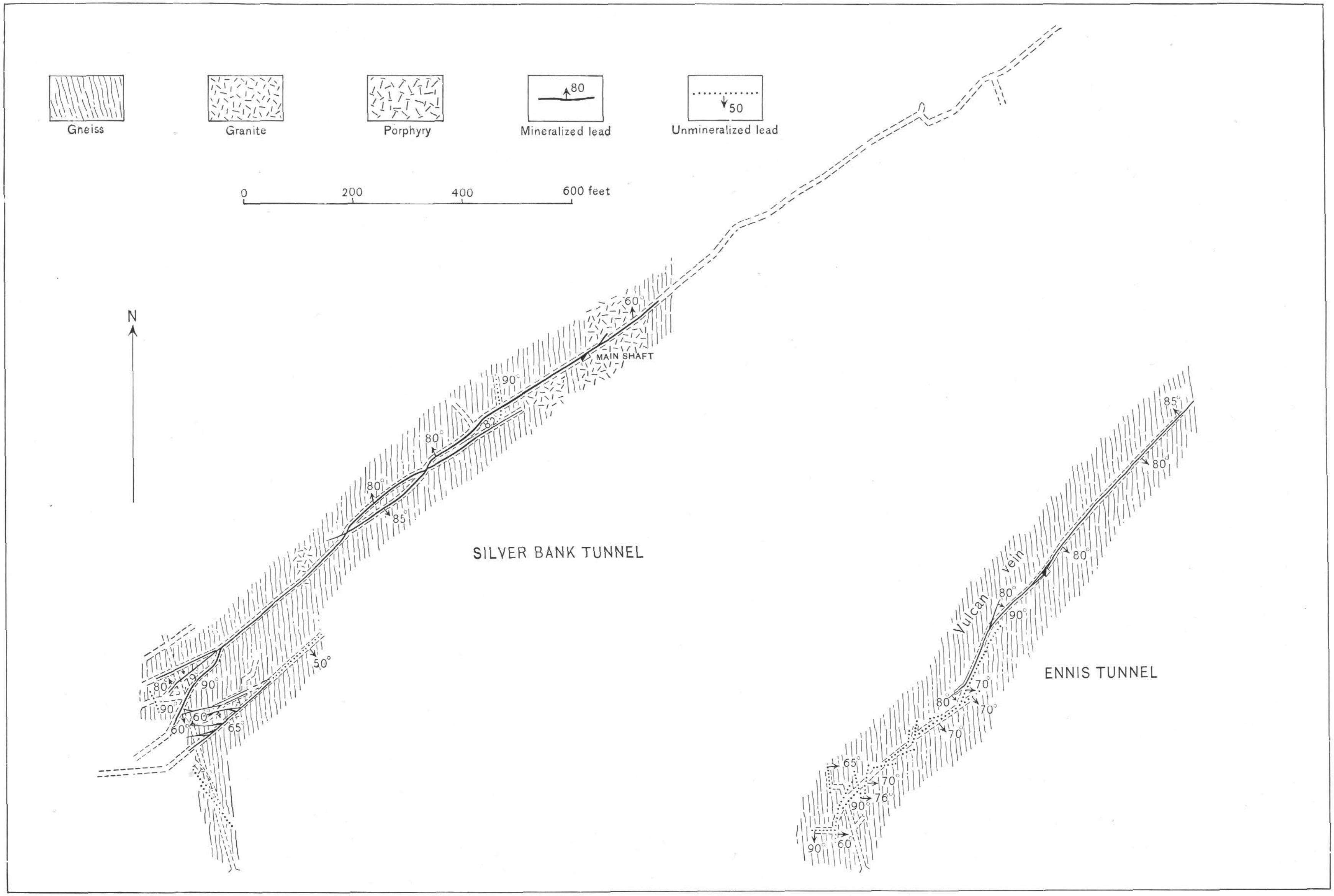
This porphyry dike is locally known as the Silver Point lode, and has been somewhat explored. It is reported to be unmineralized, however. It is said to cut off and form the western termination not only of the Pay Rock vein, but also of the Vulcan, which lies not far northwest of the Pay Rock, and nearly parallel to it. Near the surface the dike is said to have been traced northwestward by shallow workings to Cherokee Gulch, as well as a considerable distance to the southeast; but at present many of these small tunnels are inaccessible, and the débris strewing the surface hinders the following out of the dike. The resemblance of the porphyry to that found in the Corry City workings is difficult to confirm, on account of the profound alteration which the rocks in both places have undergone. The position and trend of the Silver Point dike, however, suggest the possibility that it may be practically the same as that in the Corry City; its dip is also similar, and its relation to the probable extension of the Corry City lode on the surface, near the Silver Bank tunnel (of the Pay Rock mine), is similar to that shown in the Diamond tunnel workings on the Corry City. In the Diamond tunnel the porphyry splits off from the Corry City lode at a point west of the tunnel, so that in the crosscut tunnel only a little was detected, and that 200 feet northwest of the lode. On the surface, near the Silver Bank tunnel, the relation between the Silver Point porphyry dike and the extension of the Corry City lode is similar, the former lying about 200 feet northeast of the latter.

NATURE OF VEIN.

The Pay Rock vein has formed along a strong fault slip or fault zone. Movement along the slipping planes is shown by discordance of the opposing walls, by crushing, and by slickensiding. In the Silver Bank tunnel, in one place, the striæ dip 25° SW.; in another locality on the same level a polished surface shows an earlier and stronger set of grooves dipping 3° NE., and a weak later set dipping 20° SW. The movement then was more nearly in a horizontal than a vertical direction, as was true in a general way of all the contemporary faults of this region.

On the Silver Bank level (Pl. XXXIV) the fault lead is very strong and has been followed for 1,100 or 1,200 feet northeast of the main Pay Rock shaft. On the lowest level, that of the Ashby tunnel, the drifts west of the shaft also show a fairly strong fault lead; but a short distance northeast of the shaft the lead dies out, passing into mere fractures. In this place crosscutting was resorted to, and other fractures, having a similar trend, were found and followed. A similar condition was found in the first level, 140 feet above the tunnel level. The main lead divides, toward the northeast, into numerous little slips in the gneiss. Many of these leads die out and are continued by parallel overlapping leads, and about 300 feet northeast of the shaft the leads are practically lost.

In the Silver Bank tunnel the vein splits into a network of branches at its southwest end, just before intersecting the Silver Point porphyry dike, and these branches, though representing in general weak slips, are highly mineralized. The same condition is not found at the



GEOLOGICAL PLANS OF SILVER BANK AND ENNIS TUNNELS.

Ashby tunnel level, where the lead is weak and unmineralized near the porphyry. The vein is not present in the porphyry, but on the southwest side was encountered in the upper workings (according to Mr. Kendall, the superintendent) as an entirely barren lead, which in one place was followed for several hundred feet. There is little evidence of fissure filling in any part of the mine; the ore seems to be rather the result of replacement and impregnation along fault zones.

LOCATION OF ORE BODIES.

It is reported that as a rule the best ore in the Pay Rock was at the junction of veins, the shoot beginning at the junction and extending some distance along the united vein. At one such intersection the richest pocket in the mine was found. This principle is seen in the network of branches at the southwest end of the lode, in the Silver Bank tunnel, where chimneys, or pockets, of ore have been characteristically made at the intersection of branches.

RELATION OF ORES TO DEPTH.

The contrast is striking between the Pay Rock lode, as shown in the Silver Bank tunnel, the principal accessible upper level, and in the lowest level, that of the Ashby tunnel. The vertical distance between these two levels is about 640 feet. On the Silver Bank level are very strong, straight veins, consisting of slip zones cemented chiefly by silica. On the lower level the slips are present constituting the same channels as those above, as is proved by their having been followed continuously downward; but they appear much weaker and less continuous than the same slips on the upper levels. The most striking difference, however, is in the quantity of mineralization. On the Ashby level (as also in the next level, 140 feet above) the slips are usually barren. On the Silver Bank level a slight fracture zone, weak and splitting, may serve as a locus for a deposit of quartz and rich ore, while along the main vein the mineralization is heavy and continuous; but directly below, in the Ashby level, the presence of an important vein would in many places not be suspected.

The ore contains galena, blende, pyrite, quartz, calcite, and siderite, all intercrystallized and contemporaneous. Polybasite was probably present in the richer ores. The carbonates, calcite, and siderite, though intercrystallized with and contemporaneous with the sulphides, seem much more abundant near the surface than below. Siderite was not noted in the Ashby tunnel. A similar abundance of siderite and calcite was noted close to the surface of the Bismarck and the Wisconsin lodes, and the relations to the sulphides were also similar. The surface at these different points is at different altitudes, ranging from 10,000 to 11,000 feet, so that these siderite ores can not be accounted for as a zone due to ascending waters, but must be due to atmospheric agencies.

In the Pay Rock mine the richest and largest bodies of ore were close to the surface. Pockets were opened near their outcrops and worked downward till barren rock was reached. In many places these surface ores were very rich. Soft, black, rich secondary sulphides (locally called "sulphurets") are reported to have been found up to about 50 feet below the surface. According to Mr. Kendall, large bodies of gold-bearing pyrite occurred near the surface, some of them containing as much as 2 ounces to the ton, while farther down, galena-bearing smelting ores came in, containing much less pyrite and only traces of gold. Similarly an unusual quantity of pyrite was noted by the writers in the sideritic superficial portions of the Bismarck and Wisconsin lodes, though whether or not these ores were auriferous has not been ascertained.

The good ore on this vein appears to have reached locally a maximum depth of about 1,200 feet below the surface. Near the bottom of the ore the largest amount of "glance" (polybasite?) in the mine, including masses several inches in diameter, is reported to have been found.

Besides the practical disappearance of the lode material, both gangue and metallic minerals, in depth, the greatest geologic interest in this mine centers around the fact that the vein is completely cut off by the transverse Silver Point porphyry dike in the upper levels. According to information obtained, the fault fracture passes through the porphyry, and has been followed several hundred feet farther southwest, but is absolutely barren. On the northeast side the same fracture is highly silicified and mineralized. Moreover, close to the dike, on this side, there is an extraordinary amount of mineralization. The vein splits into many branches here, a condition which in general is elsewhere attended by weakening or lack of mineralization, but in this case good ore in considerable quantity has made along many of these minor slips, so that a network of ore-bearing veins about 200 feet wide is present. According to Mr. Kendall, when the lode encountered the porphyry dike it spread out and followed the east side of the porphyry dike for some distance, forming considerable bodies of mostly low-grade ore.

The above-stated facts indicate very strongly that the mineralizing solutions were intercepted by the decomposed porphyry dike, and barred from the channels southwest of the dike; and that the solutions circulated most vigorously along the eastern contact of the dike. This dike dips about 50° NE., so that the solutions circulated along its upper surface; therefore the work of descending waters is suggested.

All the above considerations indicate that the ore deposits in their entirety were deposited by descending waters. That the secondary sulphides and other rich ores in the surface zone were the result of double or, let us say, multiple concentration and the partial separation of the different metals according to their relative solubilities is undoubtedly true, but there seems good reason to assign the low-grade ores also to deposition from similar waters. According to Mr. Kendall, before the Ashby tunnel was run (which changed the course of underground drainage) the presence of water was considered a good sign of ore, and where water was encountered in any amount ore was looked for.

PRESENT ACTION OF DESCENDING WATERS.

In the Ashby tunnel special attention was paid to a remarkably active and important process observed everywhere in the underground workings throughout this district—the action of the present underground waters. The water in this country is close to the surface. Even on hilltops, as, for example, on Leavenworth Mountain, water was standing at 50 or 60 feet below the surface in shafts at the time of this examination. Underground, as in the Ashby tunnel, water circulates along slips and fractures in the rock. Most watercourses are found in granite and hard gneiss, rocks whose rigidity makes it possible for continuous open cracks to exist. The softer schist is without good fractures, and is free from any considerable amount of underground water.

Every stream of water entering the Ashby tunnel along a water course has coated the rocks, as well as the tunnel floor, with copious deposits of calcite, hydrated iron oxide, and manganese dioxide. The metallic oxides are in many places distinct from one another and from the calcite, though in other places the deposits are mixed. Generally the calcite has been deposited first on the walls of a crevice, with the oxides above, indicating successive deposition. The invariable occurrence of these deposits wherever water courses enter the tunnel and their abundance in rocks remote from veins show that they have no connection with lodes, but represent the universal action of descending waters.

This fact indicates that surface waters leach lime, iron, manganese, etc., from the granites and other rocks, and carry these materials far down. The breast of the Ashby tunnel, where, as elsewhere in the tunnel this process has been active, is 1,200 feet below the surface.

The deposition has been produced only by artificial means, by the introduction of air along tunnels. Where the waters emerge into the tunnel and come into contact with the oxygen of the air they drop the material they hold in solution. These solutions are evidently carbonates, and the process of deposition of the materials is similar to the precipitation of lime, carbonate, manganese dioxide, and limonite in bogs at the surface. A similar deposit of manganese and iron oxides on the floor of a cave has been noted at Aspen, Colo.[a]

[a] Spurr, J. E., Mon. U. S. Geol. Survey, vol. 31, 1898, p. 239.

At the breast of the Ashby tunnel the granite was noted to be darker and fresher than any of that seen above or at the surface, while along joints and other cracks it has been bleached, plainly by percolating waters, to a light color, more like that of the surface rock. This locality is 150 feet north of the Pay Rock vein, which, moreover, is in this portion entirely unmineralized.

A thin section of the fresh granite contains feldspar, quartz, biotite, and muscovite, with accessory apatite and zircon and a little pyrite. The muscovite is not abundant. The biotite is fairly fresh. The feldspar may be divided into two classes, the first clear and unaltered, the second brown and clouded, partly altered to sericite, which in part becomes coarser, changing to clear, fine muscovite crystals. In the feldspars of the first class microcline is predominant. A second variety is an unstriated feldspar, transitional to microcline. Three determinations by the Fouqué method indicate microcline-orthoclase. A third variety shows a single set of twinning striations. A determination of this by the Fouqué method also indicates probable microcline-anorthoclase. The partly sericitized feldspars constituting the second class are striated or unstriated. Nine determinations by the Fouqué method show albite and oligoclase-albite.

The bleached granite near the joints is much more altered than the rock just described. The feldspars, as in the fresh granite, may be divided into an unaltered and an altered class. In the unaltered class the perfectly clear feldspars are, first, predominantly microcline; second, an unstriated feldspar transitional to microcline; third, a singly striated feldspar whose optical properties indicate probable microcline-anorthoclase. The altered feldspars are almost entirely decomposed—much more than in the fresher granite. There is a little residual feldspar, but the species is indeterminable. The alteration products consist of sericite, fine crystalline muscovite, and carbonates, in good crystals. The biotite is entirely altered and bleached with the development of carbonates.

The results of the alteration of this alkaline granite by carbonated waters descending from the surface are the complete alteration of biotite and albite, while microcline, microcline-orthoclase, microcline-anorthoclase, and muscovite were free from attack. The biotite yielded to the waters abundant iron, which went into solution in the form of bicarbonate, and a little manganese. The albite and albite-oligoclase yielded soda and some lime. The carbonate surface waters took these materials into solution as carbonates.

The widespread importance of this process is shown by the surprising abundance of calcite, limonite, and manganese dioxide precipitated from underground waters in tunnels and other mine workings throughout the district, and by the universal alteration of the granites near the surface.

The solutions which deposit the calcite ocher and wad in the tunnels would normally deposit their iron and manganese along their channels as carbonates in the absence of excessive oxygen. The abundant calcite and siderite, much of the latter more or less manganiferous, in the superficial portion of the veins seem naturally referable to this origin. Siderite-filled veinlets, such as that in the Diamond tunnel (p. 193), about 650 feet below the surface, moreover, seem the natural results of such waters at a greater depth. In the case just mentioned a gash fissure which had first been lined with quartz was again partly filled by a brown ferriferous carbonate, though spaces were still left empty. This carbonate, however, incloses some contemporaneous pyrite, galena, and blende, and the same is true of the carbonates that are characteristic of the surface portion of the principal veins. Moreover, the deposition of the carbonate layer on top of the quartz layer, and the fact that the sulphides occur here entirely within the quartz, there partly in the quartz and partly in the carbonate, and elsewhere entirely in the carbonate, suggests a continuous process of deposition for the whole vein.

A specimen of "gouge," or soft triturated material, obtained along the Bismarck-Pelican fault lead, on the Pelican tunnel level, at a depth of 1,600 feet, examined by Doctor Sullivan, contained large amounts of ferrous carbonate (siderite). This gouge is being percolated through continually by descending waters, which have no doubt deposited the siderite. The fault lead at this point is on the contact of porphyry and gneiss.

VULCAN LODE.

The Vulcan vein lies about 300 feet northwest of the Pay Rock vein and has practically the same strike and dip. It is neither so strong nor so well mineralized as the Pay Rock, but has been followed underground for a distance of about 1,000 feet. The wall rock, so far as examined, is gneiss, in some places thinly laminated, in others hard and granitic. As in the Pay Rock tunnel, the strike of the gneiss appears to be everywhere north and south, so that the vein traverses it at an angle of 45°.

The pay ore taken from the Vulcan vein was near the surface, practically all being at a depth of 300 feet or less. In fact, there has been no encouragement for exploration of the vein much below this depth. The Ennis tunnel (Pl. XXXIV), which is the lowest working on the vein, exposes the vein at depths ranging from 100 to 400 feet, but on this level very little ore was encountered. The total production of the mine is very roughly estimated to have been in the neighborhood of $100,000. Burchard,[a] at the end of 1882, stated that the value of its production was over $41,976 from 132 tons of ore.

In the Ennis tunnel workings the southwestern portion of the vein for about 500 feet consists of a very poor branch lead in gneiss with no mineralization. Farther northeast the lead

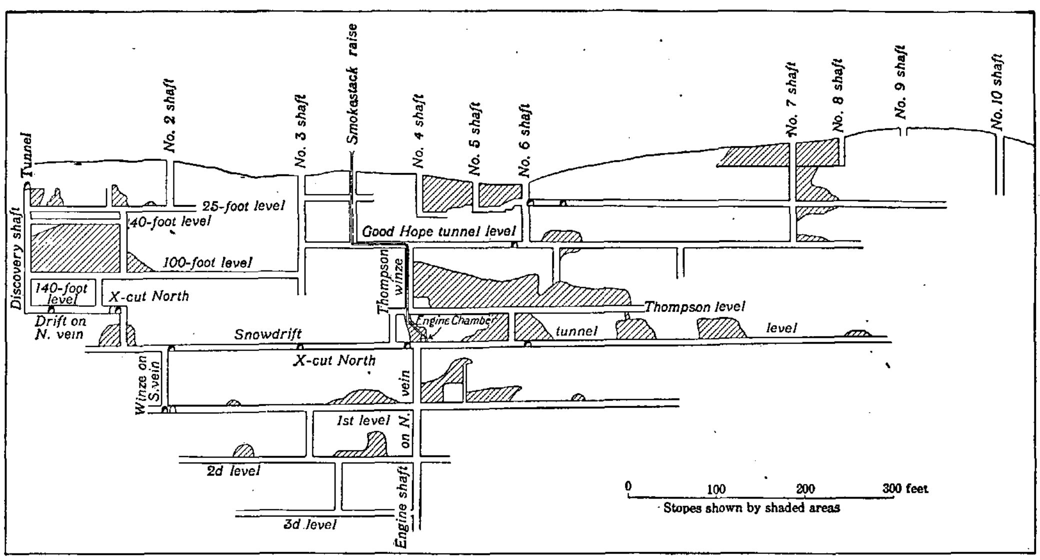


FIG. 52.—Vertical projection of Snowdrift mine.

becomes a strong crushed zone with splits, probably indicating relatively slight faulting, and in this portion of the workings there is some mineralization. The metallic minerals are probably blende, galena, and pyrite, the blende being everywhere largely in excess. Some tetrahedrite is present here and there. This ore runs 20 to 30 ounces in silver, with a trace of gold.

The gangue is in many places a dense cherty quartz. Examination of a thin section of this quartz under the microscope shows that it is probably a crushed and silicified gneiss, containing crystals of sulphides. Some of the sulphides in the ore represent the filling of small fissures which have first been lined with quartz.

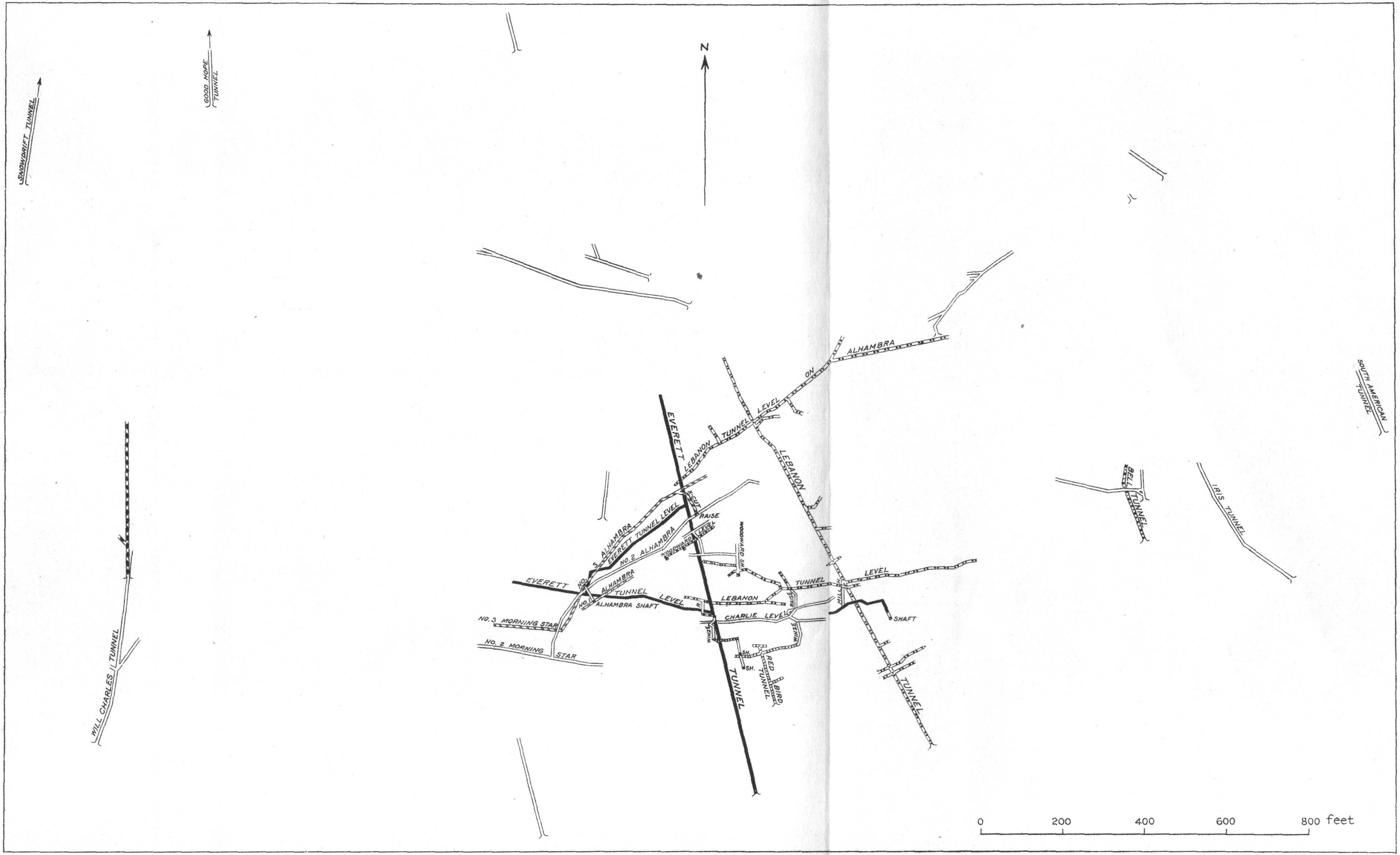
SNOWDRIFT LODE.

DESCRIPTION.

The Snowdrift mine,[b] which was being worked by a single lessee at the time of the writers' examinations, lies about 1,200 feet east of the main opening on the Pay Rock. The vein has an east-west trend, and, like the Pay Rock, a practically vertical dip. The ore has formed along slip planes, upon which striations showing movement are abundant. In different places

[a] Burchard, H. C., Precious Metals in the United States, 1882, p. 427.

[b] Comprising, apparently, also the old Hopewell.



THE NORRIS PETERS CO., WASHINGTON, D. C.

LEBANON-EVERETT GROUP

the angle of pitch of these striations on the fault plane, measured from the horizontal, was 5° E., 7° E., and 15° E. This shows that the movement was nearly horizontal. The vein has been explored for a horizontal distance of nearly 1,000 feet and a vertical distance of about 400 feet, and a moderate quantity of ore has been stoped out. The ore extends down about 300 feet from the surface, but occurs in larger bodies farther up. In all about 4,500 feet of drifting and tunneling has been done in this mine, and two shafts aggregate over 300 feet in depth. (See figs. 52, 53.) At present, however, only a portion of the Snowdrift tunnel level is open. This cuts the vein at a point about 250 feet below the surface.

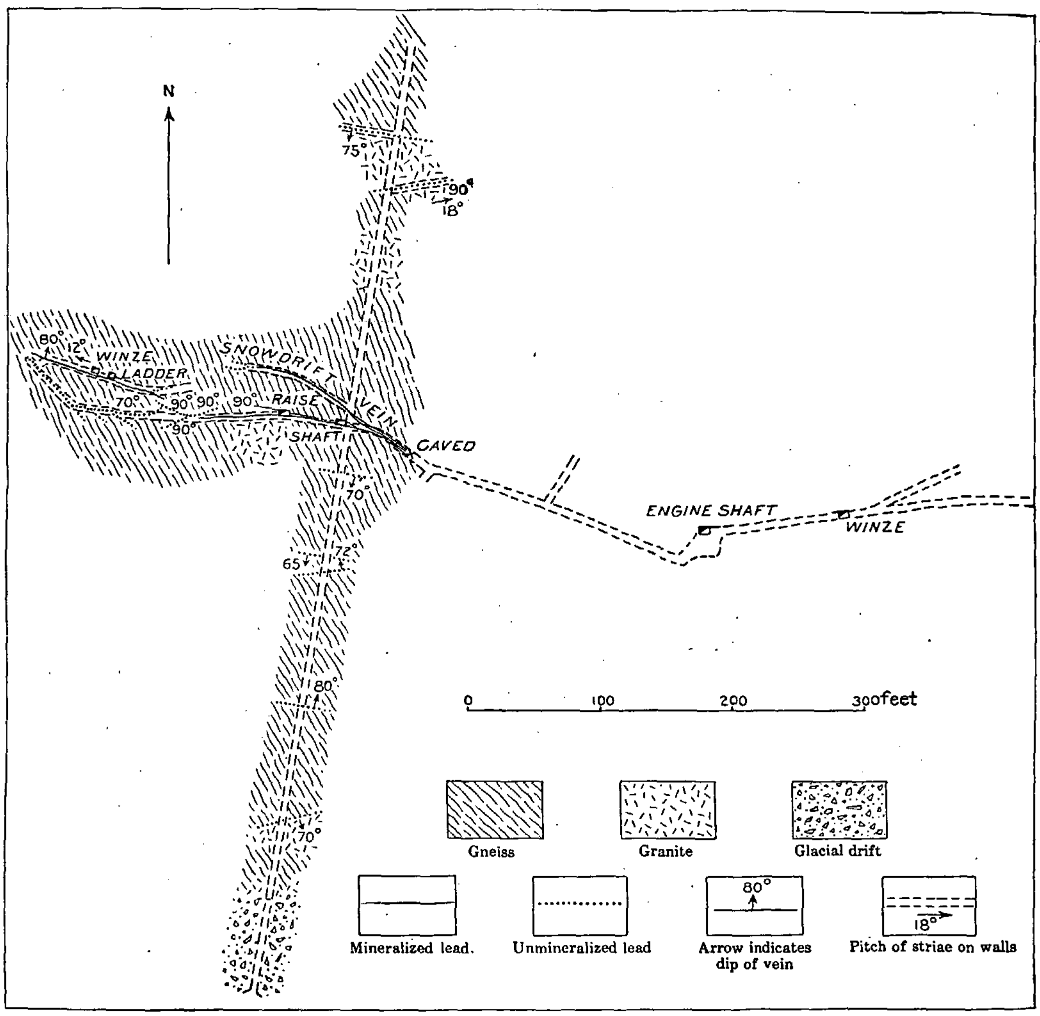


FIG. 53.—Geological plan of Snowdrift tunnel.

NATURE OF VEIN.

The wall rocks in the tunnel level consist of soft gneiss alternating with patches of granite, generally porphyritic. In the gneiss the vein lead repeatedly branches, in many places to such an extent that it is entirely lost among the gneiss laminæ. Portions of these leads are wholly unmineralized; other portions have been somewhat stoped. The junctions of branches, so far as noted in the small areas exposed, are not particularly enriched.

The whole vein, to judge from its location and attitude, is apparently a branch of the Pay Rock, but its junction with the Pay Rock does not seem to have been found, if present, nor does the vein seem to be accompanied at any point by an increase of mineralization suggesting such a junction, so far as can be made out. This is one of the most characteristic features of veins in this district. It has been repeatedly noted that strong veins, evidently branches of larger veins, grow weaker as they approach the junction. In many of them, as in the Snowdrift and Pay Rock, the junction is not seen; in others where a junction has been detected, it is very obscure, as, for example, that of the Seven-Thirty and Bismarck-Pelican lodes.

Where the vein is most strongly developed in the Snowdrift tunnel (fig. 53) it shows 3 or 4 inches of jaspery quartz containing abundant small vugs. These vugs are evidently due to the removal by solution of certain portions of the original veins, and on the walls of some of the cavities the molded imprints of crystal outlines suggest that the material removed was crystalline sulphides. Here and there residual fragments of crystalline galena and blende occur in other portions of the ore. The brown jaspery gangue contains much iron carbonate. When broken open the cavities are found to be full of water, though the rock itself is dry. On the walls of some of these cavities are deposited layers of dark-brown botryoidal limonite, in general relatively thin. Other cavities have been lined with chalcedonic silica, of the same kind as that universally found in the mines and forming the last deposit in the veins. Plainly both the silica and the limonite are due to the action of surface waters.

According to early reports,[a] much of the profitable ore in the upper workings was very rich in silver. This ore consisted of black decomposed sulphides, galena and blende, and some gray copper.

PRODUCTION.

The Snowdrift mine was one of the early producers of the camp, for, according to Raymond,[b] it yielded largely in 1869, 1870, and 1871. In 1870 the production was $96,316.80, currency value.

In 1883 the mine gave regular employment to 23 men.[c]

VICE-PRESIDENT LODE.

LOCATION AND DEVELOPMENT.

The Vice-President mine is located on the west side of Brown Gulch, at an elevation of about 10,400 feet above the sea. The vein, which is parallel to the Seven-Thirty and only a couple of hundred feet south of it, is opened by a tunnel which runs westward from the gulch. At the time of visit this tunnel was caved shut at a distance of about 600 feet from its mouth.

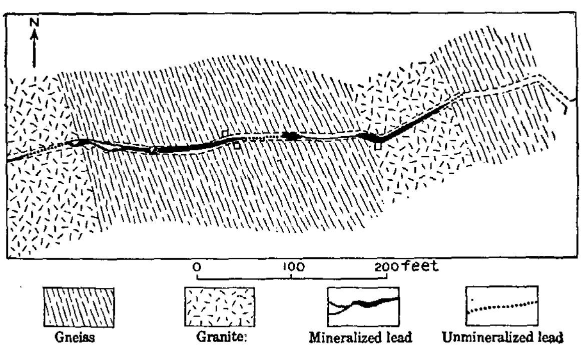


FIG. 54.—Plan of tunnel of Vice-President mine, showing geology.

COUNTRY ROCK.

The wall rock consists of biotite gneiss with patches of porphyritic biotite granite and seams of coarse pegmatite (fig. 54).

DESCRIPTION OF VEIN.

The vein, which has a general S. 85° W. trend, in most places has a very steep dip to the south, but the dip ranges from 65° S. to vertical. The lead in places is a mere clay slip which is hard to follow; in other places it is a quartz (or quartz and clay) lead 1 to 4 feet wide. It has a tendency to split into foot and hanging leads, and loop about "horses" of rock. The ore where present occurs in fractured zones from 1 to 3 feet in width, and forms a cement for angular fragments of silicified wall rock. These angular fragments, as well as the wall rocks themselves, are as a rule separated from the ore by a thin coating of comb quartz.

[a] Old, R. O., Colorado, London, 1872.
[b] Fossett, Frank, Colorado, 1880, p. 394.
[c] Burchard, H. C., Precious Metals in the United States, 1883, p. 268.

ORE AND GANGUE.

The ore consists of argentiferous galena and black sphalerite, with small amounts of chalcopyrite and pyrite. The gangue is chiefly quartz.

OCCURRENCE OF ORE.

The ore bodies pitch toward the west and appear to be due to the union of small branch veins with the main vein. According to B. J. O'Connell, of Georgetown, the best shoot in the mine is said to have occurred at the intersection of the comparatively flat John J. Roe vein (a minor transverse vein) with the Vice-President. By the union of these two there was formed a V-shaped trough that pitched westward. Along the vein itself the best ore seems to occur close to the south or hanging-wall side of the fissure. The south wall rock is usually more silicified than that of the north wall, which is rather soft and kaolinized.

The mine produced considerable ore, but has been idle for many years.

MONTREAL LODE.

LOCATION AND DEVELOPMENT.

The Montreal lode is located about 300 feet south of the Vice-President lode, and like it strikes east and west. The chief development is a tunnel which runs westward on the vein from Brown Gulch for a distance of 600 feet. From this vein an irregular crosscut runs in a general northeasterly direction to a stronger vein, which is probably the Vice-President.

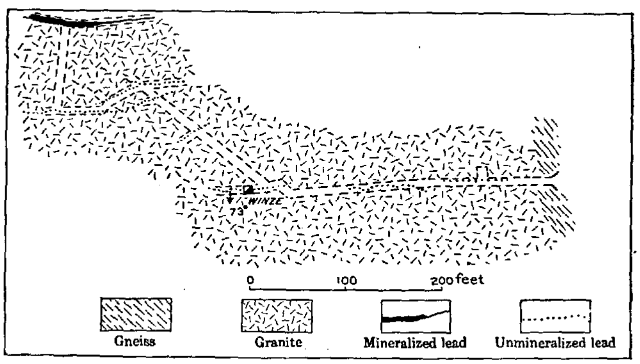


FIG. 55.—Plan of tunnel of Montreal mine, showing geology.

COUNTRY ROCK.

The mine workings are entirely in porphyritic biotite granite, with the exception of a few feet of gneiss near the mouth of the tunnel (fig. 55).

DESCRIPTION OF VEIN.

Clay and a small amount of crushed granite mark the main lead, which is a fractured zone in granite. The Montreal vein proper dips 75° to 80° S. and is not very heavily mineralized. The vein intersected by the crosscut (probably the Vice-President) showed evidence of having contained some small and narrow but rich streaks of silver ore and some stoping had been done. The mine has long been unworked.

SHIVELY LODE.

The Shively lode, which was discovered and opened during the summer of 1873,[a] at one time had nearly 2,000 feet of tunnels, drifts, and crosscuts and a shaft about 500 feet deep. At the time of visit, however, these workings were entirely inaccessible, owing to the caving which had taken place during the years the mine had lain idle.

In the early eighties this mine gave employment to twelve or fifteen men and produced considerable ore. Fossett[b] estimates the production previous to 1880 at about $60,000. The vein is said to be a vein with 2 to 6 inches of very high-grade ore, some of which ran as high as 425 to 450 ounces in silver.

The vein is an approximately east-west vein dipping about 80° S. Frank A. Maxwell[c] states that the workings of the Shively show three porphyry dikes running nearly at right angles to the vein, and also that the ore was all taken from the portion of the vein included

[a] Raymond, R. W., Mineral Resources West of the Rocky Mountains, 1873, p. 275.
[b] Fossett, Frank, Colorado, 1880, p. 398.
[c] Oral communication.

between two of these porphyry dikes. The probable explanation for this occurrence of the ore is that the porphyry became relatively impervious to waters on account of decomposition, and thus the mineralizing solutions, circulating along the vein fissures, became confined mainly to the portion between the dikes.

LEBANON GROUP OF LODES.

DESCRIPTION.

The name Lebanon is applied to a group of lodes of medium importance lying on the slopes of Republican Mountain, in the eastern part of the area shown on the Silver Plume special map (Pl. XXI). This group consists of a network of branching and probably to some extent crossing lodes, which run in a general northeasterly or easterly direction. The two principal lodes of this group are the Morning Star and the Alhambra, of which the former, as already noted, may be the extension of the Dunkirk, although there is an undeveloped section lying between the Dunkirk workings and the Lebanon mines (Pl. XXXV). The Alhambra is a branch of the Morning Star. These lodes subdivide and branch, most of the branches opening out to the east, but some to the west. Some of these branches, particularly those which open out to the west, are strong and persistent, and indicate a distinct set of northwestward-trending fracture zones traversing the main northeast minor faults and being deflected by them in many places at the junction, rather than actual branches of the northeast fissures. Undoubted branches, however, are common. A distinct feature of this group of lodes, differing from the group comprising the Pelican, Seven-Thirty, Pay Rock, etc., is that the intersections are as a rule well marked and notably enriched. In some places, as at the junction of the Alhambra and lode No. 9 of the Lebanon tunnel, both of the uniting veins and also the trunk vein are mineralized at the junction. In other places, as at the junction of the Morning Star lode and the No. 4 lode in the Lebanon tunnel, only the stronger vein is mineralized, the weaker branch being barren.

CHARACTERISTICS OF GROUP.

Mineralogically the lodes of this group are characterized by the presence of a certain amount of chalcopyrite, which distinguishes them from the lodes of the Pelican-Seven-Thirty-Pay Rock group, to which they are otherwise mineralogically similar. The outcrops therefore show in many places azurite with some malachite. Structurally the veins resemble those of the Pelican group, being replacements along fault zones of slight throw, but there is somewhat more fissure filling in the Republican Mountain group.

It is reported that surface work on this group of lodes was begun in 1868–69. The most extensive and the lowest workings are those in the Everett and Lebanon tunnels. The Lebanon tunnel is 1,082 feet long from mouth to breast and was begun in 1870. The production of this tunnel is estimated by miners at $500,000.

MORNING STAR LODE.

DESCRIPTION.

The Morning Star lode is well marked on the surface, but, like all the veins of this group, continually splits and branches in various directions, making the identification of a single main vein difficult. This lode is traceable on the surface for over 2,000 feet. At the east edge of the Silver Plume special area it is called the East Peru lode; on the west it unites with the Alhambra lode. The intersection of these two lodes dips to the east with increasing depth, so that where encountered in the Everett tunnel it is several hundred feet farther east than at the surface.

The Morning Star lode is shown in both the Everett and Lebanon tunnels (fig. 56). In the Lebanon the veins are currently designated by numbers running from 1 to 10, No. 5 being undoubtedly the Morning Star and No. 4 a branch. In this tunnel it is plain that the lode channel was due to faulting, as is shown by the discordant walls. The vein here forks repeatedly, the branches diverging both to the east and to the west from the trunk. The country rock is gneiss, having a northeasterly trend, so that the vein crosses it at an angle of 45°. The dip of the vein is to the north at angles ranging from 50° to 65°. At the intersection of branch No. 4 (which itself is an unmineralized slip) with the main lead an ore body has been found, extending both ways on the main vein, but farther toward the east, considerable ore having been stoped for nearly 200 feet in that direction. Beyond this point the vein splits into several branches or slips in the gneiss.

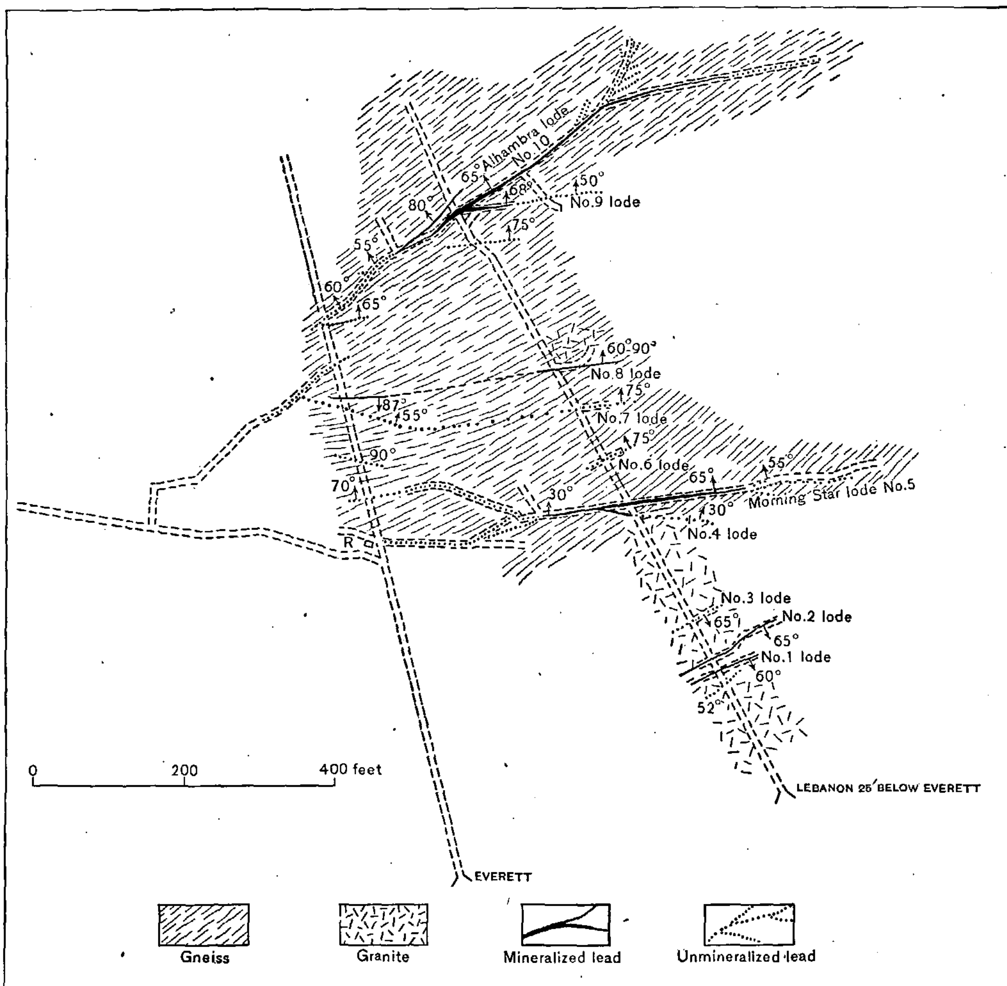


FIG. 56.—Geological plan of Lebanon and Everett tunnel workings.

RELATION TO PORPHYRITIC GRANITE DIKES.

The strongest portion of the Morning Star vein in this tunnel, between the points where branching is common, runs along a dike of highly porphyritic granite (the corn rock of the miners). This dike is in gneiss and is only a few feet wide, being too small to be shown in the geologic plan of the tunnel. The lead lies in some places on top of this dike, in others on the bottom, and in still others it cuts through the dike. This rock is considered by the miners a favorable formation for a strong vein. Evidently it plays the same rôle in deflecting and localizing the fault slips as do the porphyry dikes. Therefore along the contact of the porphyritic granite dikes, which are definite lines of thickness, an unbroken and relatively strong lode is apt to run.

EVERETT LODE.

The Everett lode appears to be a branch of the Alhambra. The junction of the two, as nearly as can be found out, lies at the surface at the Alhambra discovery shaft. Here a body of ore was worked down for some distance. The location of the junction of these lodes underground is not certainly known, but from information obtained it is probable that the Everett, dipping more flatly than the Alhambra, joins the latter at a point on the line of the Everett tunnel about halfway from the surface to the tunnel level. Therefore the Everett lode is not encountered in the Lebanon and Everett tunnels.

ALHAMBRA LODE.

DESCRIPTION.

The Alhambra lode and its branches are traceable on the surface for about 2,200 feet. It runs in a northeasterly direction and the dip as seen in the Lebanon tunnel is about 60° N. In this tunnel the slickensided fault faces of the lead exhibit strong striæ dipping 10° to 12° E., indicating a nearly horizontal differential movement.

LOCUS AND CHARACTER OF ORE.

The most ore along the vein is found at its junction, in the Lebanon tunnel and above, with the No. 9 vein of the Lebanon tunnel, which is perhaps the Peru lode. Here there is a big stope going up 100 feet above the tunnel and representing the largest and richest ore body in the mine. This ore was richest at the junction of the two veins, but extended a short distance along both and a short distance also on the trunk vein beyond the intersection. This ore contained argentiferous tetrahedrite and ran 100 to 125 ounces of silver. At the time of the examination of the mine in 1904 the last unsorted shipment of the lessees was reported as yielding 26 per cent zinc and 19 per cent lead. The last sorted shipment ran 26 per cent lead, 14 per cent zinc, 42 ounces silver, and 0.1 ounce of gold. A large part of the vein material is coarsely crystallized brown blende, which is never shipped, as it carries less than 30 ounces of silver to the ton and some of it runs as low as 6 ounces. This blende makes up the greater part of the vein material, so far as can be judged from what still remains in the stopes. Galena is abundant and chalcopyrite occurs here and there. The low-grade blende ores alternate with parallel streaks of relatively high-grade lead and silver ores.

PARAGENESIS OF ORES.

Examination of the ores indicates that the vein has been successively reopened and that later deposition has occurred in the reopened fissures. The galena and chalcopyrite are closely associated; the blende does not seem to be associated with chalcopyrite, though locally it is with galena. A study of specimens indicates that at least some of the galena was precipitated later than some of the blende. The following succession of events is shown in places: (1) Opening of a vein channel; (2) deposition of blende; (3) reopening; (4) deposition of galena; (5) reopening; (6) deposition of native silver on the walls of vugs. Another specimen shows the following order of deposition of minerals: (1) Quartz; (2) blende; (3) quartz; (4) siderite. The minerals of the last two periods of deposition are in free crystals, coating cavities in the blende. Tetrahedrite, as well as native silver, occurs coating cavities, and these minerals were found in the Lebanon tunnel 400 or 500 feet below the surface.

On the surface the Alhambra is a strong vein, containing considerable galena, lead, etc., for 500 feet or so east of the Alhambra discovery shaft.

NORTHEASTERN EXTENSION OF ALHAMBRA LODE.

The northeastern extension of the Alhambra is known as the Scott lode. From a mining standpoint this has been of no great importance, but it is a strong lode showing solid sulphides in places several inches thick, consisting of galena, blende, pyrite, and chalcopyrite. A thin section of a portion of the vein shows quartz, pyrite, barite, and siderite, all intercrystallized and contemporaneous. The lode lies in granitic gneiss and pegmatite, and is opened up by a tunnel drift for nearly 300 feet along the vein. Near the mouth of the tunnel it makes a junction with an east-west lode which is very likely the Edinburgh lode.

The Scott lode as seen in this tunnel is somewhat branching and splitting. A little ore occurs here and there.

About 600 feet northeast of the mouth of the Scott tunnel and 300 feet northeast of the breast of the tunnel drift what is probably the same lode is again exposed in a crosscut tunnel running 100 feet into the hill. This shows an iron-stained lead with no ore, although small quantities of ore are found in the dump of a caved tunnel 100 feet or so farther southwest.

PERU LODE.

The Peru lode lies on the extreme eastern edge of the area covered by the Silver Plume special map. It has an east-west trend. As shown in the Iris tunnel, it is vertical and lies in porphyritic granite. It is here a strong, soft lead with much quartz, containing abundant pyrite and some galena, blende, and chalcopyrite. One specimen shows a veinlet in granite 1 inch in thickness, three-fourths of which is filled with quartz containing very little pyrite, while the central part is blende with a little pyrite (fig. 57). Barite is also present as a gangue mineral. The metallic minerals occur embedded in solid vein quartz and also as fissure fillings. There is no sign here of any considerable quantity of ore, though the lead is well defined. The Peru tunnel, which lies just above the wagon road, is caved at its mouth, but the maps show that it runs 260 feet into the mountain, crossing the East Peru (which is the extension of the Morning Star) and the Peru lodes. The tunnel on the hill 50 feet above the Bell (Pl. XXXV) runs in a drift on the Peru lode also. The latter tunnel showed a fairly strong lead in gneiss and porphyritic granite.

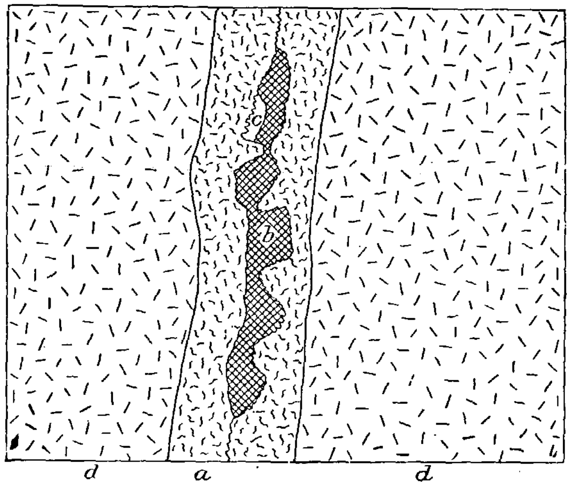


FIG. 57.—Sketch showing successive deposits in fissure, Peru lode, Iris tunnel. *a*, Comb quartz, with occasionally a grain of pyrite; *b*, zinc blende, with a little pyrite and galena; *c*, open cavity or vug; *d*, Silver Plume granite, country rock. Three-fourths natural size.

Farther west the Peru lode at its junction with the Alhambra is very likely represented by No. 9 lode in Lebanon tunnel. At this junction, as already noted, a large body of ore has formed.

ELIJAH HISE LODE.

The location of the Elijah Hise lode seems to have been considerably in doubt in past times, but as traced by the writers the lode runs on the surface from the Elijah Hise discovery shaft in a northwesterly direction. The lode is strong near its junction with the Alhambra, and shows some ore containing galena. Just northeast of the junction the united vein is stronger than either of the uniting veins. The Elijah Hise lode is traceable for 400 feet northwest, and with a break in the outcrops considerably farther. It is in general slightly or not at all mineralized, except as before stated, and appears of very minor importance. Both the Elijah Hise lode and the Peru lode, though apparently branches of the Alhambra, belong to a set of eastward or southeastward striking lodes which are so persistent that they appear to be rather a set of crosscutting veins than true branches.

EDINBURGH LODE.

The Edinburgh lode is parallel with the Elijah Hise, and lies 400 or 500 feet farther northeast. It is traceable for 1,000 feet, and probably is continuous for 1,500 feet at least. It is very likely the same lode as that which joins the Scott lode in the Scott tunnel. At the junction with the Scott it is a strong lode showing 6 to 8 inches of quartz, with iron oxide and galena.

Farther northwest, up the hill, the lode is opened up by a tunnel drift 2,500 feet long on the Edinburgh vein and by a shorter tunnel 100 feet higher up the hill. These tunnels show a strong fracture zone, dipping 80° S. or nearly vertical, in porphyritic granite. At the breast of the tunnel the lode splits into two branches which open up to the west. A little ore was taken out of this tunnel, but from what can be seen the streak was probably small. One specimen taken shows a 1-inch fissure vein with bands of clear comb quartz and a filling of blende, fine-grained galena, and pyrite.

BARITE-BEARING LODE.

A lode near United States mineral monument No. 10 is shown on the map as running northeastward and crossing the northwesterly extension of the Elijah Hise. This lode affords an interesting study in vein formation. It follows a fractured zone in granite. At the crossing of this lode and the extension of the Elijah Hise there is a considerably silicified altered zone in the granite, and veins have formed containing abundant barite and calcite, with jasper and a little comb quartz. The calcite and pyrite are intercrystallized and contemporaneous, and in many places line cavities. There are no signs of any metallic minerals in the vein, so that the color of the vein is similar to that of the granitic country rock. Therefore the contact between the two is not plainly marked, and the coarseness of the barite and calcite crystals give the vein at first glance the appearance of pegmatite. In places the barite and calcite form only a veneer on the walls of the fissure. The barite here is rather more abundant than has been observed anywhere else in the region, and its association with calcite and a little chalcedonic quartz suggests derivation from the wall rock.

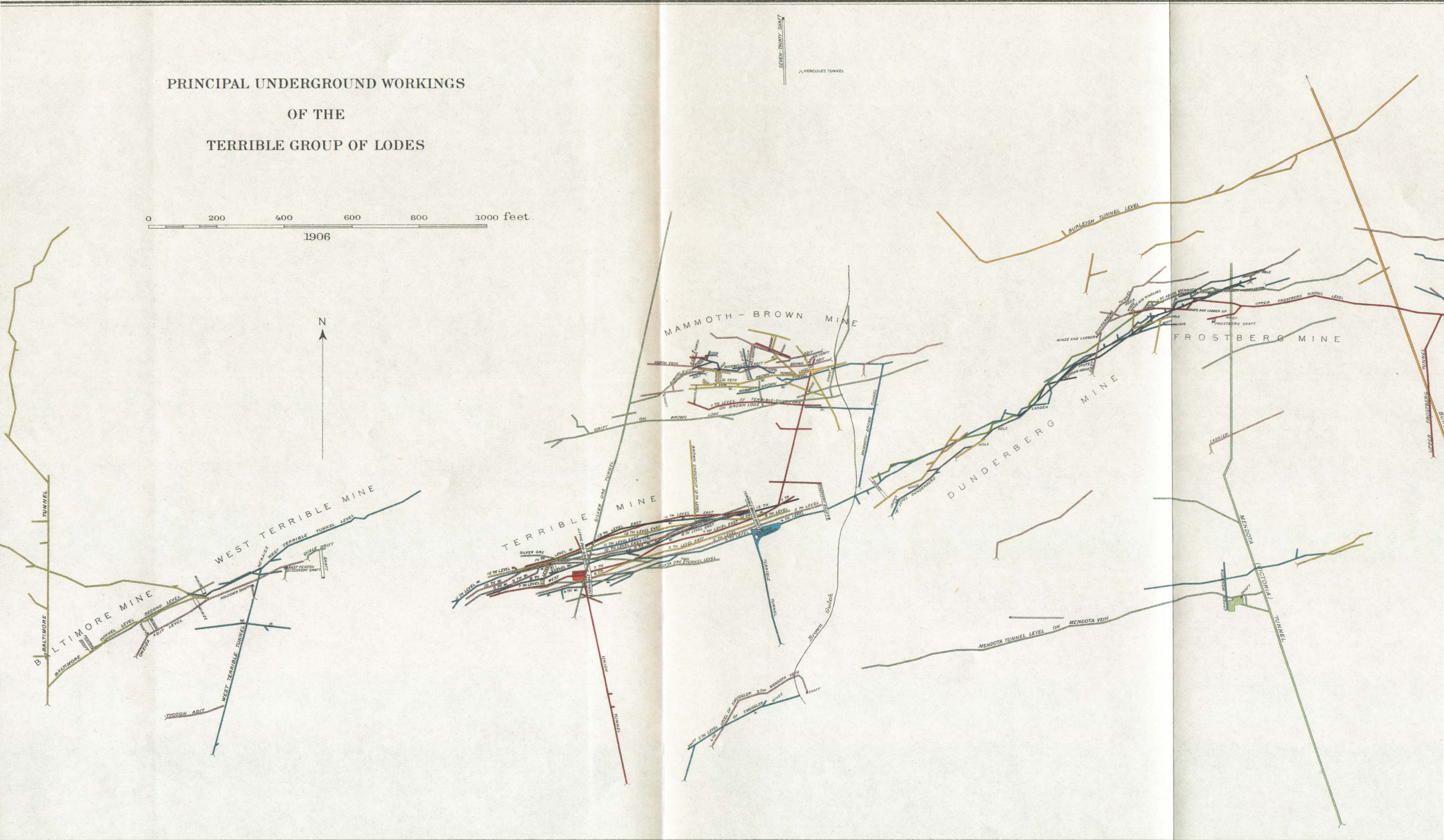
CHANGES IN VEIN-DEPOSITING WATERS.

In general in this Lebanon group of lodes it is plain that a given fissure was occupied at different times by waters of different composition. The first deposit on the walls of a fissure is very commonly a layer of pure quartz. The quartz may fill the whole vein, or the deposition may be incomplete, leaving a cavity in the center; or, finally, the central part may be filled up with other materials, including metallic minerals. These facts show that the waters which formed the veins differed in separate fissures and at different times in the same fissure.

DEPOSITION FROM PRESENT UNDERGROUND WATERS.

In the Lebanon tunnel calcite is formed wherever water drips down, whether along a lode or not. The heaviest deposit of calcite, however, has formed where the most abundant surface water enters the mine—on the drift on the Alhambra vein in the Lebanon tunnel southwest of the crosscut tunnel. Here the vein is marked by a strong mineralized lead in gneiss and pegmatite. The waters that enter the drift have formed on the floor a crust of calcite from 3 to 4 inches thick and on the walls a beautiful deposit resembling a frozen waterfall. Much of the calcite of this wall deposit is 1 to 3 inches thick. From the roof fine stalactites, upward of 6 inches long, have formed, and in the floor are pisolitic aggregates of calcite formed by the deposition of the mineral around small rock fragments. Fine calcite crystals have also formed on the walls. On the surface of pools of standing water in this drift a crust of calcite gradually forms by evaporation of the water, attaining a thickness of a small fraction of an inch. It then sinks to the bottom of the pool by its own weight, when a new crust begins to form. Thus at the bottom of some pools a pile of these crusts several inches thick has accumulated, and the different crusts are cemented together by calcite crystals. Much of the calcite is stained with iron and manganese, and some of it with a little copper.

This drift in the Lebanon tunnel was begun in 1880 and closed in 1888. The portion where the calcite is most abundant was probably opened up in 1881 or 1882. These deposits have been accumulating, therefore, for not more than twenty-three years. According to this the whole drift, 8 feet high, will be cemented solid with calcite in five or six hundred years.


PRINCIPAL UNDERGROUND WORKINGS
OF THE
TERRIBLE GROUP OF LODES
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200
400
600
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1000 feet
1906
N
MAMMOTH - BROWN MINE
WEST TERRIBLE MINE
BALTIMORE MINE
TERRIBLE MINE
DUNDERBERG MINE
FROSTBERG MINE
BALTIMORE TUNNEL
WEST TERRIBLE TUNNEL
SILVER ORE TUNNEL
UNION TUNNEL
TERRIBLE TUNNEL
MAMMOTH-BROWN TUNNEL
BURLEIGH TUNNEL LEVEL
UPPER FROSTBERG TUNNEL LEVEL
MENDOTA TUNNEL LEVEL ON MENDOTA VEIN
MENDOTA (VICTORIA) TUNNEL
SEVEN-THIRTY SHAFT
HERCULES TUNNEL
DRIFT ON BROWN LODE
TYCOON ADIT
Brown Gulch

TERRIBLE VEIN GROUP.

DEFINITION AND GENERAL DESCRIPTION.

The name Terrible vein group may be applied to an extensive and important group of veins of which the Terrible lode is one of the largest (Pl. XXXVI). Taken all together this vein group represents a northeastward-trending zone of minor faulting and heavy fracturing, about 1,000 feet in width and upward of 5,000 feet in length. This zone is practically vertical. The principal individual veins are also vertical or have a northerly dip, varying slightly from the perpendicular. Exceptions to these general statements will be mentioned later on.

Considering this vein group in the largest sense, we may regard it as composed principally of three master veins parallel to one another and about 500 feet apart—the Mendota, the Terrible, and the Fenton-Mammoth. The Terrible and Fenton-Mammoth come together both on the northeast and on the southwest, the distance between the two fields of junction being about 4,500 feet. These two master lodes thus constitute in a sense a single vein fascicle. The Mendota vein, however, is not known to be connected with the others.

These veins follow slight branching fault slips in granite and gneiss. As a rule they are not accompanied by porphyry. In the northwestern portion, near the Seven-Thirty wagon road, they all pass at nearly right angles into the large porphyry dike which has been described (p. 199) as intersected also by the Seven-Thirty vein. Just northeast of this crossing, on the upper side of the wagon road, are two small porphyry dikes, resembling the porphyry of the Bismarck rather than that of the Seven-Thirty. In this district the Fenton-Mammoth and Terrible veins split repeatedly, and several of the branches are deflected by the east-west porphyry dikes, so that their main trend changes from southeast and northwest to east and west; farther east it becomes south of east, and the different branches apparently tend to unite into a single continuous vein—the Maine. The Maine vein swerves around until it strikes nearly parallel to the Bismarck-Pelican lode; it has been traced and worked southeastward nearly as far as the Pelican tunnel.

FENTON-MAMMOTH-TERRIBLE VEIN SYSTEM.

VEINS INCLUDED.

The above term may be applied in a general sense to the branching and interlocking veins comprising the Terrible lode and branches, the Fenton-Mammoth lode and branches, the zone of branching and reuniting veins at the intersection of the Fenton-Mammoth and Terrible lodes, and the easterly or southeasterly continuation of this zone, the Maine lode.

RELATIONS OF DIFFERENT LODES.

FENTON-MAMMOTH LODE.

Fenton lode.—The southwest end of the Fenton-Mammoth lode is the Fenton lode. In the area of the Silver Plume special map this lode is first recognized near the mouth of the Baltimore tunnel (fig. 58), whence it is drifted on for 500 or 600 feet to the northeast. Very near the point where this lode crosses the Baltimore tunnel an important branch leaves it on the north side and runs toward the west. This branch is called the Baltimore lode; it has an east-west strike and a northerly dip of about 60°. It is explored by a shaft more than 300 feet deep and six levels which develop the lode laterally to a point 700 feet west of its junction with the Fenton. Northeast of the junction of the Baltimore and Fenton lodes the Fenton gives off another branch, also on the north side. This branch is the Queen lode. It is practically parallel in strike and dip to the Baltimore lode, and west of the junction with the Fenton has been drifted on for about 700 feet on the Baltimore tunnel level.

The exploration of the Fenton lode accomplished by the northeast drift on the Baltimore tunnel level is continued with very little break and at nearly the same level by a drift from the West Terrible tunnel, which follows the lode continuously for about 700 feet farther. From the northeast end of this drift there is a gap in the underground development where the vein has not been continuously traced on the surface, but about 400 feet farther northeast and approximately 250 feet higher up in the Silver Ore tunnel is a drift which is probably on practically the same lode, though this is locally known as the Brown lode. This drift extends northeastward about 900 feet to a point beneath Brown Gulch.

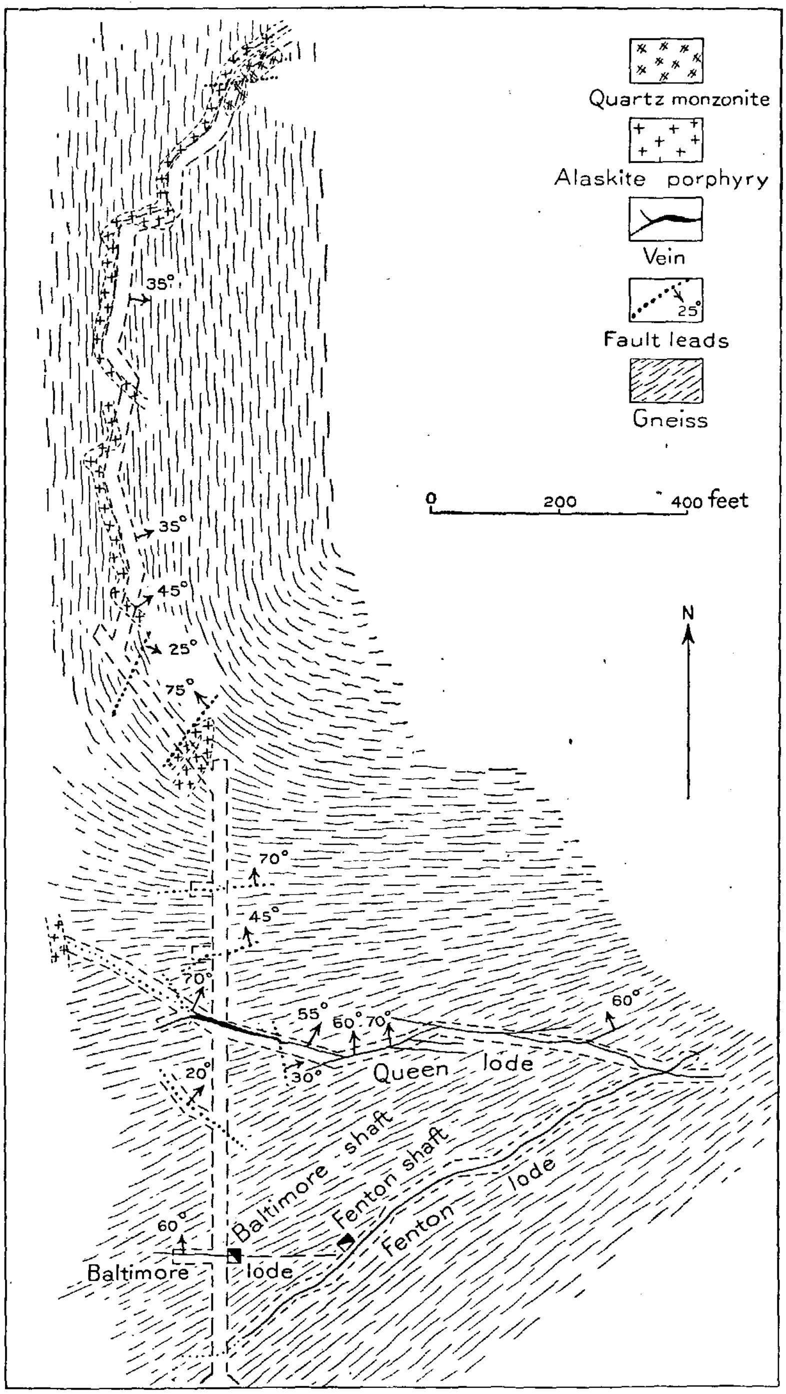


FIG. 58.—Geological plan of Baltimore tunnel workings.

Relations of Fenton, Brown, and Glasgow lodes.—At and near the surface in this region, especially just west of Brown Gulch, conditions are complicated by the intersection of minor east-west veins with the main lode.

The chief east-west vein is the Brown, which crosses the main northeast lode (with probably some slight deflection resulting in offsetting by it) and is mineralized and developed by mining exploration principally west of the intersection. Here in the Brown mine both the east-west Brown lode and the northeast Fenton lode have been followed. This mine is not worked at present and most of the workings are inaccessible, but, to judge from the mine maps, it appears probable that what was known in this mine as the south vein represents the main Fenton lode, and it is certain that the north vein represents the Brown lode proper. The relation of these two lodes at greater depth is obscure, but the maps of the different levels indicate that the Brown lode dips steeply into the Fenton lode and joins it with increasing depth. A branch of the north vein, known as the Coin lode, diverges from the Brown on the north side, opening out to the west. Workings on this lode indicate that it has a northerly dip. Probably as a result of the dipping together of the Brown and Fenton lodes between the surface and the level of the Silver Ore tunnel, this tunnel cuts only a single strong lode, which, as before stated, has the general trend of the main Fenton.

The intersecting east-west veins continue also on the east side of the Fenton lode. One of these lodes was recognized at the surface and is practically a continuation of the Brown. A little farther south and parallel to it is another, not very well recognized on the surface, but shown on mine maps as the Glasgow lode near the surface. The map of the workings of the Mammoth-Brown tunnel, which runs in to tap this group of lodes, shows near their intersection and beneath Brown Gulch a northeast drift on the line of the main Fenton-Mammoth and an east-west drift on the Glasgow. The Union tunnel (fig. 59), running in under these lodes at a depth 400 feet greater, shows an east-west drift on a vertical lode directly under the Glasgow drift on the Mammoth-Brown tunnel, and this drift in the Union tunnel appears therefore to be probably also on the Glasgow lode. According to this the main Fenton-Mammoth vein has not yet been cut in the Union tunnel. The Burleigh tunnel, however, is on nearly the same level as the Union tunnel, and has a long drift on the Mammoth vein, locally called in this tunnel the Phillips vein. By projecting this vein in the Burleigh tunnel (Pl. XXXVII) southwestward past the last point of development to a point opposite the breast of the Union tunnel, it is seen to be probable that the Fenton-Mammoth or Mammoth lode lies 100 feet or so beyond the present breast of the Union tunnel.

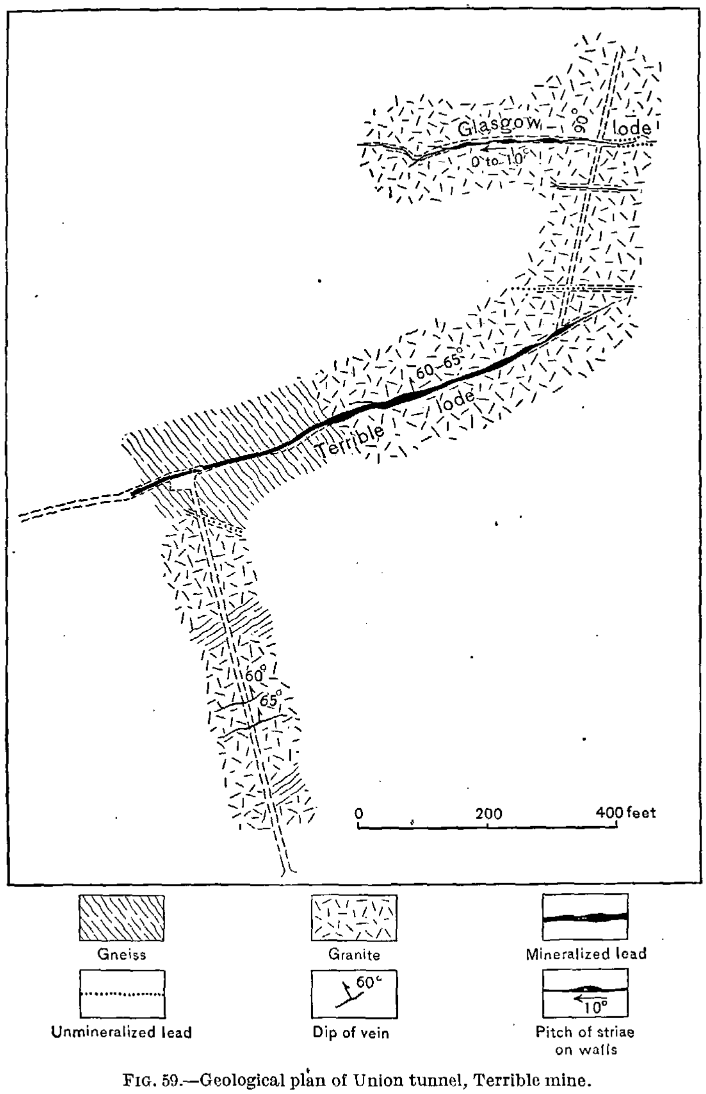


FIG. 59.—Geological plan of Union tunnel, Terrible mine.

All the evidence available indicates that the intersection of the east-west lodes, of which the Brown is the principal representative, with the northeast or Fenton-Mammoth lode pitches steeply on the west.

Mammoth lode.—The main Fenton-Mammoth northeast of its intersection with the Brown is called the Mammoth. It is opened up by tunnel drifts on the lode on the northeast side of Brown Gulch. Farther northeast, near the Seven-Thirty wagon road, the lode is cut by a small crosscut tunnel. Still farther northeast a tunnel drift beginning on the Seven-Thirty road and running northeastward exposes the lode for a distance of 200 feet. Near this point the lode branches; one branch is traceable on the surface eastward to a shaft on top of the ridge overlooking the Dives-Pelican workings. The dump from this shaft indicates considerable workings, but they have not been investigated. Another branch turns eastward farther up the ridge, and is well exposed in a tunnel drift on the Backbone claim. This tunnel starts from a point 100 feet or less above the Seven-Thirty road on the west side of the depression lying east of Sherman Mountain and runs westward into the mountain. So far as known this branch forks repeatedly to the east and practically ends in this vicinity, but the branch first described connects by minor oblique leads with the northeast branches of the Terrible lode.

The Mammoth section of the Fenton-Mammoth lode is most continuously shown in the Burleigh tunnel, where it is called the Phillips vein. In this tunnel the lode is strong, with a steep northerly dip. The southwest end of the drift on this lode is within 200 feet of a point directly beneath some of the upper tunnels of the Mammoth. The drift runs northeastward on a strong mineral-bearing lode, extending several hundred feet past the most northeasterly point where the Fenton-Mammoth has been traced on the surface and, as a strong though unmineralized slip or lead, for a few hundred feet still farther to a point under the southeastern slope of Sherman Mountain. At this last-named point the dip is vertical or at a high angle to the south. The relative position of the Fenton-Mammoth lode between the surface and the Burleigh tunnel, involving a vertical difference of altitude of 1,200 to 1,400 feet, indicates that the average dip of the vein is to the north at an angle of about 83° or 84°.

In the principal accessible tunnel of the Mammoth near the surface the dip of the lode is 65° to 75° SE.; in the small crosscut tunnel noted, farther northeast, it is 90°, as it is also in the tunnel on the upper side of the Seven-Thirty road. The whole Fenton-Mammoth lode along its entire extent has a wavering dip that is near 90° but averages slightly off the vertical, to the north.

TERRIBLE LODE.

Branches of main lode in and west of the Terrible mine workings.—The Terrible vein is best shown in the various workings of the Terrible and Dunderberg mines, now consolidated (fig. 60).

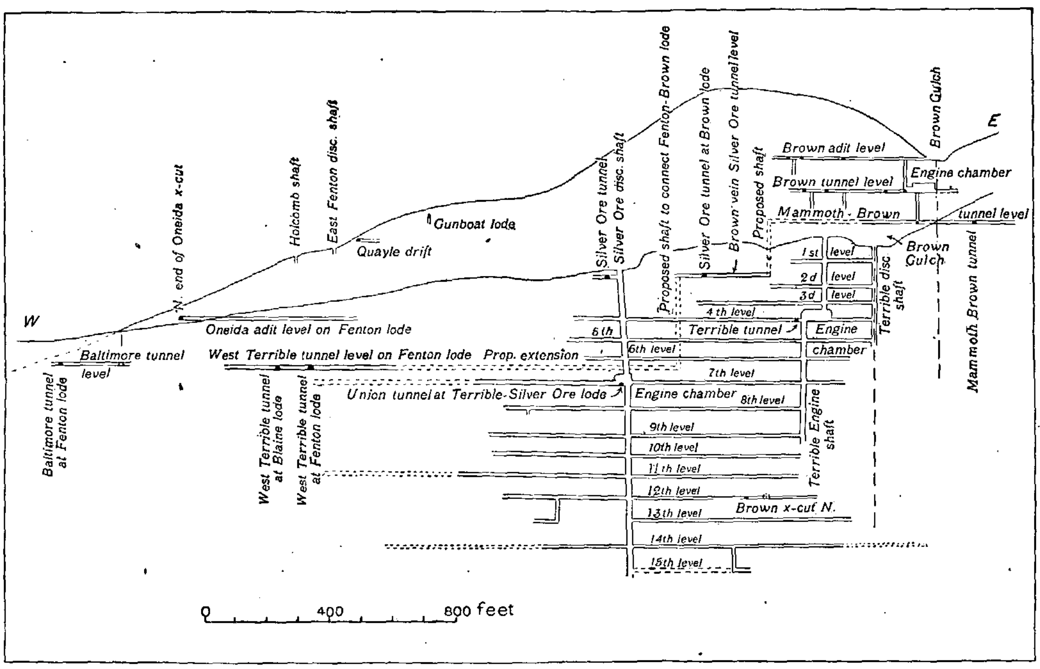
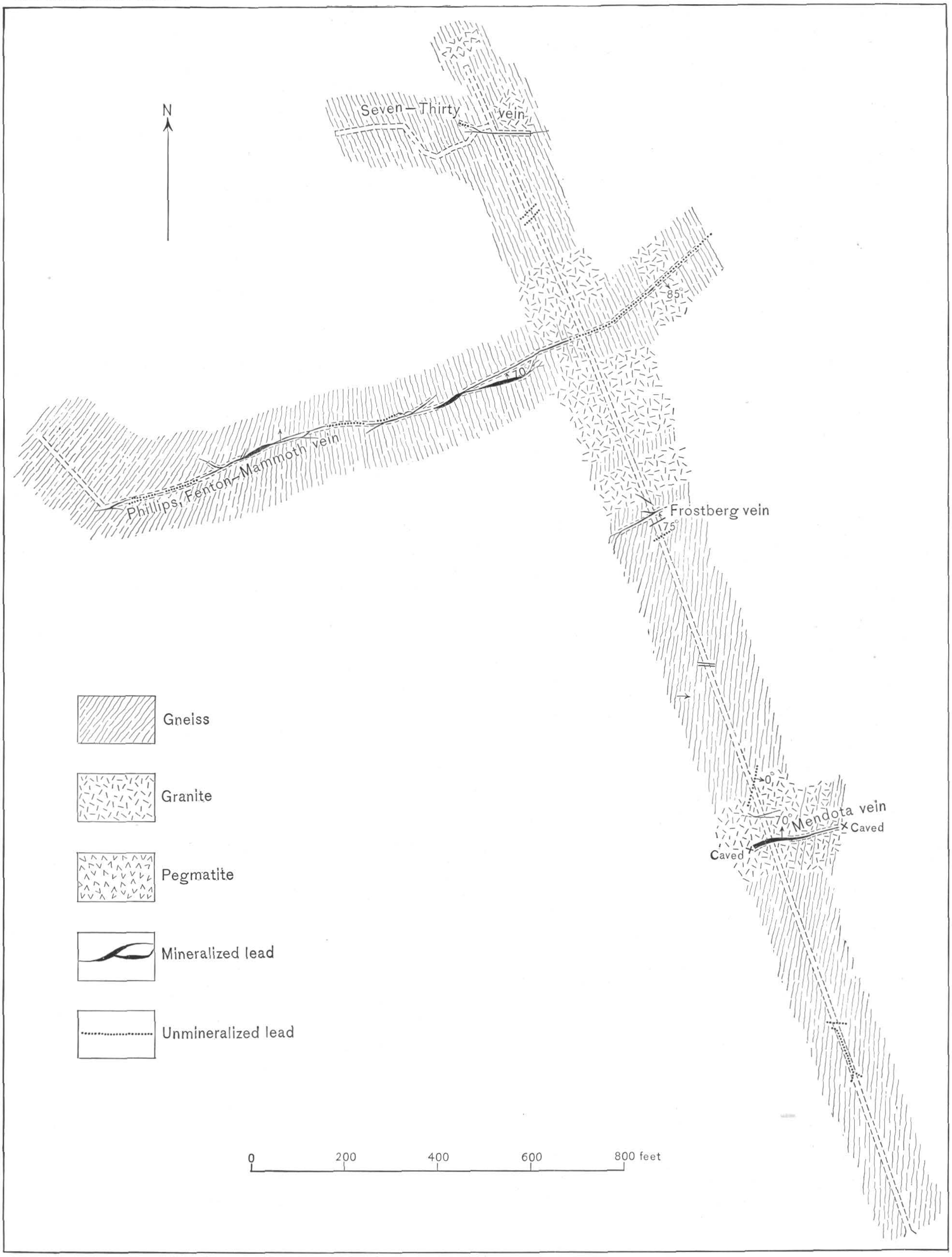
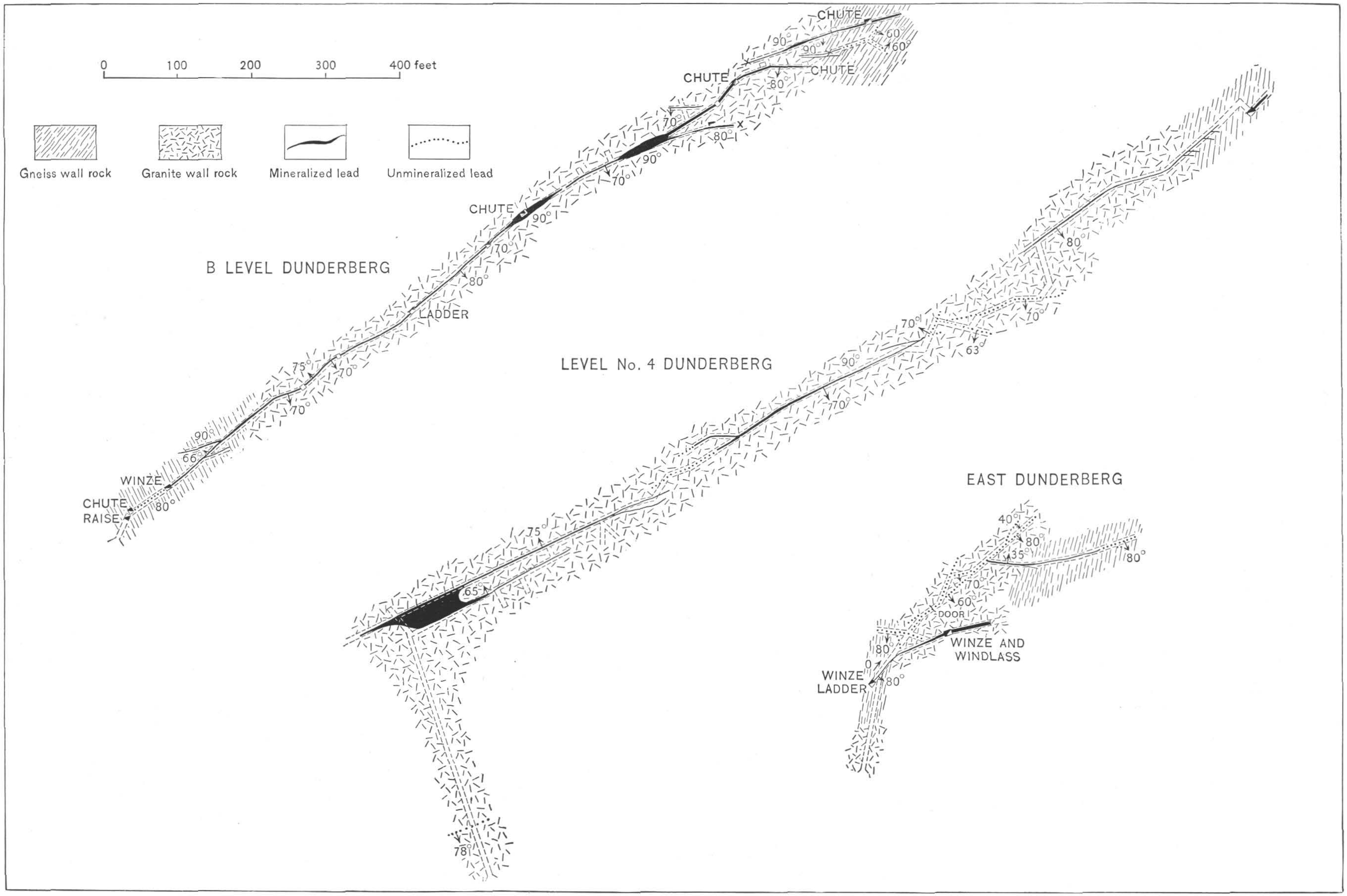


FIG. 60.—Vertical section showing levels of Terrible mine.

In the Terrible mine this vein is shown as a strong lode striking east-northeast and dipping 60° to 65° NW. On the west this lode splits into three principal branches, shown in some of the mine workings. The northern is called the Gunboat lode, the central the Elephant, and the southern the Silver Ore. All three near the point of their separation are seen near the mouth of the Silver Ore tunnel (fig. 61). All the branches turn more to the west than the strike of the main lode and approach the Fenton lode, which they probably join. A very plain branch of the Fenton lode, diverging from it on the southeast side and having an east-west strike, is very likely the continuation of the Elephant; and the western continuation of the Silver Ore lode is not improbably that known as the Blaine lode, which is developed at the surface and has been drifted on in the West Terrible lode. The Blaine lode is undoubtedly a branch of the Fenton. In the West Terrible workings the Blaine lode dips 70° to 75° N., and its probable



GEOLOGICAL PLAN OF BURLEIGH TUNNEL WORKINGS.



GEOLOGICAL PLANS OF B, NO. 4, AND EAST DUNDERBERG WORKINGS.

continuation, the Silver Ore lode, dips 60° N. in the Silver Ore tunnel. The Baltimore lode, described above as a branch of the Fenton lode separating from it on the northwest side and striking east and west, probably represents a continuation of the Terrible zone of fractures on the opposite side of the Fenton lode.

From the position of the branches of the main Terrible lode at the surface and at various points underground it is evident that their intersection with one another to form the Terrible lode pitches flatly to the west, like the intersection of the Brown lode with the Fenton-Mammoth. This last-named field of intersection lies only about 500 feet north of that first mentioned.

Dunderberg and Frostberg lodes.—Northeast of the point where the Terrible lode separates into branches diverging to the west, and very near Brown Gulch, an important branch leaves

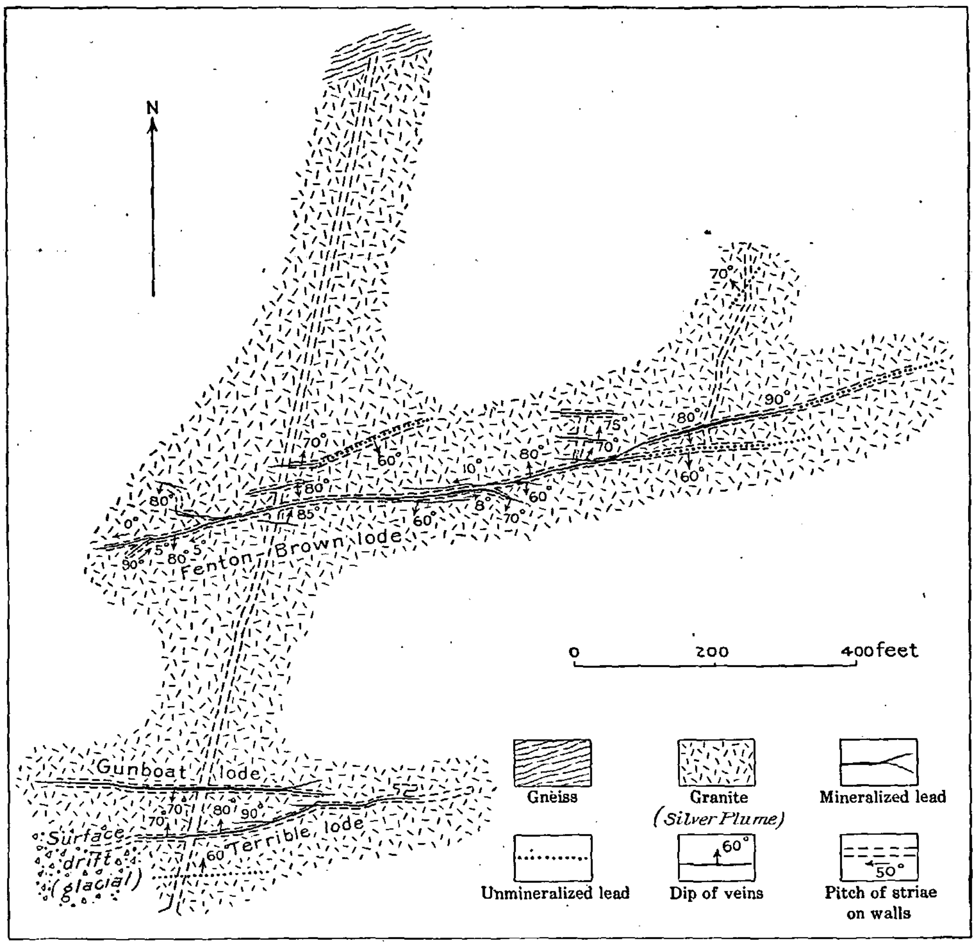


FIG. 61.—Geological plan of Silver Ore tunnel.

the main lode on the south side, opening out to the east. From this point of junction the main vein, continuing on with a rather more pronounced northeasterly trend, is called the Dunderberg (Pl. XXXVIII), while the minor branch, which may be called the Cascade, at first has a southeasterly trend, then swings around to the northeast parallel to the Dunderberg.

The main Dunderberg is continuously developed underground by different levels that make, together with the workings of the Terrible mine, an uninterrupted stretch of underground development extending for a distance of about 2,500 feet. At the northeast end of this region of development the Dunderberg vein branches again. A strong lode leaving the main vein on the southeast side and striking off to the east is shown in the Dunderberg B level and in the East Dunderberg; and another branch keeps on northeastward on the regular Dunderberg trend, but within a short distance.

The east branch, which is the Frostberg lode, is the stronger of the two. The workings on this branch connected with the workings of the Frostberg a short distance below, causing considerable litigation. In the workings of the Frostberg this lode was followed eastward along its strike for 1,100 or 1,200 feet (fig. 62). On this level the Frostberg has a northerly dip of 50° to 72°. The position of the outcrop of this lode relative to its position in the Frostberg tunnel gives it an average dip between these two points of 75° N. The lode as shown in this tunnel has a curving strike, which becomes due east in its eastern portion and south of east still farther east.

This trend is similar to that of the Maine lode at this point, and this portion of the Frostberg is either actually a part of the Maine or a parallel lode not far distant. On the surface the corresponding northwestern portion of the Maine lode is exposed by two tunnel drifts running northwestward into Sherman Mountain from the lode outcrop—one situated just below the Seven-Thirty wagon road on the southeast side of Sherman Mountain, and one about 250 feet farther southeast and down the hill. The Maine lode in the lower of these tunnel drifts dips 50° to 75° NE. In the first-named tunnel the dip ranges from 75° to 35° NE. This flat dip is due

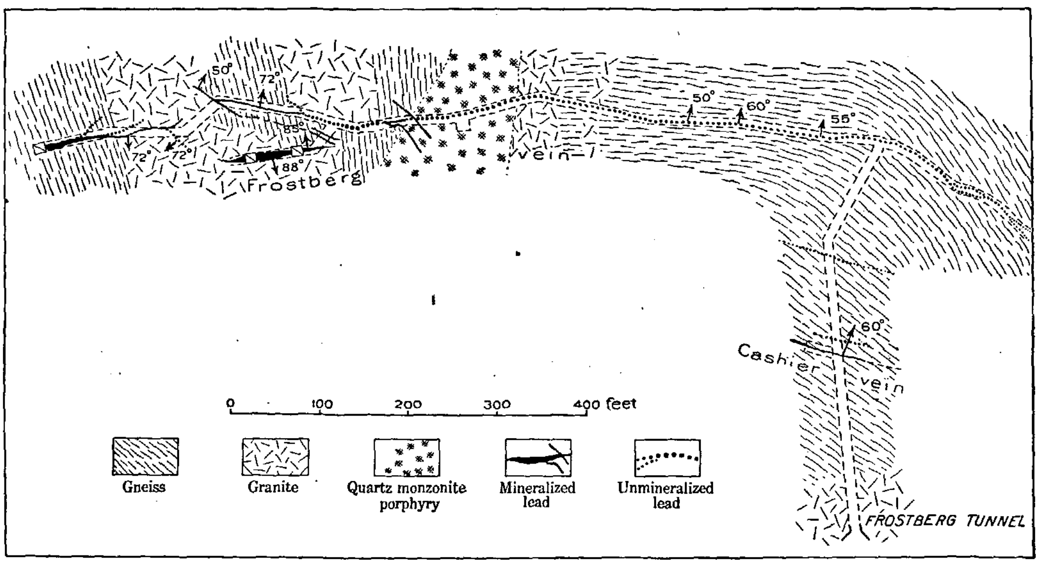


FIG. 62.—Geological plan of upper Frostberg tunnel.

to a small dike of porphyry striking east and west and dipping flatly to the north, which has deflected the vein so that it departs from its normal steep dip and follows the flat dip of the dike.

The normal dip of the Frostberg—with which, as above stated, the Maine is actually or almost continuous—as measured from its outcrop at the surface to its position in the Mendota tunnel 1,000 feet in depth is 83° N., or the same average angle as that calculated for the Mammoth vein, which lies a few hundred feet north of the Frostberg at this point. There are numerous variations and irregularities in the dip, however. In the Mendota and Burleigh tunnels, 1,000 feet above the outcrop, the Frostberg is a well-marked, plain lode, which has been followed for about 600 feet along the strike. The dip in these tunnels is variable, but is as a rule nearly vertical.

Maine lode.—The Maine lode is traceable in an east-southeast direction from the tunnels above mentioned by a line of now mostly inaccessible workings. It is well shown, however, in a tunnel drift lying 300 feet northeast of the mouth of the Pelican tunnel. This tunnel runs northwestward into the hill, following the lode. Near the mouth of the tunnel the strike of the Maine lode has swerved so that it has become parallel with the Pelican, which lies 400 feet to the northeast. The tunnel has a drift on the Maine lode for a distance of approximately 350 feet. The lode has a dip of about 70° N.

Southeast of this tunnel the Maine lode has not been traced, nor have other lodes belonging to this general group been identified.

Cascade lode and branches.—The Cascade lode, which has been mentioned above as branching off from the main Terrible-Dunderberg lode at the point where the latter crosses Brown Gulch, has at first a southeasterly strike and is well exposed by surface cuts, by shafts, and by a tunnel drift running 350 feet on the lode. This tunnel drift shows the lode with a northeast strike, having curved around from its initial southeast direction, and a nearly vertical dip. The vein in this vicinity shows considerable mineralization and some stoping has been done.

Farther northeast this lode probably splits again, although the exact point of branching has not been identified. One branch of the lode is apparently represented by a tunnel drift about 250 feet long on the Cashier claim, which shows a strong mineralized lead striking to the east-northeast. The other branch appears to be represented by a tunnel drift on a lode 150 feet northwest of the Cashier and parallel to it. This tunnel is probably on the Groundhog claim; the lode dips to the northwest at angles ranging from 40° to 60°. Both of these branches seem from the surface showing to run into and unite with the eastward-trending portion of the main Terrible-Dunderberg—the Groundhog branch into the Frostberg portion, the Cashier into the Maine, both junctions occurring near the Seven-Thirty wagon road.

In the Frostberg tunnel the Cashier lode is probably represented by a fairly strong mineralized lode crossing the tunnel halfway between the mouth and the drift on the Frostberg lode. In the Mendota tunnel an east-northeast lode diverging from the Frostberg, which here trends east and west, has been drifted on for upward of 400 feet. This is a definitely mineralized but

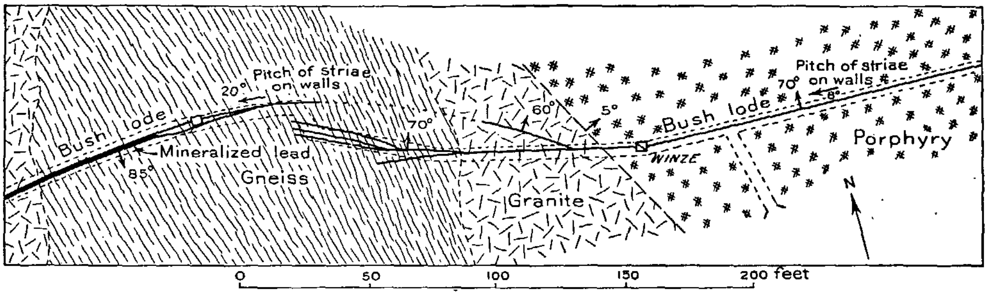


FIG. 63.—Geological plan of Bush tunnel. Note local deflection of lode on passing through gneiss.

not very strong lode with a practically vertical dip. East of the drift on this lode in the Mendota tunnel the lode is represented in the Burleigh tunnel by an unmineralized clay lead. This may be the Cashier lode of the surface, as the flatter dip of the Groundhog branch would make it unite with the Frostberg above this point. If this lode is actually the downward extension of the Cashier, the average dip of the lode from the surface would be about 73° NW.

MENDOTA VEIN SYSTEM.

The southwest end of the Mendota vein is known as the Smuggler vein. This portion is well opened up by tunnels and drifts, and is traceable from a point near the mouth of the Union tunnel northeastward across Brown Gulch to the Petersen shaft, from which workings go down to the Victoria tunnel level. The workings near the surface are continued northeastward from the Petersen shaft, with very little break, by the drifts of the upper Mendota tunnel which run along the road for more than 500 feet. About 200 feet northeast of the crosscut portion of the tunnel, along the drift on the lode, the Mendota vein divides into two branches. On the surface not far above this point these branches can be identified and followed. One branch runs nearly due east to a shaft on top of the ridge on the Tishomingo claim, and is traceable eastward along the surface for about 600 feet, beyond which it is not recognizable. This Tishomingo lode has had some little production.

About 250 feet northeast of the upper Mendota tunnel, and farther up the hill, is another tunnel drift whose mouth is situated near the branching of the Tishomingo lode from the Mendota lode proper. This tunnel runs in on the main north branch. At a point less than 200 feet in this branch divides again into two forks (both mineralized leads), dipping 70° N.

to 90°. Both of these branches can be followed on the surface. The southern of the two seems to curve around and rejoin the Tishomingo. The continuation of the other branch is shown chiefly in the underground workings of the last-named tunnel. Then, with a break of 250 feet, what is probably the same lode is shown in the workings of the Bush tunnel. In these workings the lode was drifted on for about 400 feet. It runs in a generally east-west direction, with a variable dip which approximates the vertical. In the east end of the workings the lode passes

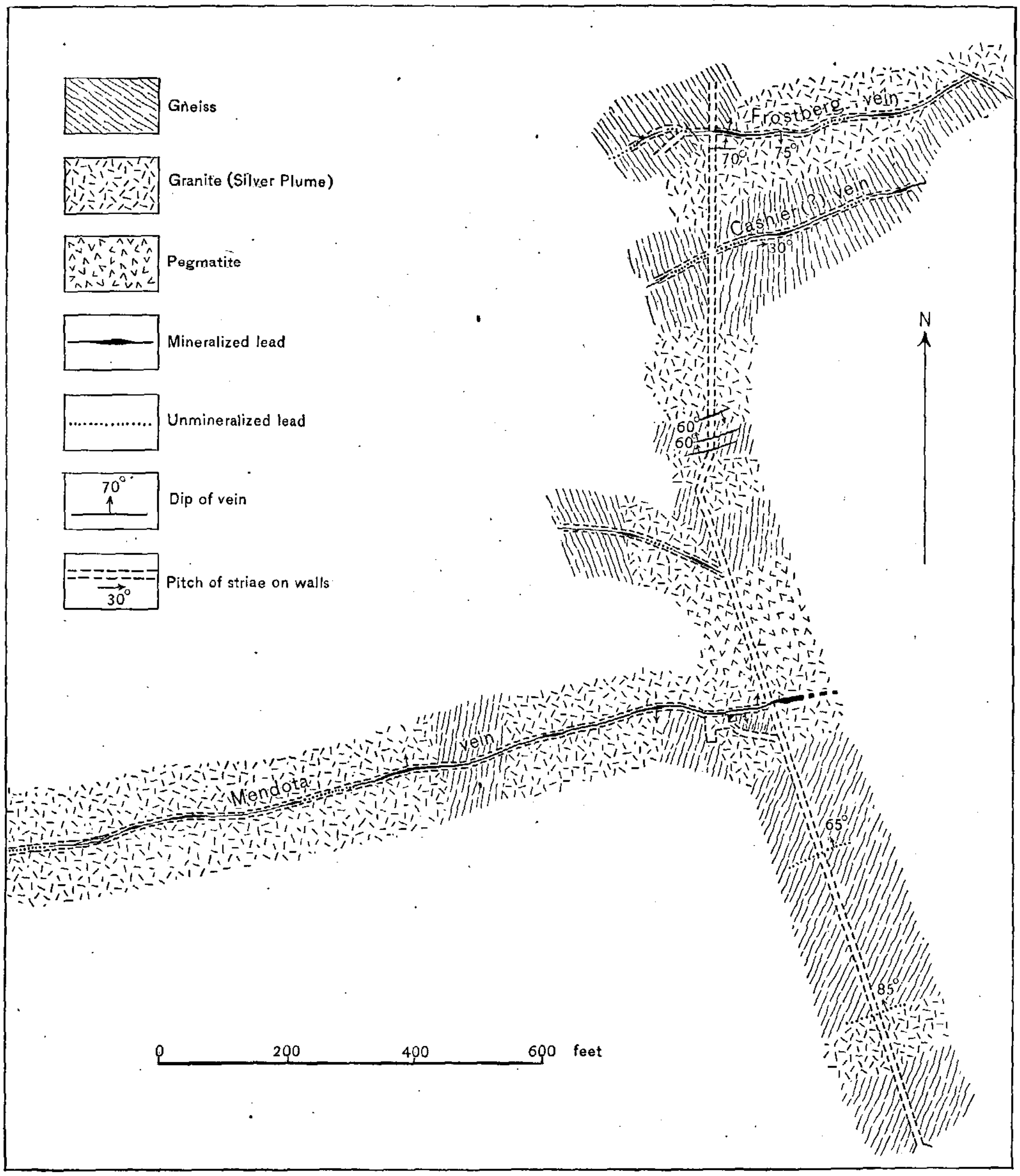
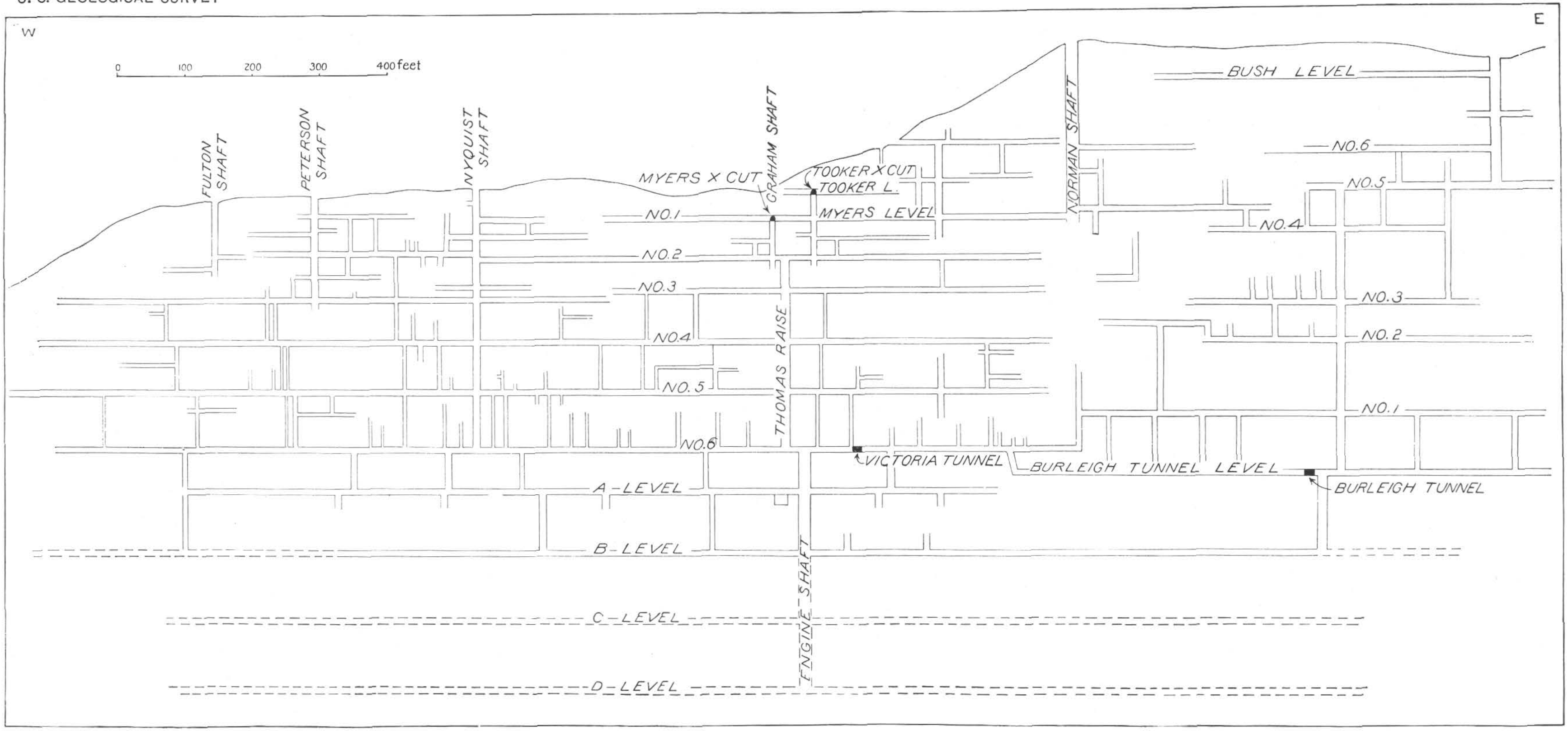


FIG. 64.—Geological plan of Mendota tunnel workings.

transversely through the same porphyry dike that is crossed by the Seven-Thirty vein (fig. 63). The lode here near the Bush tunnel workings gives off a weak branch which strikes to the southeast.

Farther east the main lode splits into two parallel branches that can be traced to a point just beyond the summit overlooking the Pelican tunnel, beyond which neither branch can be followed.

Underground, the Mendota lode is followed continuously by workings on a number of levels in the Smuggler mine from a point near the mouth of the Union tunnel northeastward



VERTICAL LONGITUDINAL PROJECTION OF CHIEF WORKINGS ON MENDOTA VEIN.

to the Mendota workings. In the Mendota mine (Pls. XXXIX, XL, *A*) the lode is also exposed by many levels. The longest drift on the lode is that on the Victoria tunnel level of the Mendota, which runs for more than 1,200 feet west of the tunnel (fig. 64). The position of the vein in the Mendota tunnel as compared with that at the surface shows an average southerly dip of about 83°. The Burleigh tunnel cuts the strongest branch of the Mendota, the Bush, at 700 feet below the outcrop and vertically beneath it. In this tunnel the lode has been drifted on both east and west, but the drifts are now caved. The western drift on the lode is reported to have connected with the workings of the Mendota tunnel. The Tishomingo branch of the Mendota is not recognized in the Burleigh tunnel. Immediately above the tunnel this branch is also weak at this point.

COMPOSITION OF VEINS.

All the lodes of the Terrible group have similar characteristics, which are distinct from those of the veins of the Bismarck–Pelican–Corry City–Pay Rock group already described. In the lodes of the Bismarck group vein quartz is usually present, though ordinarily subordinate in amount to the metallic minerals. Large quantities of coarsely crystalline, dark-colored blende are characteristic of the Terrible lodes. The other common metallic minerals are galena and pyrite, with some chalcopyrite. The galena is not invariably argentiferous to any important extent, though as a rule it contains a small amount of silver. From some of the mines considerable high-grade silver ore has been extracted, notably from the Terrible (Pl. XL). It is also reported that considerable high-grade ore, running from 200 to 500 ounces of silver, has been produced from the Baltimore. The high-grade ore from the Terrible ran from 100 to 800 ounces or even higher in silver. Some of the lodes of the group, however, have produced very little high-grade ore. The Mendota and Dunderberg as a rule show low-grade ore almost to the surface. The great bulk of the Mendota ore assays from 25 to 30 ounces of silver, contained in coarse blende and galena within 50 feet of the surface down to a depth of 700 feet or more. The ores contain generally a very small quantity of gold, but sometimes the amount is sufficient to be paid for by the smelters. The reports of the production of the Tishomingo lode in 1890 show $19,368 in silver and $1,950 in gold. In this case the value of the gold was 10 per cent of that of the silver, but usually the proportion is much less.

The ores near the surface show in many places considerable siderite as gangue. Barite was observed at one point in the Dunderberg workings on the third level, 150 feet from the surface. The barite occurs as clear crystals lining the walls of a cavity and associated with quartz. Where it was found the Dunderberg lode was represented only by a faint unmineralized slip.

In some of the lodes gray copper has been found, especially near the surface. Ruby silver and polybasite also occur, most abundantly in the upper levels. Fine specimens of light-red ruby silver (proustite) associated with polybasite have been described.[a] The following is an analysis by Genth[a] of polybasite from the Terrible mine:

Analysis of polybasite from Terrible mine.

Silver	62.70
Copper	9.57
Iron	.07
Arsenic	.78
Antimony	10.18
Sulphur (by difference)	16.70
	100.00

Although the general composition of all the lodes is similar, there are slight differences throughout. It has even been noted that where a vein splits into two branches the ores in each have a slightly different character.

[a] Genth, F. A., Proc. Am. Phil. Soc., vol. 23, 1886, p. 39.

NATURE OF VEINS.

The Terrible group of veins embraces the strongest lodes in the Silver Plume district. They are in the main well-defined fissure veins following strong fracture zones or filling open fissures, many of which have been partly filled with angular rubble before cementation by the ore minerals (fig. 65). The vein filling is characterized by large masses of blende and by relatively small amounts of silver. The proportion of blende to galena is greater than in the veins of the Bismarck group.

While the more important lodes are filled fissures or heavy fracture zones the smaller ones are simply clay leads composed of altered rock material following along slip planes. Such decomposed zones may be several inches thick. Two strong fractures may form the walls of such a lead. In some places a third fracture, at first slightly divergent, may join the main zone, forming a new wall, when one of the former wall fractures is forced to become a center fracture. This is often noted. In many places two nearly parallel small veins or leads approaching closely together form the walls of a larger vein, the intervening rock being replaced by ore. A good example of this is seen in a tunnel of the Brown mine (fig. 81). A vein thus formed has usually two good walls.

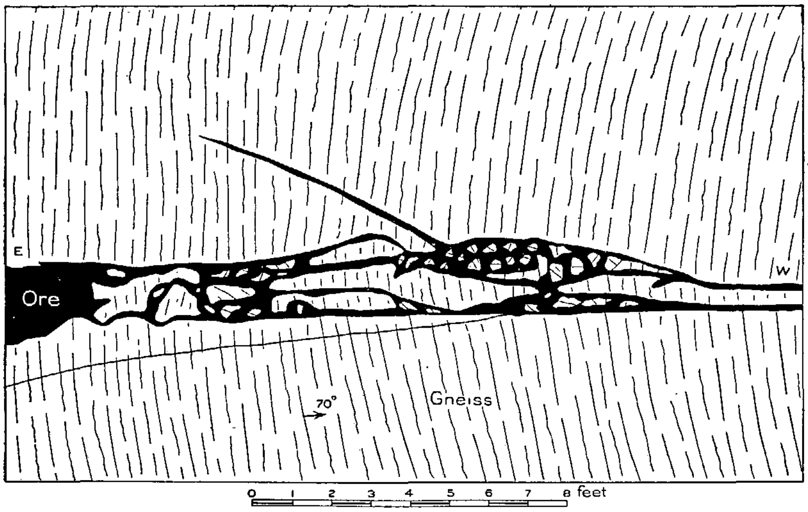
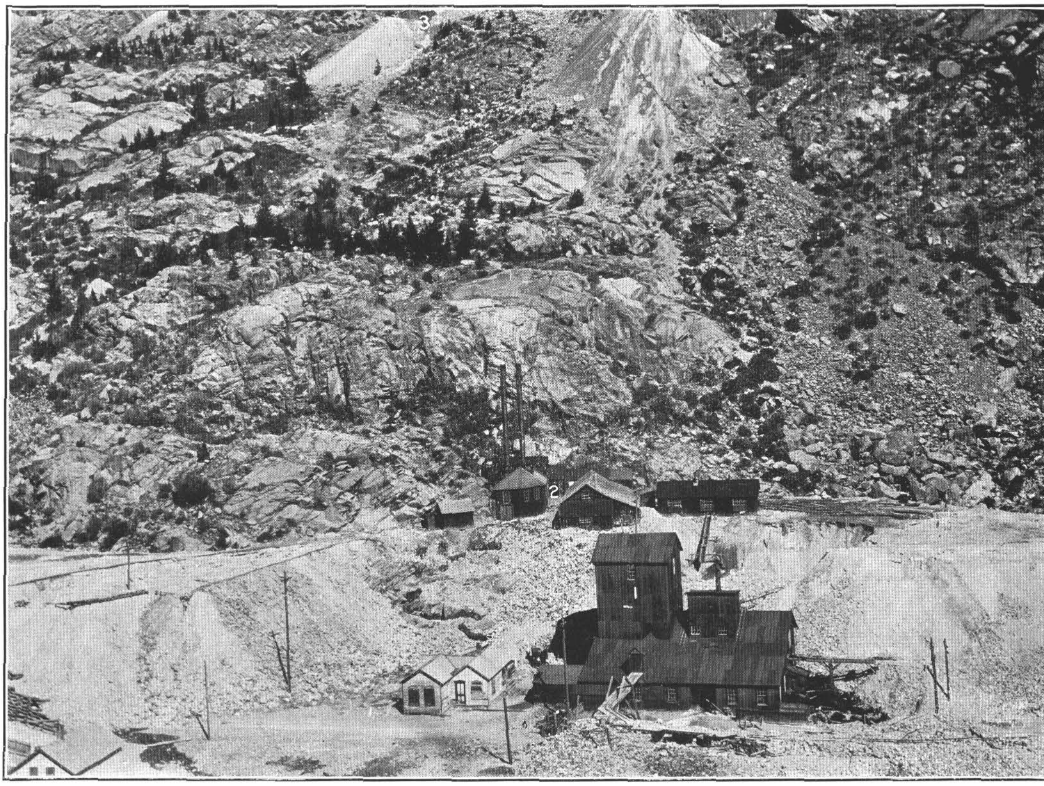


FIG. 65.—Horizontal sketch showing Mendota vein as exposed in roof on second level east below Victoria tunnel level, Mendota mine. Shows blende cementing a rubble-blocked fissure.

All the leads and veins have formed along definite but relatively slight faults having an approximately horizontal movement. Evidence of the faulting is furnished in many veins by discordance of the opposing walls, but as a rule this discordance is only slight. Evidence of the movement and of its direction is also furnished by abundant striæ. The following is a list of some of the striæ observed along lode walls:

Fenton lode, West Terrible tunnel, striæ are horizontal and also pitch 25° W. on lode.
Fenton lode, Silver Ore tunnel, striæ pitch 5° E. and also 5° W. on lode.
Mammoth lode, above Seven-Thirty road, striæ pitch 25° W. on lode.
Glasgow vein, Union tunnel, striæ are horizontal on lode.
Mendota vein, Smuggler mine, fifth level, striæ pitch 20° E. on lode.
Frostberg vein, East Dunderberg tunnel, striæ are horizontal on lode.
Terrible vein, level No. 3, Dunderberg mine, striæ pitch 12° W. on lode.
Mendota vein, Petersen shaft, 30 feet below surface, striæ pitch 15° E. on lode.
Mendota vein, upper Mendota tunnel, striæ are horizontal on lode.
Mendota vein, Bush tunnel, striæ pitch 8° W. on lode.
Mendota vein, second level below tunnel, striæ pitch 5° W. on lode.
Mendota vein, third level below tunnel, striæ are horizontal on lode.
Mendota vein, fourth level below tunnel, striæ pitch 30° W. on lode.
Maine vein, upper main tunnel, striæ pitch 15° W. on lode.
Maine vein, upper main tunnel, striæ pitch 7° W. on lode.
Branch of Mammoth lode, Backbone tunnel, striæ pitch 10° on lode.

The lodes are prone to weakening by repeated branching. As a rule the branches open out in the direction of the weakening vein so that a main lode splits and feathers on both ends; in many lodes, however, minor branches diverge in the opposite direction from that of the main branches. A combination of branching in the normal and abnormal directions constitutes



A. MENDOTA MINE AND MILL.

1, Mendota mill; 2, Victoria tunnel, Mendota mine; 3, Upper Mendota tunnel.

B. TERRIBLE AND SMUGGLER MINES.

Showing also the great amount of wash from Seven-Thirty and other mine dumps brought down Brown Gulch by spring freshet. 1, Terrible mill; 2, Union tunnel, Terrible mine; 3, Smuggler mine; 4, Silver Ore tunnel, Terrible mine; 5, wash from Seven-Thirty and other mine dumps.

a splitting and reuniting of the vein, leaving a horse of rock between. This condition is not uncommon, and is well shown in the workings of the Brown tunnel. In extremely rare and unimportant cases leads cross. Such a crossing was noted in the East Dunderberg tunnel, where each of the leads contained a little mineral.

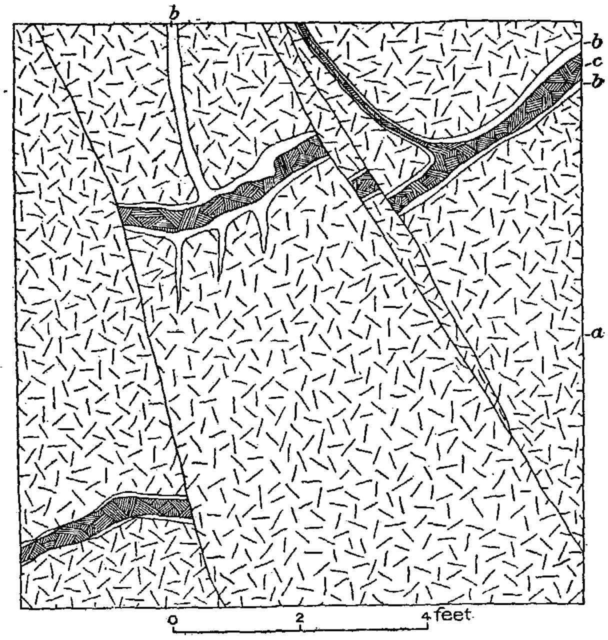


FIG. 66.—Sketch of zone of Mendota vein, third level below tunnel level, showing (1) earlier deposition of quartz and subsequent deposition of metallic sulphides in open fissures; (2) displacement of vein by postmineral faults. *a*, Granite country rock; *b*, comb quartz without sulphides; *c*, sulphides without gangue (chiefly coarse blende with a little galena, pyrite, and chalcopyrite).

STRUCTURE OF VEINS.

CHARACTERISTIC FISSURE FILLING.

The most striking thing about the veins of this group, which are typically fissure veins formed in preexisting cavities, is that all these cavities are lined by comb quartz representing a first deposition invariably preceding that of the sulphides, which usually fill up the central and greater portion of the vein and are characteristically and practically free from admixture with intercrystallized quartz or other gangue (figs. 66, 67). These quartz linings show that in nearly all the veins the deposition of metallic minerals did not take place for a very definite period after the opening of the fissures.

The Mendota lode is highly characteristic of this whole group, and its description may serve for all. In places this lode shows only slip walls with no mineralization. This tight slip, however, opens up rather abruptly into a strong breccia vein from 1 to 4 feet wide in which occur large bodies of blende with pyrite, inclosing numerous angular fragments of the country rock. This breccia vein is without doubt the cementing of a large rubble-filled fissure by ore. On the Victoria tunnel level such a fissure vein continues for several hundred feet, then it narrows again to the east, and the lead changes into a zone of fractures marked by small seams of blende. Farther on the seams become very poor and are not mineralized. Still farther east the slip leads on the vein become stronger and, although not generally mineralized, contain bunches of galena, pyrite, blende, etc., up to a few inches in diameter (fig. 68). Beyond this part the lead opens out again by the thickening of the sulphide streaks and within a short distance becomes a breccia vein $2\frac{1}{2}$ feet thick filled with blende and including angular fragments of the country rock (figs. 69, 70).

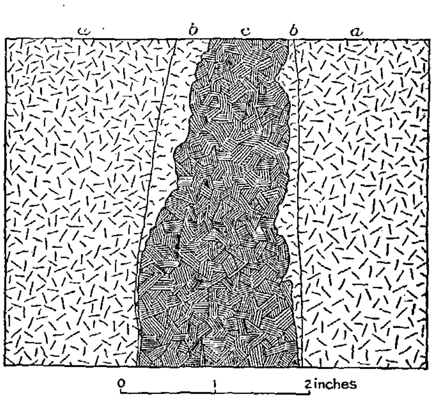


FIG. 67.—Sketch of portion of a veinlet shown in fig. 66, showing sheathing of quartz between sulphides and vein walls. *a*, Granite wall rock; *b*, comb quartz without sulphides; *c*, solid sulphides without gangue (principally blende with some galena and pyrite).

At one point here the structure is reversed and angular fragments of blende are included in a hard rock which at first sight appears to be a uniform granite or porphyry. Microscopic examination, however, shows that this rock is a finely ground granite cemented by quartz. The cement consists of fine crystalline to cryptocrystalline silica. This unusual occurrence indicates a rending apart of the vein subsequent to its formation and the deposition of the blende, and the filling of the new fissure thus created with a paste of ground granite probably brought in by waters, the granite catching up and cementing angular fragments of blende broken up by the rending of the original vein.

Although this was subsequent to the ore deposition, the interspaces were afterward cemented hard by silica (fig. 71). The effect of this postmineral brecciation, however, was not extensive, for 10 feet farther west along the vein the normal structure reappears, where coarse blende cements a breccia of the granite country rock. A little farther west the vein again closes down to a slip and then to a bare fracture.

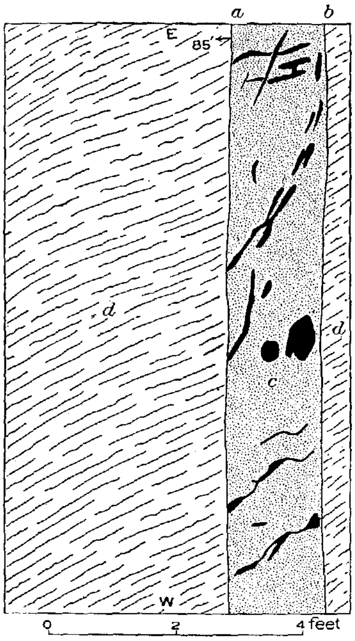


FIG. 68.—Horizontal section of roof of drift, Mendota mine, second level east, showing deposition of blende by impregnation of gouge zone. *a*, Hanging-wall slip; *b*, foot-wall slip; *c*, zone of gouge (black markings are ore, chiefly blende); *d*, hard black gneiss (wall rock).

Typical fissure veins are illustrated at many points in the other mines (figs. 72, 73). All gradations are illustrated at various points, from ore reticulating a crushed zone of rock to that cementing a rubble-filled fissure, the gradations depending on the relative size of the openings in the fissured zone and of the included granite fragments. Fig. 74, a sketch of the Frostberg vein on the Frostberg tunnel level, shows this transition very well.

FILLING OF CAVITIES OF DISSOLUTION.

While a large number of the cavities which have been filled with minerals are fissures due to rending, another large number are irregular in shape and are plainly cavities of dissolution formed by the solvent action of waters circulating along a crushed fault zone. Subsequent to the faulting and during hardening and cementation of the fault gouge these irregular openings were in places extensively formed and were subsequently filled with quartz and sulphides. The structure of these vein fillings is entirely similar to that of the fillings of cavities due to rending, the quartz invariably forming a lining to the opening and the metallic mineral occupying the center.

Similar cavities have formed at a later date, subsequent to the first filling of the vein, and indeed are probably being locally formed at the present day by the dissolving action of descending surface waters along watercourses. Extensive elongated dissolution cavities of this sort were noted along the Mendota vein. These cavities are typically lined with quartz crystals which represent the latest deposition, probably the work of present descending waters. Some of these open vugs show incrustations of other minerals besides quartz. A specimen from the Brown mine shows a vug in a mixed sulphide ore consisting of blende, pyrite, and galena. This vug is lined with free quartz crystals upon which, representing a later deposition, are crystals of calcite and a brownish carbonate, probably siderite.

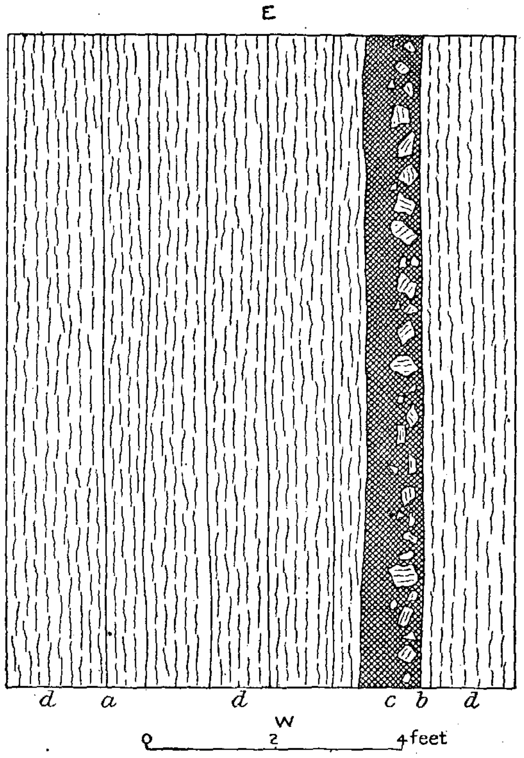


FIG. 69.—Horizontal section of roof of drift, Mendota mine, second level east below Victoria tunnel level, showing fissure filling characteristic of Mendota vein. *a*, Hanging-wall slip; *b*, foot-wall slip; *c*, zone of coarse blende, pyrite, and galena containing angular fragments of gneiss; *d*, hard black gneiss (country rock).

RENEWED MOVEMENTS SINCE BEGINNING OF ORE DEPOSITION.

There is also evidence that the vein has been disturbed by renewal of stress subsequent to its deposition, resulting in reopening of the fissures. In many veins it is plain that this has happened repeatedly at intervals.

A specimen from the Dunderberg vein shows (1) galena brecciated and cemented by pyrite, (2) pyrite brecciated and cemented by siderite, (3) jaspery silica coating cavities, as the latest deposition. A specimen from the Mendota at a depth of 650 feet shows the following: (1) Opening of the original fissure, (2) deposition of comb quartz on the walls, (3) filling of the remainder of the fissure by blende, (4) reopening of the fissure near its walls, (5) cementation of the new opening by galena, (6) reopening of the fissure, (7) cementation of the opening by pyrite. Similarly the Frostberg vein at the Burleigh tunnel, at a depth of 1,150 feet, shows a banding of different minerals. In one place, where the vein is 1 foot wide and consists of solid sulphides, there is a band of blende on both sides and the center consists of galena (fig. 75); in another place there is blende on both sides and the center consists of pyrite (fig. 76). In the last-named place there is not sufficient evidence to show whether this banding represents successive deposition or crustification in a single fissure or whether it represents the reopening of an original blende-filled fissure and the cementation of the reopened fissure by galena and pyrite. The mass of evidence elsewhere, showing that this rending is extremely common, is in favor of the latter explanation. Any stresses applied to the rock after the formation of the vein would result in the splitting apart of the brittle sulphides rather than a reopening of the wall rock. This is not only a natural result, but one which is shown very convincingly to have taken place elsewhere, as, for example, in the Griffith mine.

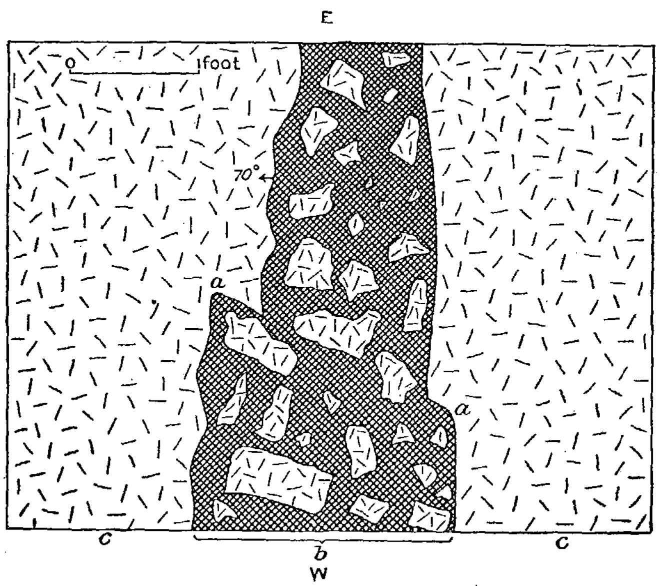


FIG. 70.—Horizontal section of roof of drift, Mendota mine, second level east below Victoria tunnel level, showing jog in Mendota vein. This jog is interpreted as probably due to premineral faulting of the vein fissure, the fault having the strike *a-a* and the direction of movement within a nearly vertical zone of the vein fissure. The effect of this movement was to bring a broader portion of the vein fissure opposite a narrow portion. *b*, Solid coarse blende with some pyrite and galena, containing angular fragments of granite; *c*, granite (country rock).

A specimen from the east end of the drift on the Frostberg vein, on the Victoria tunnel level, shows the following history: (1) Opening of the original fissure, (2) filling of the fracture with a soft, pasty mass of finely crushed and pulverized rock, inclosing a few angular fragments of porphyritic granite or "corn rock," (3) cementation of the crevice filling by silica, (4) fracturing of the cemented mass, (5) filling of these small cracks by blende and quartz, (6) reopening of the main fissure, (7) deposition of comb quartz on the walls, (8) partial filling of the fissure by blende associated with a small amount of contemporaneous cupriferous pyrite, (9) deposition of copper-bearing pyrite and galena on large crystals of blende in vugs (the galena both contemporaneous and later than the pyrite), (10) coating of the cubo-octahedral crystals of galena in vugs with minute crystals of pyrite or marcasite and coating of faces of the sphalerite crystals with a thin film of drusy white quartz.

The fact that in this last stage the minute pyrite crystals are confined entirely to the surfaces of the galena crystals, whereas the crusts of quartz occur only on the sphalerite, indicates that the different minerals had caused selective deposition.

It appears, therefore, that the solutions circulating along a given fissure were constantly changing in character, just as the slightly but constantly changing character of mineralization in different lodes testifies to different solutions or different blends of solutions circulating along different channels. The whole process of ore deposition was plainly very slow indeed, lasting through intervals of quiescence and the reopening of fissures which probably represent a long period of time. The evidence afforded by the veins, indeed, does not indicate clearly that the cementation by ore of the openings that still exist has ceased. Inasmuch as the primary ore deposition was preceded by the lining of the cavities by quartz crystals, and as the abundant cavities, many of them large, that are now found along the veins are usually lined with similar quartz crystals of a later generation, the question arises whether the later deposition of quartz lining the cavities might not be succeeded by a new deposit of metallic sulphides. In beautiful specimens from the Argentine district, which is a few miles from the Silver Plume district, we have indeed examples of this occurrence. Here large cavities or druses in the older ore are lined with comb quartz, and sitting free on the quartz crystals, as the last deposition from circulating waters, are beautiful and perfect crystals of metallic sulphides—pyrite, galena and blende, copper pyrite, and polybasite, comprising all the species of the original deposition. These cavities are now the channels of descending atmospheric waters. It is plain that these waters are not hostile to the formation of the sulphides and are not dissolving them. Indeed, it is probably from these waters that they are being deposited.

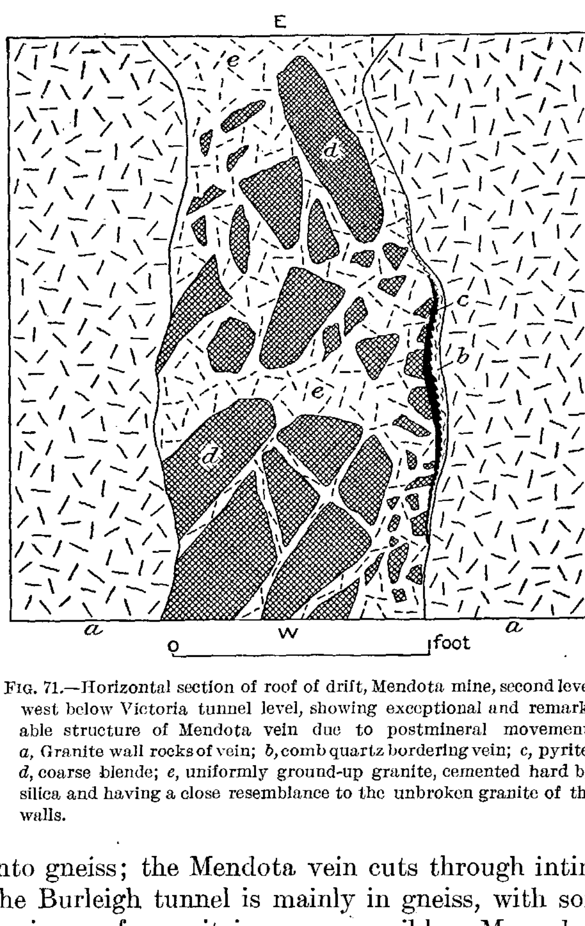


FIG. 71.—Horizontal section of roof of drift, Mendota mine, second level west below Victoria tunnel level, showing exceptional and remarkable structure of Mendota vein due to postmineral movement. *a*, Granite wall rocks of vein; *b*, comb quartz bordering vein; *c*, pyrite; *d*, coarse blende; *e*, uniformly ground-up granite, cemented hard by silica and having a close resemblance to the unbroken granite of the walls.

NATURE OF WALL ROCKS.

The wall rocks of this group of lodes consist of gneiss and granite. Granite unmixed with gneiss occurs over considerable areas here, and some of the strongest lodes lie entirely in it. Other considerable portions of the wall rock consist of granite intimately mixed with gneiss, and pure gneiss, without any great admixture of granite, forms the walls in a smaller number of veins. Of the larger openings, the Baltimore tunnel is chiefly in hard gneiss; the Silver Ore tunnel is in massive granite; the Union tunnel workings are principally in granite with a minor quantity of gneiss; the Dunderberg workings are all in granite except at the north end, where they run into gneiss; the Mendota vein cuts through intimately mingled gneiss, pegmatite, and granite; the Burleigh tunnel is mainly in gneiss, with some granite; the West Terrible tunnel is all in gneiss, so far as it is now accessible. More detailed evidence of the relation of granite and gneiss as wall rock to the lodes is given in the general map (Pl. XXI), and in the detailed plans of different mine levels.

The granite is identical with that found all over the area shown on the special map and already described. The gneiss is of different varieties, ranging from rather soft and schistose to hard and granitic.

Porphyry is of very minor importance as a wall rock to this group of veins. The large northwestward-striking dike of porphyry, traceable on the surface from the northwest corner of the area mapped down to Clear Creek valley, east of the Burleigh tunnel, is cut through almost transversely by a number of lodes belonging to this group, such as the Mammoth, Dunderberg, and Frostberg. Northeast of the intersection of the porphyry dike with these lodes, in the area just north of the Seven-Thirty wagon road, where the principal lodes split into a number of branches with a general east-west trend, two small porphyry dikes have deflected some of these branches and act as walls to the lodes. These dikes, however, have been traced for only about 500 feet along the strike, and it is not probable that they extend very much farther. The veins are more persistent, and, passing on southeastward, come again into granite and gneiss as wall rocks.

In the Baltimore tunnel, north of the vein zone, porphyry has been encountered and drifted on for some distance, but is entirely unconnected with any mineralization.

Moreover, two porphyry dikes were encountered in the Burleigh tunnel in driving a cross-cut from the east drift on the Phillips vein to the Bismarck-Pelican lode. The first of these dikes encountered was only 5 feet wide; the second, however, was a broad dike corresponding probably to the large dike of quartz monzonite porphyry, which runs northwestward on the surface and is cut by the Seven-Thirty, Frostberg, and other veins.

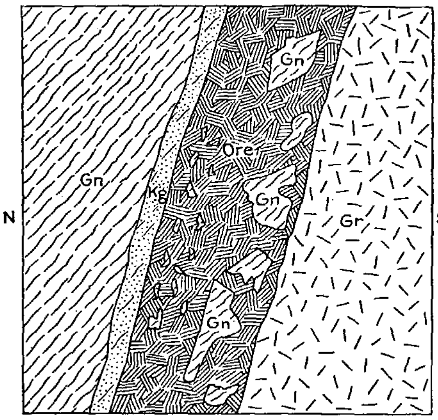


FIG. 72.—Cross section of Phillips vein, Burleigh tunnel level, showing angular fragments of wall rock in the vein filling. Gn, gneiss; Gr, granite; Kg, kaolinized gneiss and gouge.

ALTERATION OF WALL ROCKS.

The wall rocks of the lodes are invariably altered. It is difficult to distinguish the alteration which has been accomplished by the vein-forming waters from that which has been accomplished by the ordinary surface waters penetrating downward. The effects of these waters in portions of the rock remote from the veins will be described later. The following is a description of some of the alteration in the very walls of some of the important veins:

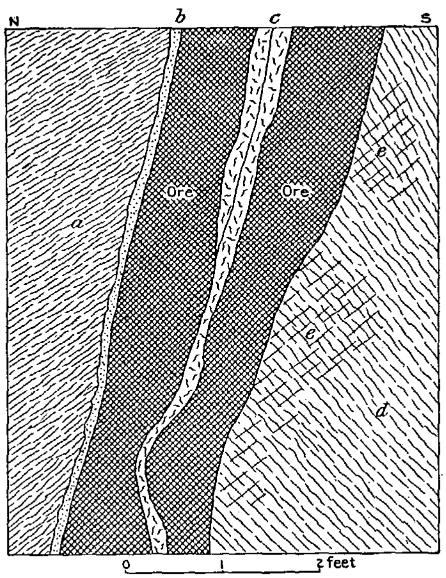


FIG. 73.—Cross section of Phillips vein, west end of Burleigh tunnel level, showing horse of gneiss in vein. *a*, Micaceous gneiss; *b*, gouge selvage; *c*, mixture of quartz and crushed silicified gneiss; *d*, hornblende gneiss; *e*, fractured gneiss.

A specimen of granite from the wall of the Dunderberg vein, on the D level, near the surface, proves under the microscope to be slightly stained throughout. The microcline is fresh as a rule, but along cracks is altered to sericite and is somewhat impregnated by crystalline siderite. Muscovite and zircon are also unaltered. The other minerals are completely altered. Biotite is entirely decomposed and is recognized by cloudy, partly crystalline siderite, which obscures the bleached mica, and by webs of unaltered sagenite (rutile). The feldspar, other than microcline, is entirely decomposed to coarse sericite. Along cracks in the rock siderite has crystallized, and one veinlet is lined with crystalline siderite and the interior is filled with quartz. The relation of the siderite derived from the alteration of the biotite to that which has formed along cracks as veinlets indicates that the vein siderite also has been derived from the rock.

It is only on extreme alteration that the microcline of the granite is decomposed. A specimen of the granite wall rock of the Mendota vein, more highly altered than that just described, shows, of the original more common granitic minerals, only muscovite surviving. The feldspar is represented only by mats of sericite. This rock contains isolated grains of crystalline, idiomorphic quartz showing zones of growth on the outside. These grains probably represent the granitic quartz grains enlarged by deposition from mineralizing waters. Associated especially with the quartz are large grains of intergrown blende and galena.

Several specimens of extremely altered gneiss from the wall rock of the northwest extension of the Mammoth lode in the Backbone tunnel, above the Seven-Thirty road, show of the original

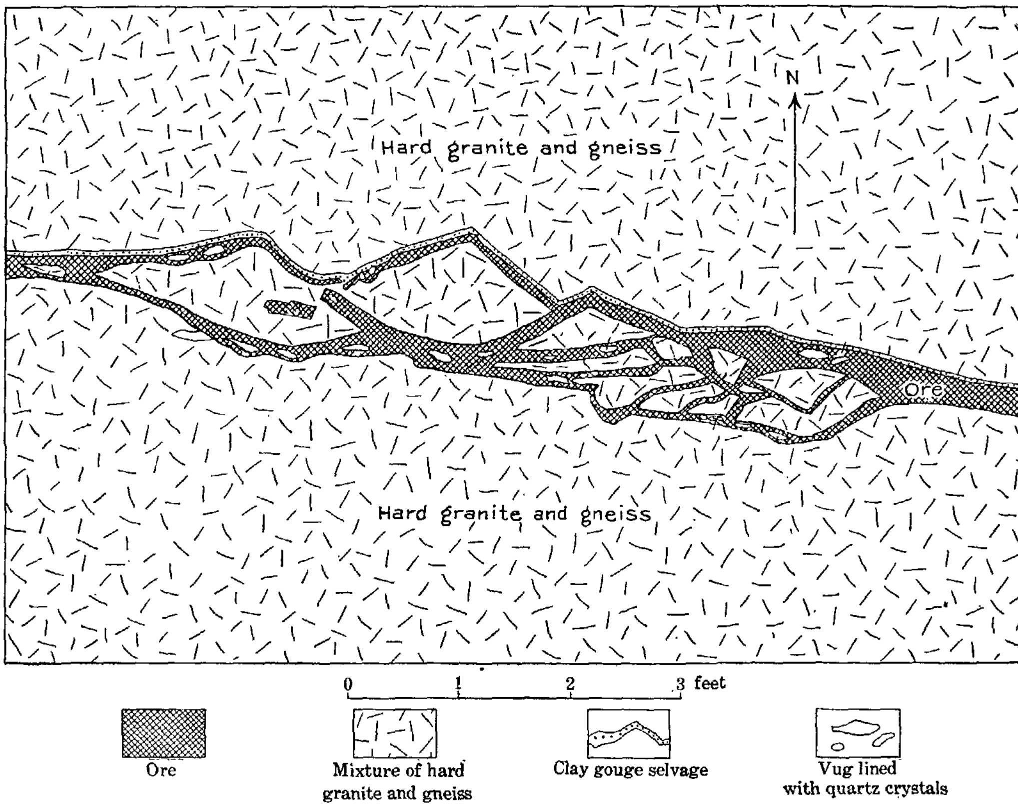


FIG. 74.—Sketch of Frostberg vein near shaft on upper tunnel level, showing a condition of the vein transitional between a zone of reticulating veins in granite and a zone of ore containing angular granite fragments.

minerals only quartz and zoisite unaltered. The feldspars are represented by areas of fine sericite; the biotite is bleached, with the separation of abundant siderite, which is replaced in part by limonite. In the last stage of alteration the rock becomes simply an aggregation of quartz, sericite, and crystalline siderite, with some pyrite and numerous zeolites. Siderite forms microscopic veinlets, and kaolin occupies portions of the rock that possibly represent shrinkage cracks. This locality is from 100 to 300 feet below the surface. Originally this rock seems to have been a fine quartz-feldspar-biotite schist containing some muscovite.

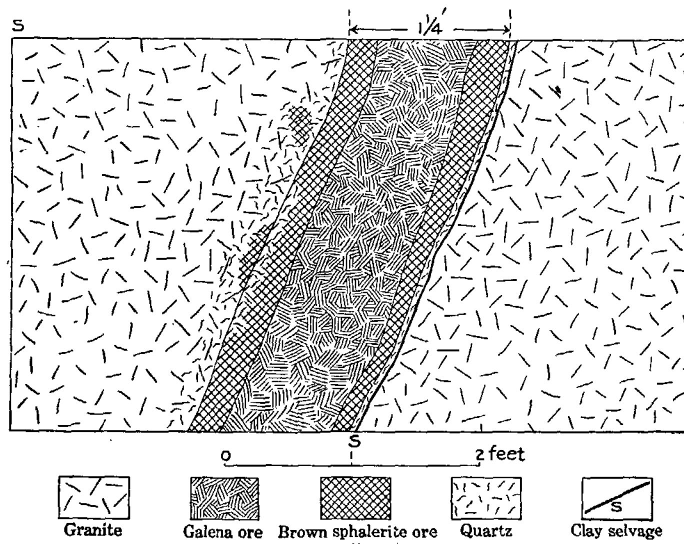


FIG. 75.—Cross section of Frostberg vein, showing probable reopening of blende vein and deposition of galena.

INFLUENCE OF WALL ROCK ON VEINS.

RELATIVE INFLUENCE OF GRANITE AND GNEISS

It is proved everywhere in this group of veins, as indeed throughout all this general mining district, that the physical nature of the wall rock exerts a very delicate and important influence on the veins (figs. 77, 78).

The principal wall rocks of the Terrible group of veins, as before stated, are granite and gneiss. Of these rocks the granite has proved the most favorable for strong, persistent fissures by reason of its homogeneous structure. These veins are strongest, straightest, and most productive when passing through granite. Moreover, in granite fissure fillings are very common

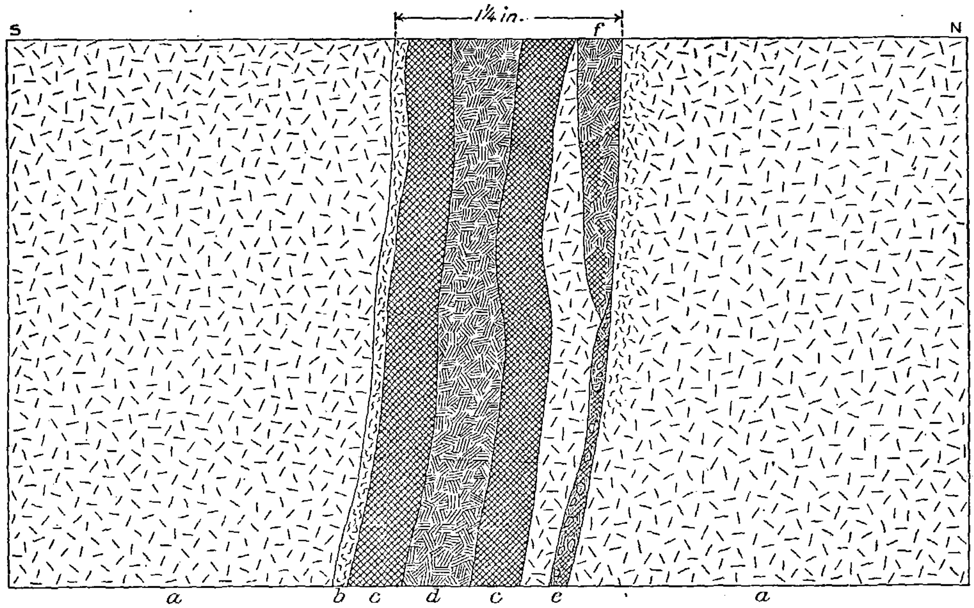


FIG. 76.—Cross section of Frostberg vein, showing probable reopening of blende vein and cementation by pyrite. *a*, Granite; *b*, quartz; *c*, sphalerite; *d*, pyrite; *e*, mixed pyrite-sphalerite ore and country-rock breccia fragments; *f*, pyrite-sphalerite ore.

or characteristic, but when the same vein passes into gneiss the fissure vein becomes a decomposed rock lead with less mineralization. In granite the walls are generally well defined, whereas in gneiss, especially the softer varieties, the lead is mineralized much more irregularly.

The effect of a vein on passing from granite into gneiss is well shown at the northeast end of the Dunderberg workings. This strong vein here passes from granite to soft gneiss on the northeast; an immediate weakening and splitting of the lode is very plain and is noted on all levels, being especially observed on the Dunderberg B level (fig. 79). At the southeast end of this level the vein also passes into gneiss and the weakening and impoverishment of the vein is again noted. The same thing is well shown on the Dunderberg A level. A strong shoot of ore in granite goes as far northeast as the granite contact with the gneiss. This shoot follows the granite contact from level to level, pitching at a flat angle with the contact, but does not enter the gneiss. The lead continues on and enters the gneiss, but is poor and practically unmineralized. On the B level by far the greatest production of ore was from that portion which lies in granite near the gneiss, though some extended into the gneiss. It is probable that at this point the fractures may have scattered and forked in the granite by reason of the resistance of the tough gneiss to the stress. Thus a number of forks were produced, furnishing the intersecting channels which have proved so favorable for ore bodies in this region.

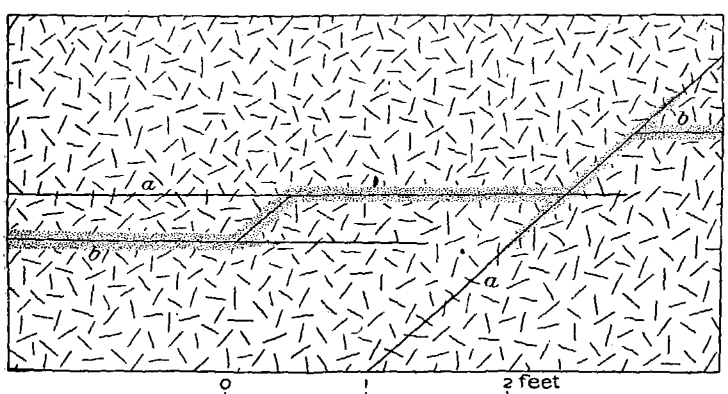


FIG. 77.—Sketch of outcrop on hill north of Brown vein, showing path chosen in homogeneous rock (porphyritic granite). *a*, Joints; *b*, joints with silicification along margins.

EFFECT OF CHARACTER AND ATTITUDE OF GNEISS.

The character of the gneiss, whether soft and tough or hard and brittle, is of great importance to the existence of a vein, as shown in this vein group. In the soft gneiss the vein splits repeatedly and is not far traceable, but in the hard and rigid gneiss the conditions are favorable for strong lodes. A mixture of granite, pegmatite, and gneiss has proved in this vein group, as in other parts of the district, a favorable vein formation, permitting the existence of strong and persistent fractures.

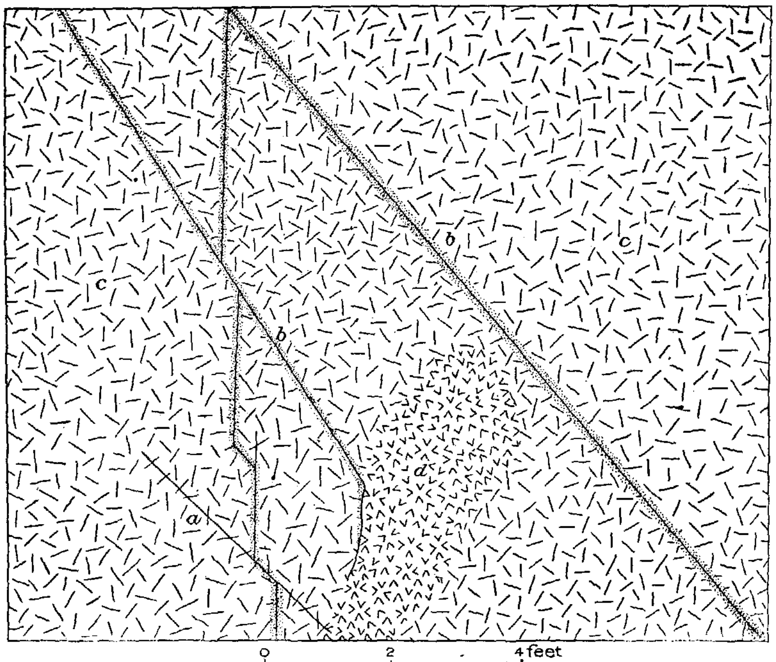


FIG. 78.—Sketch of outcrops, same locality as fig. 77, showing deflection and displacement of lode following a joint in granite on encountering a bunch of pegmatite. *a*, Unmineralized joints; *b*, joints with silicified borders forming quartz vein; *c*, porphyritic Silver Plume granite (homogeneous); *d*, pegmatite.

The strike of the gneiss has in many places undoubtedly some influence on the lode. In this group of veins the relations of the strike of the gneissic lamellæ to the trend of the lode are not so significant as elsewhere, as the trend of the principal lodes was undoubtedly determined by regional stresses operating on the homogeneous granite which constitutes the principal rock mass here. It is therefore possibly accidental to a large degree in this group of veins that the strike of the lode generally quarters across the strike of the gneiss. Where, however, a lode is deflected so that it is parallel with the strike of the gneiss, this relation seems as a rule rather unfavorable to mineralization. It is to be seen, for example, in the east end of the drift on the Frostberg lode in the Frostberg tunnel. Here the Frostberg is parallel in strike and dip to the inclosing gneiss, and is weak and unmineralized.

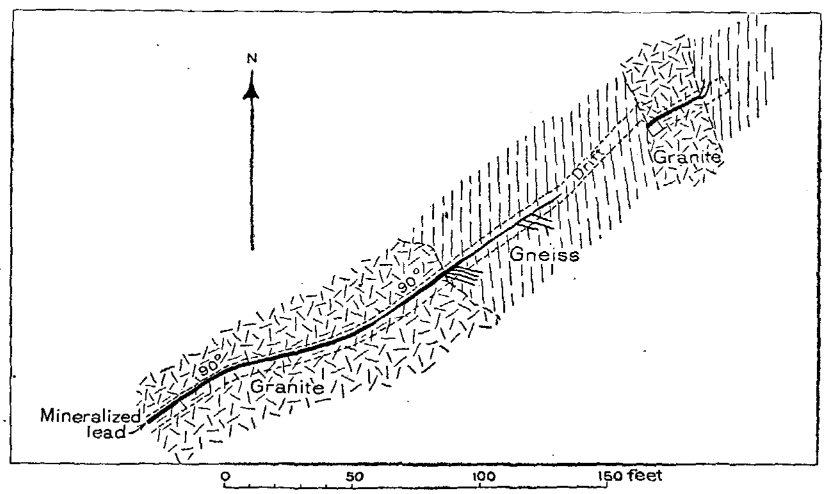


FIG. 79.—Plan of northeasternmost portion of No. 4 Dunderberg level on Terrible lode, showing influence of relative rigidity of different rocks (controlling the formation of fractures) on the strength of the veins which have formed along the fractures. A strong vein in passing from rigid granite to yielding gneiss immediately branches and disappears, but farther on another dike of granite is encountered in which the vein is once more well marked, though on encountering gneiss beyond this dike it again disappears, showing that the strain passed through the gneiss without forming a fracture, but was unable to do so in the rigid granite.

EFFECT OF PORPHYRY.

As stated above, porphyry plays a very minor part as a wall rock to this group of veins. The large northwestward striking dike which is cut by the Seven-Thirty lode is also cut by a number of the lodes belonging to the Terrible group. This porphyry dike has a flat east-northeast dip. In the Frostberg tunnel, where the Frostberg vein traverses this lode diagonally, the vein has been largely productive on the west or under side of the dike. The productive portion continues eastward as far as the dike, and there are some good stringers of ore in the dike itself near its western contact; farther east, however, though the lode passes through the porphyry and into gneiss, it is unmineralized. The lode was followed in the gneiss for 600 feet west of the dike, but showed no mineralization.

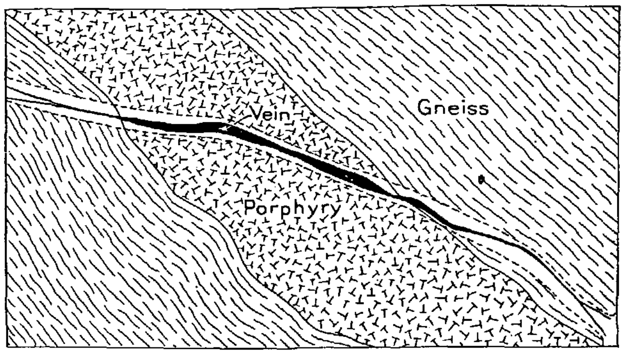


FIG. 80.—Horizontal plan of vein in one of the tunnels of the Maine mine, showing thickening of vein on passing from gneiss into harder and more rigid porphyry. Dotted line shows tunnel.

The Mendota or Bush lode cuts through the same dike at a point about 1,000 feet to the southeast. As seen in the Bush tunnel, this porphyry has the same effect on the Mendota vein as it has on the Frostberg vein in the Frostberg tunnel. The vein on the west or under side of the porphyry is in granite with some gneiss, and is a very strong fissure vein containing blende, galena, etc. On entering the porphyry the vein becomes very little mineralized, and on passing through the porphyry to the granite, which lies on the east or upper side of the dike, the lead is still faint and contains little mineral.

The extension of the Dunderberg lode crosses the same porphyry dike near the surface in a tunnel on the upper side of the Seven-Thirty road. This tunnel starts in the porphyry and passes northeast of it into granite. In the porphyry the lead is well defined and there is a little ore but no stopes. In passing northeast of the porphyry into the granite the vein widens and becomes strong, showing considerable ore which has been stoped out. About 350 feet west of the above-mentioned tunnel another tunnel starts on the upper side of the same road on the continuation of the Mammoth lode. This tunnel starts in the same porphyry dike and runs

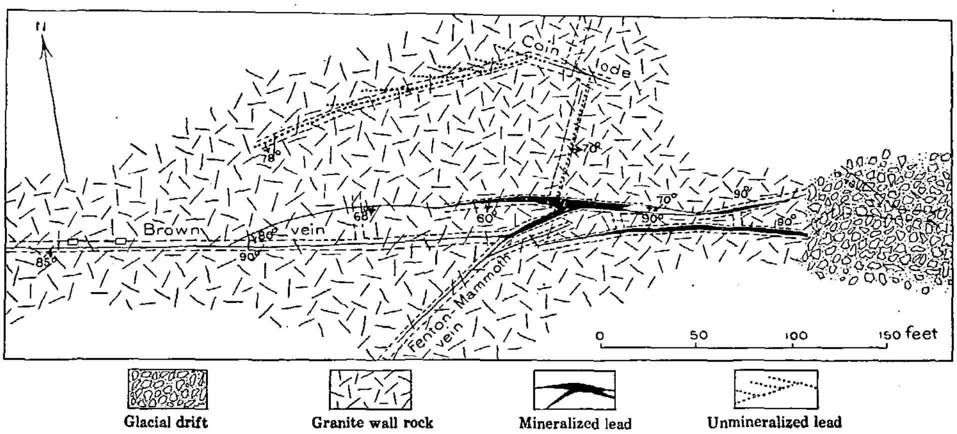


FIG. 81.—Geological plan of tunnel on Brown vein.

through it into gneiss on the northeast or upper side of the dike. In the porphyry the lead is well defined and shows a little mineral, as was the case in the tunnel on the extension of the Dunderberg just mentioned. On passing into the gneiss the lead becomes very poor and splits into a number of branches, and there is no mineralization.

The conditions in the important Frostberg and Mendota lodes, where the mineralization is cut off by the porphyry dike, suggests that the porphyry has opposed a barrier to solutions and limited their mineralizing action to the west or underside of the dike. In the two tunnels described in the preceding paragraph the veins are not so strong as the Frostberg and Mendota. The porphyry is fairly hard and the lode fracture has extended through it to the other side.

In the first mentioned of these two tunnel drifts the granite on the northeast side of the porphyry is a more rigid rock than the porphyry, and better fitted for the formation of lode fractures, so that the vein is stronger in it than in the porphyry. In the other tunnel, however, the porphyry is a more rigid rock than the soft gneiss which adjoins it on the northeast; therefore the vein, while well defined in the porphyry, loses itself in the gneiss. In these two tunnels there was no opportunity for studying the relative strength of the lode on the two sides of the porphyry.

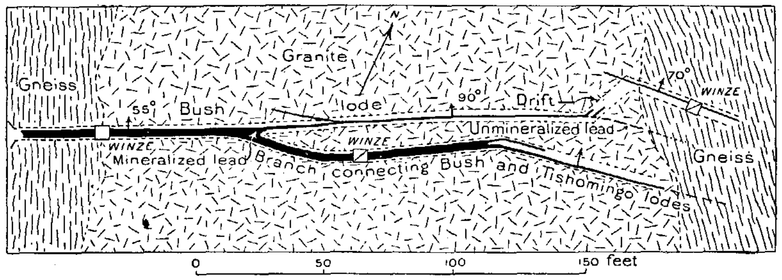


FIG. 82.—Plan of tunnel on branches of Mendota vein, showing forking and ore deposition on the south branch and along the united vein at the intersection with the north branch; also the imbrication or overlapping of the vein fractures of the north branch.

On the northwestern extension of the Maine lode and the northeastern extension of the Mammoth and Terrible lodes, where these lodes break into a number of branches, two porphyry dikes from 4 to 10 feet in thickness, striking east and west and dipping from 35° to 65° N., have governed the course of two of these branches and made the branches conform to themselves in strike and dip.

In a tunnel drift on the northwestern extension of the Maine, starting about 10 feet above the Seven-Thirty road on the southeast side of Sherman Mountain, there is exposed a lode having a west-northwest strike and a dip of 45° N., which for a distance of 150 feet cuts lengthwise through a porphyry dike 6 or 8 feet thick and passes diagonally out of this porphyry into gneiss at each end. Where the lode has porphyry for both walls it is very strong and has been stoped continuously, the width of the mineralization being from 1 to several feet (fig. 80). In the gneiss at both ends of the stoped region the lead is small and the mineralization is much less, and there has been no stoping. In this locality the porphyry is hard and has fissured better than the gneiss, so that the ore bodies have had better channels and better opportunities to form within the porphyry walls. The same vein is shown in another tunnel drift at an elevation 100 feet greater. Here the lode still runs along the porphyry dike, for the most part entirely in the dike, though locally on one wall or the other. The mineralization has taken place in various parallel or overlapping slips throughout the dike. This occurrence of ore is similar to that in the porphyry dike along the Bismarck-Pelican lode. As the dike represents a zone of relative weakness in the rock mass, the formation of later fissures has been induced along it. This dike is the northern of the two parallel east-west dikes in this locality.

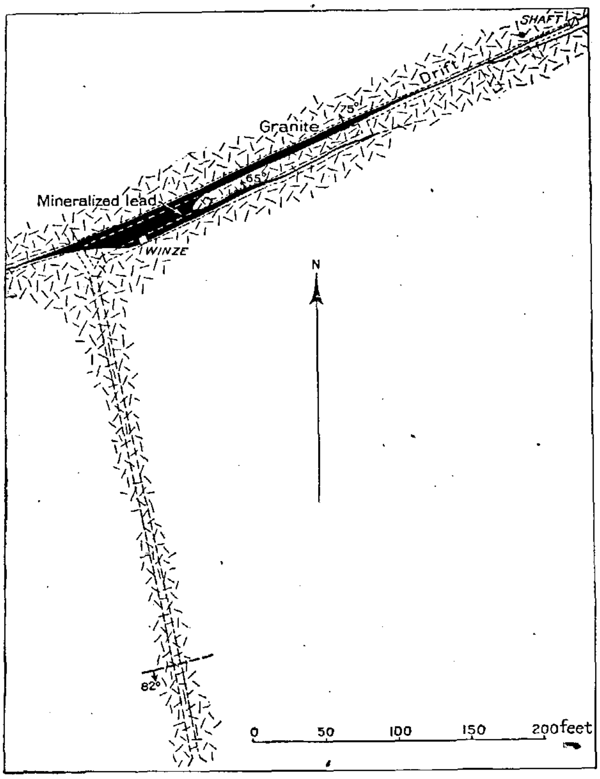


FIG. 83.—Plan of a portion of No. 4 Dunderberg tunnel level on Terrible lode, showing the effect of parallel fractures, which finally join, within the main fracture zone. This junction produces enlargement of the united fracture and increases the strength of the vein channel. Mingling of solutions has also evidently taken place (just as it does at the intersection of fractures having different strikes) and resulted in the formation of an ore shoot.

The southern of the two dikes is exposed in the lower tunnel of the Maine, starting about 150 feet below the Seven-Thirty road, and also in another tunnel on the same lode above the Seven-Thirty road. The lower tunnel has a length of about 500 feet; it encounters the dike at a point 150 or 200 feet in and runs along it to the breast. The lode in the main follows the wall of the porphyry, which is highly silicified. The vein is stronger along the porphyry contact than elsewhere.

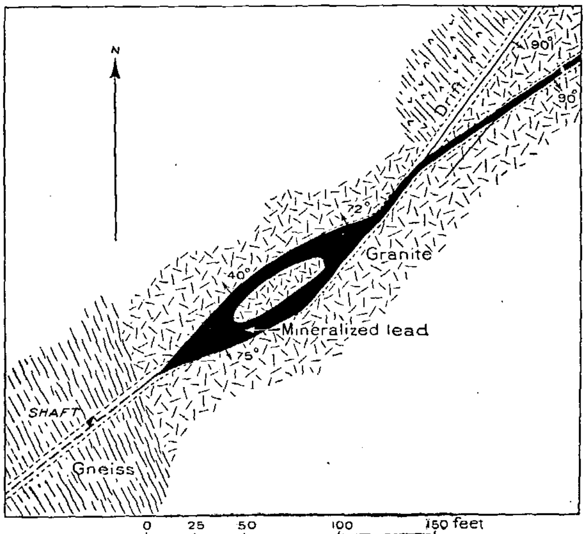


FIG. 84.—Horizontal plan of No. 1 Dunderberg level, showing mineralization on two branching and uniting leads. The process carried further, as seen on another level, makes a solid ore lens along the lead.

LOCATION OF ORE BODIES.

In the lodes of this group the junction of branches has been a very favorable place for ore deposition (fig. 82). In the Silver Ore tunnel on the drift on the Fenton lode east of the tunnel an ore body was noted at the junction of several leads which, after running nearly parallel for some distance, came together. Similar conditions are shown on the Dunderberg No. 4 level (fig. 83). The effect of the junction of leads in producing an ore body is well shown in the workings of the Brown mine (fig. 81), and also in the Dunderberg. On the B level of the latter mine a large ore body is located at the branching off of the Frostberg lode. The splitting and reuniting of a lode inclosing a horse of country rock appears to have in many places a similar influence. At both junctions there is enrichment, and locally the mineralization may be so great that the entire horse of country rock may be changed to ore, forming a lens-shaped shoot on the lode. The different stages in the production of such a lens-shaped shoot are shown in the Dunderberg workings (fig. 84).

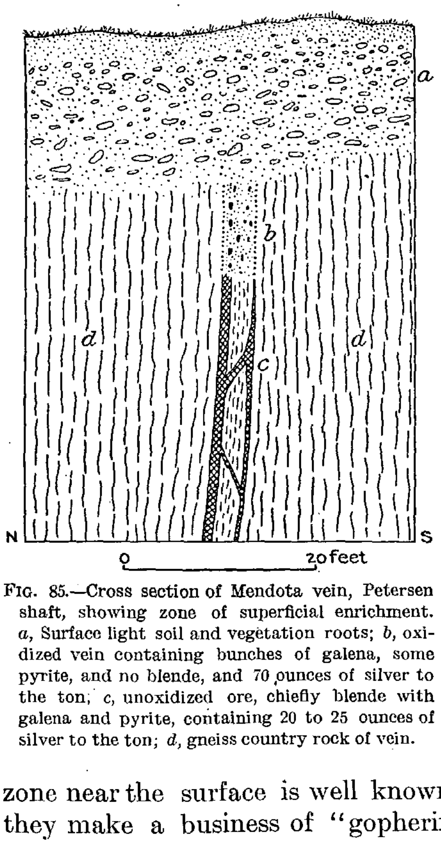


FIG. 85.—Cross section of Mendota vein, Petersen shaft, showing zone of superficial enrichment. *a*, Surface light soil and vegetation roots; *b*, oxidized vein containing bunches of galena, some pyrite, and no blende, and 70 ounces of silver to the ton; *c*, unoxidized ore, chiefly blende with galena and pyrite, containing 20 to 25 ounces of silver to the ton; *d*, gneiss country rock of vein.

INFLUENCE OF DEPTH ON VEINS.

In this group of veins the formation of soft secondary sulphides (locally called sulphurets) has taken place down to a limited depth in the same way that it has in the Bismarck group. The Mendota vein at the Petersen shaft (fig. 85) may serve for a general example for all the lodes of this group. At this shaft the roots of vegetation, slide rock, etc., cover the vein for a depth of 15 feet. Immediately below is an enriched zone 5 to 10 feet thick, consisting of oxidized clayey material containing bunches or nuggets of secondary galena and some pyrite, but no blende. These ores are said to carry 50 per cent of lead, \$3 in gold, and 70 ounces in silver. Below this altered zone, with almost a sharp line between the two, are ores consisting of coarse blende with some galena, pyrite, and chalcopyrite. These ores are of low grade in respect to their silver content, the maximum being reported as about 20 ounces. The existence of this enriched zone near the surface is well known to some of the miners who work on a small scale, and they make a business of "gophering" out the enriched zone beneath the grass roots near the outcrops of the various lodes. The enriched ore is said to extend as much as 150 feet down in some places, and to have run on the Mendota as high as 200 ounces in silver.

The Mendota vein extends downward from a point immediately beneath the enriched zone, or from a point about 30 feet below the surface, to the lowest depths examined, about 800 feet below the surface. From top to bottom this vein is composed chiefly of blende, with galena, pyrite, and a little chalcopyrite. The silver content as a rule does not run over 25 or 30 ounces; nevertheless, various reports, including those of miners familiar with the mine, indicate that somewhat better ore was obtained from the upper than from the lower portions. It is reported that rich ore, containing a little polybasite and ruby silver, was occasionally found near the surface. It is also reported by the miners that as the depth increases there is less lead and more zinc in the ore. In general, also, it is said that the amount of silver decreases in depth. If this is true the rich ores have been locally concentrated, for it is certain that some of the uppermost workings of the Mendota contain heavy blende ores of as low grade as any found in the lower workings.

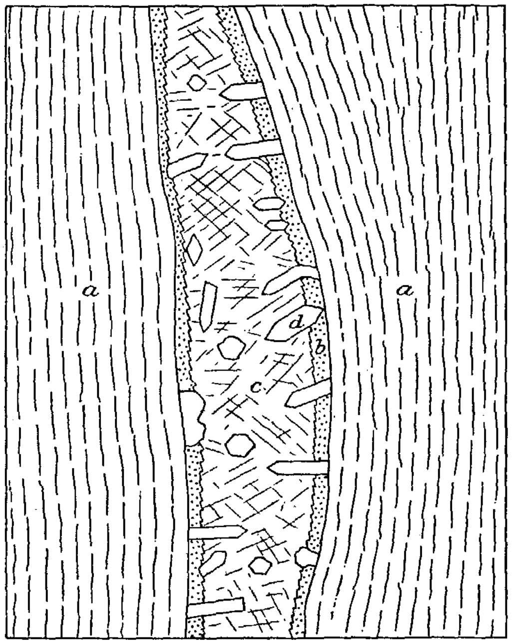


FIG. 86.—Sketch of portion of veinlet near Mendota vein, Mendota mine, second level below Victoria tunnel level. Shows paragenesis of siderite, calcite, and quartz in a filled fissure. *a*, Gneiss wall rock; *b*, dark-brown siderite, comb structure; *c*, white calcite, slightly ferriferous; *d*, crystals of quartz. Natural size.

The workings on the group of branching veins at the junction of the Maine, Mammoth, and Dunderberg lodes above the Seven-Thirty road show a larger amount of pyrite associated with the blende than is the case in lodes encountered farther down the hill or cut at greater depth, though otherwise the composition of the veins is similar. The fact that the abundance of pyrite was also found to be characteristic of the superficial portions of the Bismarck, Wisconsin, and Pay Rock lodes suggests that the pyrite is directly dependent on proximity to the surface. The abundance of pyrite can not be regarded as characterizing a zone having no relation to the surface, for in the Maine veins these ores are at an elevation 1,000 feet less than that of the similar ores of the Bismarck. The effect of descending waters therefore seems to be the probable explanation. The collection of many specimens from the region of the branching veins at the junction of the main Dunderberg and Mammoth zones shows that the pyrite is typically later than the blende, cementing it where it has been crushed and also succeeding the blende as a regular subsequent crust in cavities.

This same relation has been noted in manyother portions of this group of lodes. Specimens from the Dunderberg D level show repeated brecciation and recementation by sulphides in which the pyrite is subsequent to the galena, the siderite is subsequent to the pyrite, and jaspery silica is the latest deposition. Of these minerals the jaspery silica has everywhere been noted as the last deposit in the veins, being probably due to descending waters. It has been concluded that in the Bismarck, Pelican, Corry City, and Pay Rock group of veins the siderite also has an atmospheric origin, and microscopic study of the altered granites indicates that the iron carbonate originates in part by the alteration of the iron in the biotite by carbonated surface waters. Much of the pyrite which is closely associated with the siderite and in many places contemporaneous with it must be considered to have a similar origin. A specimen from the Mendota lode at the junction of the Tishomingo at the surface shows a heavy pyritic ore. This specimen shows the rending of earlier crystallized galena and cementation by pyrite. There is no blende. A specimen from the Mendota, from the second level below the Victoria tunnel level, at a depth of 650 feet below the surface, shows also repeated opening and recementation by sulphides. In this specimen the galena is subsequent to blende, which was the first metallic mineral formed in the vein, and pyrite is subsequent to galena. Specimens from the East Dunderberg tunnel indicate the same rending and recementation. Here again pyrite is later than galena and siderite later than pyrite.

A barren veinlet 1 inch thick, on the second level of the Mendota below the tunnel level (fig. 86), shows the following order of crystallization: (1) Siderite, (2) calcite. Quartz is contemporaneous with both carbonates, a single quartz crystal reaching through both layers.

It seems certain that a great deal of high-grade ore was taken from the upper workings of the Terrible mine, and the reports of polybasite and ruby silver in this ore suggest an enrichment by descending waters. The lower levels of this mine were under water at the time of examination and conditions were not favorable for comparing them with the upper workings.[a]

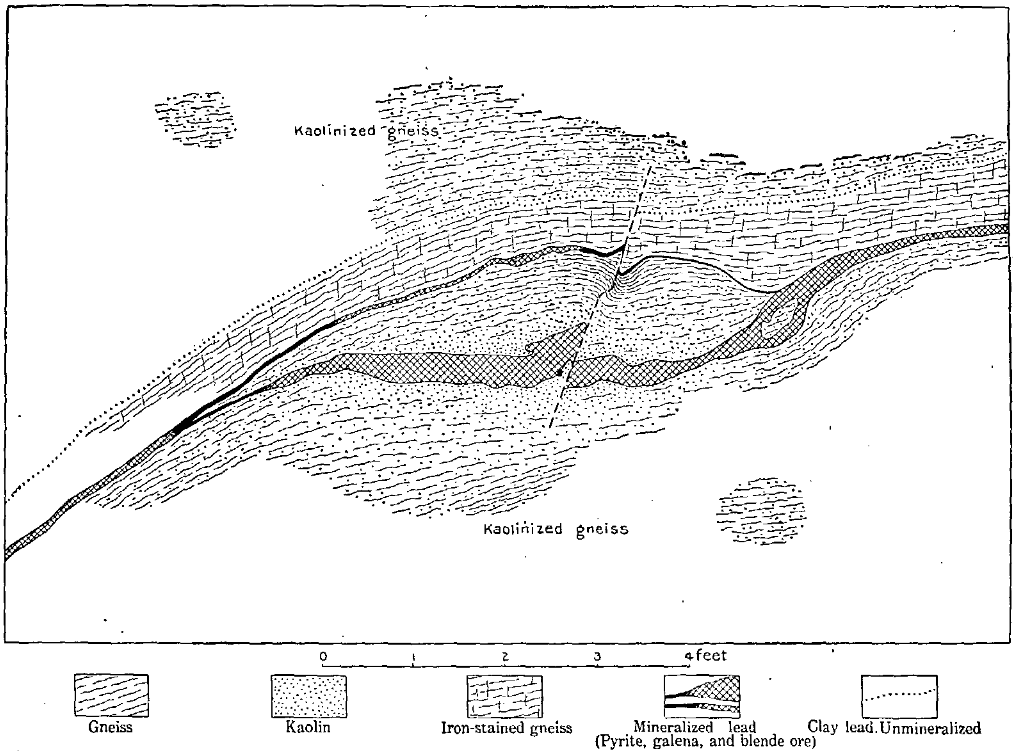


FIG. 87.—Sketch showing postmineral fault affecting upper Frostberg vein.

Some of the longer tunnels afford the best opportunities for comparing the nature of the veins near the surface and at considerable depths. The Burleigh and Mendota tunnels show the Frostberg vein at a depth of 1,250 feet. In the Burleigh tunnel there is ore along the vein, but it is not of good quality. The vein here consists of quartz and ore in places over 1 foot wide, and the lead is large and strongly mineralized. In the Mendota tunnel at the same depth there was some good galena ore containing 50 to 55 per cent of lead and from 50 to 60 ounces of silver. The ore consisted in places of 1 to 1½ feet of solid sulphides. The character of this vein seems to compare not unfavorably with that shown where the vein is drifted on in the Frostberg tunnel and with its outcrop at the surface.

[a] Mr. Waldemar Lindgren visited the Terrible mine in 1906, after it had been pumped out, and communicated his observations to the writer. He found the vein to be fairly strong and well defined to the lowest or fourteenth level, which is 500 feet below the main (Union) tunnel level. The ore at this level was mostly blende, with a good deal of galena. A specimen sent by Mr. Lindgren shows as the oldest minerals blende, galena, and a little chalcopyrite. Later than these is a small vein of dense brownish carbonates that has formed along a fissure splitting and bisecting the galena and contains a little pyrite and considerable tetrahedrite, which ramifies out from the vein, cementing the broken fragments of galena. A similar veinlet, cutting the galena and blende, consists of pyrite, slightly cupriferous, and this is also associated with a little tetrahedrite. On fracture surfaces, cutting all the foregoing, is a coating of chalcopyrite, which is the last mineral deposited. This is similar to the greenish pyrite crust noted as one of the most recently formed minerals in the Colorado Central mine. Mr. Lindgren observes that rich silver sulphides apparently do not occur below the tunnel level. The ore described is about 850 feet vertically below the surface.—J. E. S.

The Mammoth vein is drifted on at a depth of about 1,250 feet in the Burleigh tunnel, where it is called the Phillips. At one place in this tunnel the vein shows two parallel ore bodies, each consisting of a foot of solid ore. The vein here is of low grade, containing much blende, some galena, and a good deal of iron pyrite. Immediately above this level, however, and clear to the surface, the Mammoth has produced very little ore.

It therefore appears that as a rule lodes of this group, to leave out of consideration the evident effects of enrichment close to the surface, have shown themselves fairly constant in character to a depth at least as great as 1,250 feet. They probably extend downward much farther.

POSTMINERAL FAULTING.

Faulting subsequent to the formation of the viens has not been important. Most of the movements have probably been parallel to the earlier movements and so parallel to the lodes, resulting in the repeated reopenings in the veins and recementations by new vein material which have been described. There is a slight fault transverse to the Mendota lode on the first level below the Victoria tunnel level. These small postmineral faults show nearly horizontal striæ, indicating that the postmineral faulting was a renewal of the same stress as that which produced the lode channels. On the lower Maine tunnel near the Pelican tunnel there is a postmineral fault of considerable importance (fig. 88). Here the Maine lode is offset horizontally about 25 feet by an east-northeast fault. This fault shows as a strong gouge zone containing fragments of ore and accompanied by strong striæ dipping 2° E. A very small postmineral fault in the Frostberg tunnel is shown in fig. 87.

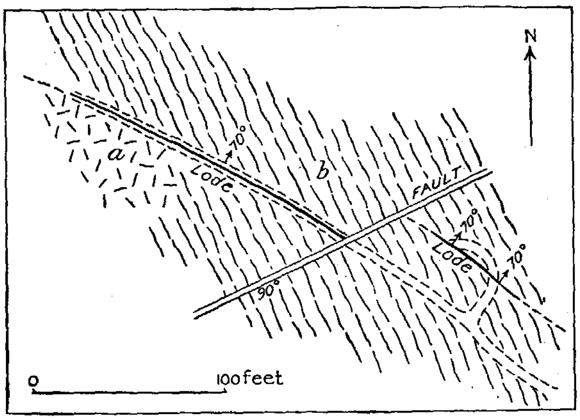


FIG. 88.—Sketch of lower tunnel on Maine lode (near Pelican tunnel), showing Maine lode offset by a postmineral fault. This fault is perpendicular, but with a horizontal movement. The wall rocks are gneiss (*b*), with some granite (*a*).

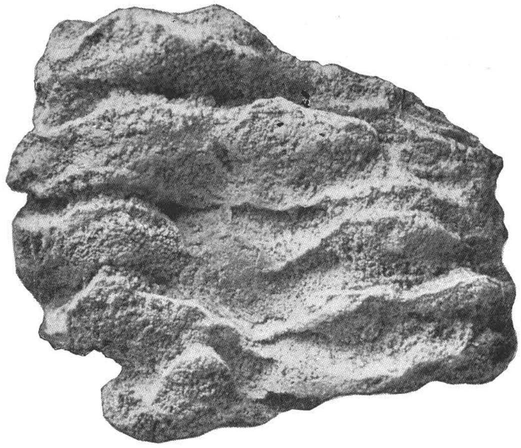
Those postmineral movements which were parallel to the premineral faulting appear also to have taken place in the same general horizontal or nearly horizontal direction. In the upper Mendota strong postmineral striæ dipping 30° E. were noted along the lode.

PRESENT EFFECT OF SURFACE WATERS.

GENERAL DESCRIPTION.

Ordinary surface waters descending through the rocks at the present day are accomplishing an immense amount of alteration in the way of abstraction and deposition of material. The effects of this work are visible in underground tunnels.

The maximum alteration takes place along watercourses that follow down along fracture zones, and is not directly dependent on distance from the surface. For example, in the Silver Ore tunnel, which is entirely in granite, a specimen taken within 40 or 50 feet of the mouth and less than that distance vertically below the surface is an unusually fresh and unaltered type of rock, more so than any other specimen collected in the underground workings; whereas near the end of this same tunnel, at a vertical depth of 800 or 900 feet, the granite is decomposed and disintegrated along a zone where abundant water seeps through the rocks and accumulates in the bottom of the drift. The fresh granite first mentioned contains quartz, muscovite, magnetite, fresh biotite, and probably original pyrite, one large crystal of which is inclosed in fresh feldspar. Of the feldspars, microcline and orthoclase are entirely fresh, but another feldspar that is finely striated and is probably oligoclase is slightly altered to sericite. At the end of the tunnel the water which seeps through the decomposed granite



A. SPECIMEN SHOWING STALACTITIC CRUST OF ZINC CARBONATE CONTAINING SOME BASIC COPPER SULPHATE WHICH HAS FORMED ON THE WALLS OF A DRIFT (VICTORIA LEVEL) ON THE MENDOTA VEIN WITHIN TWENTY YEARS.

Enlarged one-eighth.

B. SPECIMEN FROM MENDOTA VEIN, VICTORIA TUNNEL LEVEL.

a, Wall of vein (granite); *b*, comb quartz, first deposit in vein; *c*, finely ground granite (cemented hard by quartz) inclosing blende fragments; *d*, fragment of coarse blende representing main vein filling subsequent to quartz. Specimen illustrates rending apart of vein subsequent to main mineralization and filling of the new fissure with a paste of ground granite which afterward was cemented by silica. Natural size.

and forms pools in the drift accumulates on its surface a plentiful scum determined by W. F. Hillebrand to be calcite. On the walls of this drift the waters have left soft stalactites, which Doctor Hillebrand determined to be manganese peroxide, with scales of calcite.

The alteration of gneiss by atmospheric waters is shown by a specimen taken in the Baltimore tunnel 600 feet below the surface and 300 feet north of the Queen lode. It is not in the neighborhood of any vein. This is a granitic quartz gneiss showing quartz, fresh biotite, microcline, and orthoclase, and another feldspar which has been entirely altered to fine semispherulitic kaolin with some carbonates. It is probable, to judge from the result of the investigation of the altered feldspars in the granite of the Ashby tunnel, that the altered feldspar in this specimen also was a soda feldspar.

The porphyry encountered near the end of the Baltimore tunnel at a depth of more than 1,100 feet, and nowhere near any known vein, shows a certain amount of alteration throughout, representing the general effect of percolating waters. The principal dike is of rhyolitic porphyry, which under the microscope shows a glassy microgranular groundmass somewhat kaolinized, with the development of a little calcite. Most of the sections show the feldspar mostly altered to kaolin. In one section the feldspars are variously altered—one is partly altered to calcite; a second is entirely altered to sericite; a third is altered to quartz, kaolin, and a little pyrite; and a fourth is entirely altered to kaolin.

A monzonitic porphyry which is cut by alaskitic porphyry near the breast of the tunnel shows under the microscope biotite partly altered to secondary quartz, calcite, and siderite. The feldspar, which is andesine, is largely or entirely altered to abundant carbonates and a fine kaolinic aggregate. This alteration product was separated and analyzed by Doctor Hillebrand. Under the microscope the aggregate was fairly bright colored, the interference colors reaching yellow of the first order, as seen under the high power. The material was semispherulitic in structure. From this material the carbonates were leached out and found to consist of carbonates of iron, calcium, and magnesium, the residual kaolinic matter having the following composition: SiO_2, 50.0; Al_2O_3, 31.3; ignition, 10.3.

The drift on the Frostberg lode in the Burleigh tunnel at 750 feet shows abundant precipitation of yellow iron oxide and also stains of white material that may be zinc carbonate. Yellow clay in the drift contains needle-like crystals which may be sodium sulphate.

In the upper tunnel on the Maine vein, whose mouth is located about 150 feet below the Seven-Thirty road, hairlike transparent crystals were found covering fine débris left in the drift. These were examined by Doctor Sullivan, who found them to be chiefly sodium sulphate, containing also traces of calcium, magnesium, and chloride. The depth of this locality is about 300 feet.

In the same tunnel at one point an incrustation has been formed on the roof by dripping water, and similar material has been formed on the floor, covering the broken stones. Analysis of this material by Doctor Sullivan shows that it contains basic sulphate of copper and calcium carbonate. Carbonate of copper may also be present.

On the Victoria tunnel level of the Mendota vein, at a depth of 450 feet from the surface, stalactites and incrustations of a white material occur on the roof and walls. These were examined by Doctor Sullivan, who found them to consist of carbonate of zinc. Some of the white carbonate was covered by a turquoise-blue incrustation as a last deposition. Doctor Sullivan found that this incrustation is chiefly zinc carbonate containing some copper and sulphate, probably in the form of basic copper sulphate, and traces of calcium and magnesium. This drift has been opened probably about twenty years.

SUMMARY.

The universal effect of the underground waters which traverse the rocks seems therefore to be chiefly decomposition of the biotite and the soda feldspars, by means of which the waters obtain soda, iron, manganese, etc., leaving the feldspars altered to kaolin or to sericite. Precipitations from these waters include the limonite, manganese peroxide, and calcium formed when the air reaches the water in deep tunnels, and result in the formation of sodium sulphate along veins. Along veins also it has been seen that surface waters have a very considerable power in dissolving the sulphides and taking the metals into solution. Some of the coatings of zinc carbonate noted above are as much as half an inch thick (Pl. XLI, *A*), so that the aggregate amount of zinc removed from these lodes by the action of descending water since their formation must have been enormous. The numerous irregular cavities due to dissolution which occur in the veins, and many of which have a great extent, also testify to the mass of material that has been removed by the underground waters recently—since the last cementation.

The zinc stalactites in the tunnel above described were precipitated only because the waters came in contact with the air in the tunnel. Under ordinary conditions in the rocks they would not have been so precipitated. At this depth in the rocks no zinc or copper carbonates have been found, and a question arises as to the ultimate destination of the large amount of zinc that has been leached from the dissolution cavities which were found. It seems very likely that this zinc is normally deposited in the sulphide form, for we frequently find blende as well as other sulphides contemporary with siderite or forming the last deposit on the walls of geodes. Active solution and redeposition of this sort going on since the formation of the lodes must have brought about a very great amount of rearrangement of the metals.

CHAPTER IV.

MINES OF THE GEORGETOWN QUADRANGLE OUTSIDE OF THE SILVER PLUME DISTRICT.

MINES NEAR GEORGETOWN.

MINES OF LEAVENWORTH MOUNTAIN.

COLORADO CENTRAL VEINS.

LOCATION AND DEVELOPMENT.

The Colorado Central mine, which lies in Leavenworth Gulch southwest of Georgetown, is one of the most famous of the region. It was discovered in 1872, and has been worked more or less continuously up to the present day, producing an estimated total of over $8,000,000.[a] The Colorado Central vein or veins strike to the northeast, and are nearly vertical; they have been continuously opened up, both at the surface and underground, for a distance of three-fourths of a mile. The workings reach a depth of about 1,050 feet, the lower levels (beneath the 600-foot or Ocean Wave tunnel level) being worked only by shafts. A long tunnel—the Hall tunnel—was started from Clear Creek below Silver Plume, to pass under Leavenworth Mountain (Pl. XLII) and cut the Colorado Central veins at a depth approximately that of the present lowest workings, but was never carried in that far (fig. 89).

The workings of the Colorado Central mine (Pl. XLIII) show a zone of parallel, branching, or overlapping veins. Whether this zone is a single lode, or whether the individual veins are separate lodes in the legal sense, has been the subject of much litigation in the past.[b]

DESCRIPTION OF VEINS.

The main Colorado Central vein has a northeasterly strike and a nearly vertical dip. In its most productive portion it skirts along the southeast contact of a porphyry dike which has a thickness of 8 to 40 feet. This may be called the Central vein, to choose the most applicable from several names which it has received in the mine.

On some of the mine levels—for example, on the 400-foot or Marshall tunnel level (see Pl. XLIV)—there is an important forking of this vein. As seen on the 400-foot level, the southwesterly trend of the Central vein causes it to diverge gradually from the porphyry dike which it skirts. At a point where by reason of this divergence the porphyry and the vein have become separated by about 40 feet the vein splits, one branch running back diagonally to the porphyry contact, which it continues to skirt, farther southwest, and another keeping on in the same general direction as the main veins, but in gneiss on both sides. The last-named or southeastern branch may be held to represent the main vein, as it continues on the same strike, while the northwestern branch resembles the main vein in that, like it, it skirts the porphyry contact. For purposes of description, however, the separate names currently in use will be adopted, the northwestern branch being called the North vein and the southwestern branch the South vein.

Two hundred feet below, on the 600-foot or Ocean Wave tunnel level, the branching of the Central vein into the North and the South vein is also seen, but it is 300 feet or more farther northeast, showing that the junction pitches northeastward.

[a] Foster, E. Le Neve, Proc. Colorado Sci. Soc., vol. 7, 1902, p. 43.

[b] Foster, E. Le Neve, op. cit.

On the 750-foot level, 150 feet below the level of the Ocean Wave tunnel, the North vein, following the porphyry contact, is shown, and inaccessible workings on the South vein converge toward the North vein to the northeast, as on the Ocean Wave level. The veins here, however, seem to become ill defined, overlapping, and unmineralized before the point of junction is reached. The junction, if present, would be about 500 feet northeast of the corresponding point on the 600-foot level, showing that the northeasterly pitch is much flatter than on the levels above, making a horizontal difference of 500 feet with an increase in depth of 150 feet.

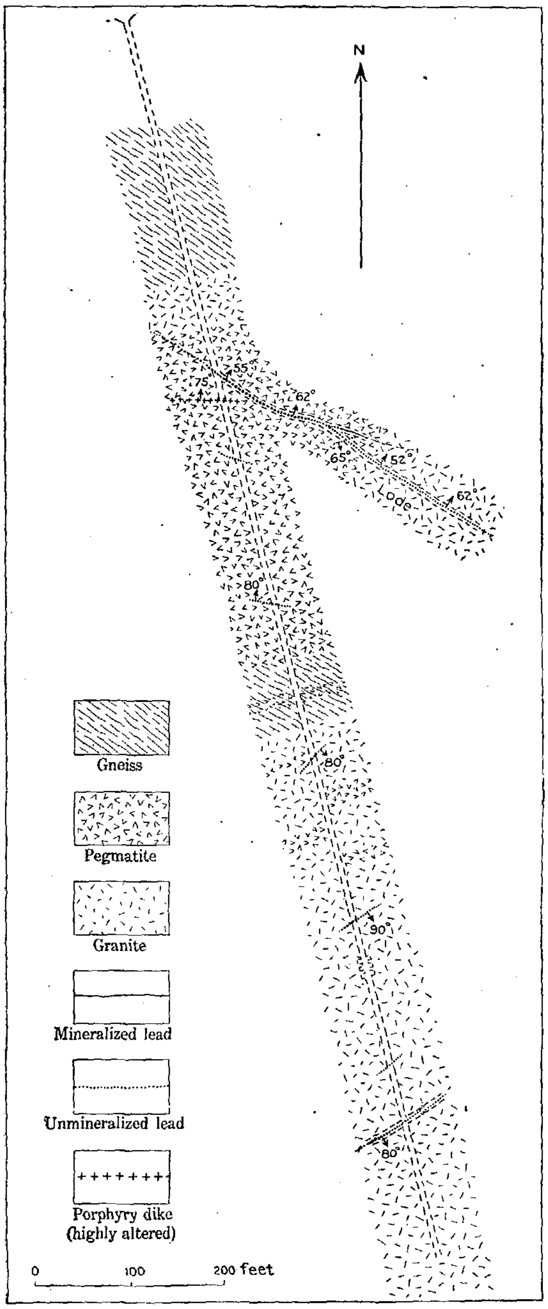
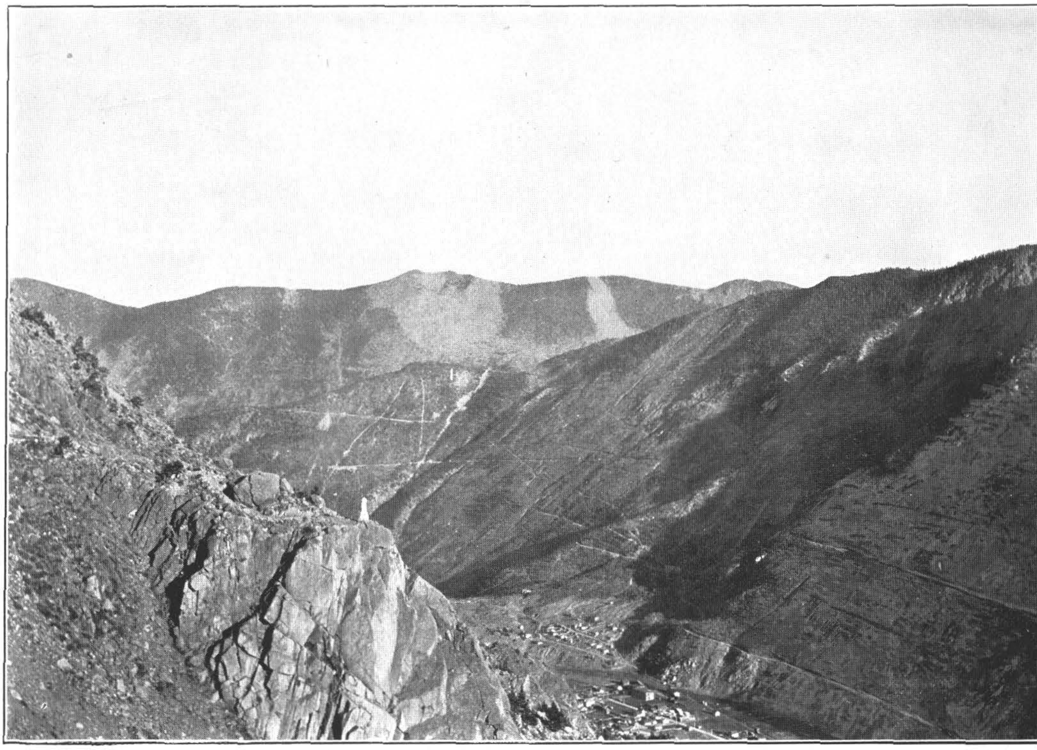


FIG. 89.—Geological plan of Hall tunnel.

On the 850-foot level the North and South veins are well represented, and run parallel to each other and 80 to 100 feet apart, with no tendency to converge. This shows that the junction of the two veins has on this level, owing to the flatness of the pitch (probably still flatter than above shown), passed so far northeast as to be beyond the field of the workings.

On the 400-foot or Marshall tunnel level (practically level No. 3 of the Aliunde workings) the South vein continues southwestward to a point opposite and about 30 feet northwest of the Aliunde shaft (Pl. XLIV). Here the normal nearly vertical dip changes to a northwesterly dip of 64°. Above this point, in the Aliunde workings, the vein does not appear to be present. Its place is taken by weaker veins, striking in general northeast, parallel to the stronger veins described, but dipping more flatly northwest, at angles averaging about 60°. These weaker veins are very apt to be discontinuous, to die out by repeated and irregular branching, and to overlap one another, as seen both in strike and in dip. (See Pl. XLIV.) On the Marshall tunnel and Aliunde No. 3 levels (25 feet apart and represented together on Pl. XLIV) the downward continuation of this zone of imbricating veins is shown not only in the South vein, but in at least two veins lying between the North and the South veins, striking parallel to them and dipping 60° to 70° NW. (fig. 90). Of these two veins the more northwestern (see Pl. XLIV) is a branch of the North vein in the same manner that, on the same level, the South vein is a branch of the Central vein. Coincident with the appearance of these intermediate flatter veins on this level, both North and South veins become weak, and have not been followed far to the southwest.

The imbricating flat veins, intermediate between the North and the South veins, are also seen in the Aliunde No. 4 and Colorado Central 500-foot levels, which are on nearly the same plane. (See Pl. XLIV.) As seen on these levels (the same feature is shown less markedly on the Aliunde Nos. 1 and 2 levels, Pl. XLIV), the flat veins have a tendency to twist around,



A. LEAVENWORTH AND ALPINE MOUNTAINS, FROM DUMP OF VICE-PRESIDENT MINE IN BROWN GULCH.

Town of Silver Plume in foreground. 1, Welch mine.

B. VIEW SHOWING RELATION OF RIDGE SEPARATING CLEAR AND LEAVENWORTH CREEKS TO THE CONTINENTAL DIVIDE, OF WHICH GRAYS AND TORREYS PEAKS FORM A PART.

1, Grays Peak; 2, Torreys Peak; 3, Colorado Central mine; 4, Wide West mine; 5, Georgetown, 6, Hall tunnel; 7, Lebanon tunnel; 8, Silver Plume; 9, Leavenworth Mountain.


OCEAN WAVE TUNNEL
ARGENTINE TUNNEL
EQUATOR TUNNEL
MARSHALL TUNNEL
BONHOLZER
ALBURGER TUNNEL
MAP OF THE
COLORADO CENTRAL, KIRTLEY, AND ARGENTINE MINES
0 100 200 300 400 500 feet
1906

so that the general strike becomes somewhat oblique to the regular trend of the main North and South veins, though the overlapping or imbrication of the separate veins preserves the normal alignment. Similar intermediate veins, many of them pitching more flatly than normal and with a somewhat oblique trend, and typically discontinuous, are found at greater depth between the North and South veins, especially as the junction of these two veins is approached. Examples are shown on the plans of the 600-foot and 750-foot levels. On the 850-foot level, where the North and South veins run parallel, with the junction beyond the field of the workings, these intermediate veins are still represented, as, for example, in the one marked on the plan (Pl. XLIV), which dips 30° NW. in general, though very irregular in detail.

These discontinuous imbricating and branching veins, many of them oblique in strike or dip, or both, to the North and South veins, but lying between them and in places connecting them, have produced considerable ore, and have played a very conspicuous part in the mining litigation.

The New North vein, a separate vein from those already described, skirts the northwest contact of the main porphyry dike. This vein is first shown on the Marshall tunnel level, where it runs parallel to the Central-South vein. Like the Central-South vein, the New North diverges from the porphyry contact, but on the northeast instead of on the southwest, thereby maintaining its parallelism. On diverging, like the Central-South vein, it splits, and has not been followed far northeast, though in the Marshall tunnel crosscut there is a "lead" on the north side of the porphyry dike which may represent the whole or a part of the continuation of the New North vein. On the 750-foot level, however, the New North approaches close to the North vein, with the thinning of the intervening porphyry dike, though no junction has actually been observed, either on this level or the 850-foot and 1,000-foot levels below.

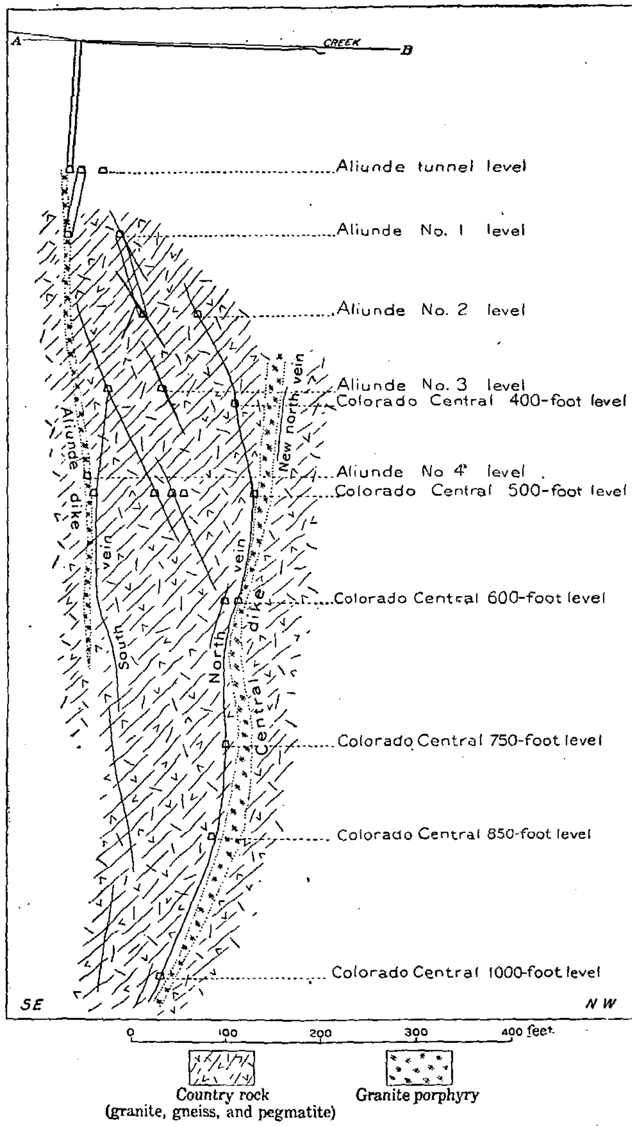


FIG. 90.—Vertical cross section along line $A'-B'$, Pl. XLIII, showing developed portion of Colorado Central veins and their relation to the porphyry dikes.

The above-described veins are the important ones of the Colorado Central group, occupying the principal zone, which, as will be shown later, is a zone of fracture and nearly horizontal premineral faulting. This zone, however, is but the core of a wider zone, where the rocks have been sheeted and subsequently mineralized. Some of the veins thus formed have had a considerable production. The principal is the Kirtley, lying a few hundred feet northwest of the Colorado Central veins; another is the Munsill vein, lying to the southeast.

A marked feature of all these veins is the tendency for an individual vein to discontinue, its place being taken by a parallel vein, offset more or less, and overlapping the first. This characteristic is prominent in the flat intermediate veins of the Aliunde Nos. 1 and 2 levels and the 500-foot level of the Colorado Central. It is also well shown in the North vein on the 750-, 850-, and 1,000-foot levels. The imbrication of the flat veins may be said to be left-handed; that is, on looking northward over a plan of the veins, the veins overlapping to the north are seen to be offset to the west from the veins to the south, in a direction opposite to the movement of the hands of a clock. On the 750-foot level the imbrication of the North vein is left-handed to a point near the field of junction of the North and South veins, where it becomes right-handed, the offset being to the east instead of the west. On the 1,000-foot level also the imbrication is strong and left-handed in the southwestern part of the workings, but it appears to become distinctly right-handed in the northeastern part.

What seems to be an example of this right-handed imbrication in the northwestern part of the productive region, and the best example in the mine, is afforded by the northeastern extension of the North vein, as seen on the plans of the Marshall tunnel and Ocean Wave tunnel workings (400-foot and 600-foot levels). On the 400-foot level the North vein becomes unmineralized before reaching the Marshall tunnel, but there is a fairly strong and nearly parallel vein overlapping it on the southeast—the Equator vein. From this vein a good deal of ore was taken out. On the Ocean Wave tunnel and Equator tunnel workings also (these two have a difference of elevation of 10 feet, and are shown on the same horizontal plan) the North vein becomes barren almost exactly beneath the similar point on the Marshall tunnel level, but has been followed as an unmineralized slip 700 feet farther. In the Equator tunnel what is probably the Equator vein is found, overlapping the North vein on the east and containing a little ore, though it has not been followed far. The Equator vein is in its turn overlapped on the east by the parallel Ocean Wave lode, the total offset between the Ocean Wave and the North vein being about 100 feet. The Ocean Wave vein, continuously mineralized, though the ore is of low grade, has been followed for more than 1,000 feet farther northeast.

RELATION OF ORES TO DEPTH.

The following statement is made by an engineer who had many years' experience with the mine,[a] and with it the more limited observation of the writers agrees:

> Concerning the effect of depth upon the value of the ores, although the mine is worked to a depth of 1,000 feet, no particular difference is to be noted. Rich and poor ore channels are found at all depths. Within 100 feet of the surface some of the richest and some of the poorest were encountered, and the same might be stated of almost any depth. Upon the same horizon were found bodies of ore which were rich in silver and others which were poor in that metal. The poor ores were apparently the same galena and zinc blende which in another place were enriched by the true silver minerals and were therefore rich in silver.

While this is true, there are certain other features worthy of note. The rich and the poor ore both occur practically at the surface. A portion of the vein outcrop examined by the writers was 4 feet wide, and the vein filling consisted chiefly of zinc with some galena. The north half of the vein is reported to have run 500 to 600 ounces of silver, and the south half only 40 ounces, the difference between the two being due to scattered polybasite. Lean blende ores, containing very little silver (8 to 10 ounces), are common in the upper workings of the mines. Yet from all that can be gathered it appears probable that the amount of polybasite (and ruby silver) which makes the rich ore was distinctly greater in the ores nearer the surface than in those more remote. It is true that rich ore has persisted in this mine to a depth unequaled in the Silver Plume mines, but it is to be doubted whether some indications of falling off in depth are not present. It is stated by miners that ruby silver was more abundant in the upper than the lower workings. According to information received, the richest ore shoot in the mine was worked downward more or less continuously from the surface to the 500-foot level. This shoot, between the 400-foot and 500-foot levels, contained the Carnahan stopes, the richest in the mine. It is reported not to have extended below the 500-foot level, though it split into rich spurs which were followed downward.

The accessible portions of the different levels have been mapped, and barren leads distinguished from mineralized portions of the veins. On the 1,000-foot level the principal vein

[a] Foster, E. Le Neve, Proc. Colorado Sci. Soc., vol. 7, 1902, p. 48.

(North vein) is exposed for 1,700 feet, but the proportionate extent of mineralized vein is only 17 per cent of the whole development along this vein, the rest being unmineralized, whereas on the 400-, 600-, 750-, and 850-foot levels, which also have long stretches of development on this vein, the percentage is from 55 to 71 per cent. The suggestion derived from this observation, therefore, is not so much that the ore is passing from high grade to low grade in depth (for high-grade polybasite and ruby-silver ore was found on the 1,000-foot level) as that the entire vein is giving way to an unmineralized fault lead in depth, as has been noted for the Pay Rock and other mines of the Silver Plume and other adjacent areas.

The surface oxidation generally extended only a few feet downward on the vein, the groundwater level lying close to the surface. The oxidized ore resembles a soft iron-stained clay, and was found forming the surface of the veins, or the harder portions occurred as loose bowlders in the overburden. It is reported that this oxidized stuff was exceptionally rich, nearly all running 1,000 to 2,000 ounces of silver. This corresponds with the condition at the Mendota vein, where the oxidized outcrop was especially rich in silver.

No zonal distribution of the galena and blende has been noted in this mine.

NATURE OF WALL ROCKS.

The principal wall rocks of the Colorado Central veins are granite, gneiss, and pegmatite. The gneiss is rather the most abundant, but is characteristically intruded by many seams and dikes of granite and pegmatite, which give it greater rigidity. Solid pegmatite occurs in this mine as a wall rock to a greater extent than in most of the other mines of the region. Porphyry also in many places forms one of the walls of the main lode, but with unimportant exceptions does not form both walls.

PORPHYRY.

There are two parallel dikes of porphyry about 150 to 200 feet apart. The more northwestern of the two appears to be the thicker. This dike shows a decided difference in texture between the center and the edges, the rock at the edges being finer grained. A quick crystallization of the margins by chilling is indicated. In many places the border phase of the dike is glassy, forming the green or red obsidian which always excites the attention of the miner or visitor, and whose origin has been much discussed by them. This obsidian was observed at various levels, including the 400-foot, the 750-foot, and the 1,000-foot, and was seen in places on both contacts of the Central porphyry dike. It does not, however, everywhere form the margin of the porphyry, the principal reason being probably that the porphyry in some places has a normal intrusive contact, where obsidian may or may not form the marginal phase, and in others is bounded by the parallel subsequent faults along which the vein has formed, in which case the present edge of the porphyry is not necessarily the original boundary. Where the porphyry has a natural intrusive contact, as it does in many places, this is readily discernible from the wavy course of the contact and the little tongues of porphyry which run into the gneiss. A very characteristic feature of such intrusive contacts is the beautifully corrugated surface of the porphyry where it abuts against the gneiss. This corrugation conforms with the lamination of the gneiss and has evidently been formed by the molding of the plastic porphyry into the softer and harder gneiss laminæ.

A specimen from the southeastern or Aliunde porphyry dike, obtained on the Aliunde No. 3 level, shows when examined microscopically a semiglassy, semimicrofelsitic groundmass with one small phenocryst of quartz and abundant perfectly fresh small crystals of sanidine; larger and more altered phenocrysts are of original biotite and probable soda-lime feldspar; accessory apatite and zircon are present.

A specimen from the more northwestern or Central dike on the 850-foot level has a groundmass varying from glassy to crystalline, and contains phenocrysts of quartz and sanidine with pseudomorphs of kaolin and calcite after feldspar. A specimen from the same dike, obtained on the 1,000-foot level, has the same characteristics, containing fresh sanidine and quartz phenocrysts in a glassy groundmass. The Colorado Central dikes have been mapped by Ball as granite porphyry.

GRANITE.

The granite is of the same nature and age as the principal intrusive granite in the area of the Silver Plume special map. In texture it ranges from massive to semiporphyritic, and even to the highly porphyritic type known by the miners as "corn rock."

PEGMATITE.

There are very large masses of pure pegmatite in the Colorado Central mine. The largest body exposed is seen in the Ocean Wave tunnel, where it forms the wall rock on both sides of the Ocean Wave lode. Reddish feldspars are abundant.

GNEISS.

The gneiss in this mine is usually black and rather soft, but typically contains many lenses of pegmatite. In many places the pegmatite and gneiss are intimately intermingled.

The relative ages of the different wall rocks are shown in fig. 91.

EXTENT OF PORPHYRY DIKES.

There are two distinct dikes of porphyry associated with the Colorado Central veins and shown in the mine workings. They are parallel and are 100 to 150 feet apart. The more northwestern of the two is that along which the Central and North veins run, and it is the better developed underground. This may be called the Central dike. It is not shown in the accessible mine workings above the Marshall tunnel or 400-foot level. On this level it is shown in the mine workings for a distance of 2,000 feet along the strike, and is still strong at both ends of the development work, its thickness at the northeast end in the Marshall tunnel being 40 feet and at the southwest end 25 feet, while its minimum thickness appears to be about 20 feet.

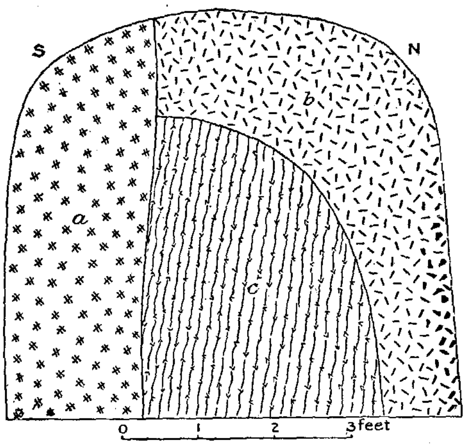


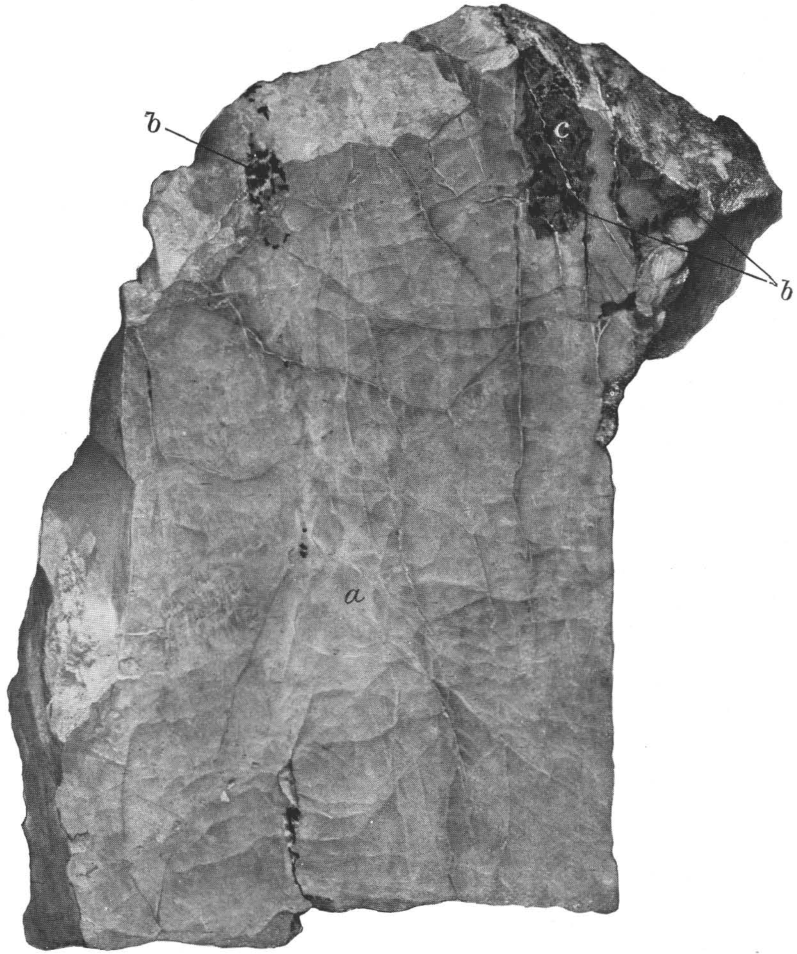
FIG. 91.—Vertical section of face of drift, 350-foot level, Colorado Central mine, showing relative ages of rocks. Black gneiss with injected pegmatite seams (c) has been intruded by granite (b), and later both have been cut by porphyry (a).

On the 500-foot level the workings are mostly caved and the thickness and strike extent of the porphyry are not shown. On the 600-foot or Ocean Wave tunnel level the Central dike has an exposed strike extent of about 1,400 feet. Its thickness at different points is from 4 to 12 feet. Beyond the porphyry, both on the northeast and the southwest, the North vein runs for long distances in the gneiss and granite. The Equator tunnel, which crosscuts the whole formation, shows that the Central dike is not present, though, as above noted, it is present in the Marshall tunnel crosscut, 200 feet above and a little more than 200 feet to the southwest. This indicates that the Central dike pinches out on the northeast. On the 750-foot level the Central dike has a developed strike extent of about 1,200 feet. The probable wedging out of the dike on the northeast is shown on the plan (Pl. XLIV), about 250 feet southwest of the point where it probably wedges out on the Ocean Wave level, 150 feet above. The thickness of the dike on this level is from 8 to 15 feet. On the 850-foot level, again, where the dike has a strike extent of 950 feet, it probably pinches out on the northeast at a point about 70 feet west of the corresponding point on the 750-foot level above. The thickness of the dike on this level ranges from 10 to 25 feet. The 1,000-foot level has a strike extent on this dike of 1,050 feet, and shows a probable wedging out on the northeast almost directly below the corresponding locality on the 850-foot level 200 feet above.

These observations indicate that the Central dike wedges out to the northeast, the line of disappearance pitching southwestward at a flat angle on the levels first described, but becoming vertical at greater depth. On all these levels the vein continues northeastward past the porphyry, in gneiss, granite, and pegmatite wall rocks.

A. SPECIMEN FROM COLORADO CENTRAL MINE, SHOWING PRE-CAMBRIAN PEGMATITIC QUARTZ AND PEGMATITE, CRUSHED AND CEMENTED BY TERTIARY GREENISH JASPERY QUARTZ CONTAINING METALLIC SULPHIDES.

a, Pegmatitic quartz containing a little feldspar; *b*, metallic sulphides; *c*, jaspery quartz, true gangue of the metallic sulphides; *d*, pegmatitic feldspar. Natural size.



B. POLISHED SPECIMEN FROM COLORADO CENTRAL MINE, SHOWING QUARTZ OF PRE-CAMBRIAN PEGMATITIC QUARTZ VEIN WHICH HAS BEEN FRACTURED AND PARTLY INVADED BY TERTIARY POLYBASITE, GALENA, AND BLENDE.

This vein has what may be termed a false gangue. *a*, Pre-Cambrian pegmatitic quartz, false gangue; *b*, Tertiary metallic sulphides; *c*, Tertiary dark-gray jaspery quartz, true gangue. Natural size.

On all the levels above mentioned the Central dike disappears from the more southwestern workings also, but crosscuts here and there indicate that the vein has simply diverged from the dike, and do not show that the dike itself has pinched out.

The more southeastern of the two dikes may be called the Aliunde dike. It is seen in the first, second, third, and fourth levels of the Aliunde and in the Ocean Wave level of the Colorado Central. On the last-named level its thickness is shown to be only a few feet, while higher up no point was seen where its thickness was displayed. This dike was not seen by the writers below the 600-foot level.

EFFECT OF WALL ROCKS ON VEINS.

In the Colorado Central mine the wall rock which is most favorable for strong and persistent veins is granite or pegmatite. Hard gray granitic gneiss mixed with pegmatite and granite is abundant as a wall rock in the central portion of the mine, and in this rock the veins are strong and productive. In the western part of the mine workings soft black gneiss is prevalent with only small seams of pegmatite. This rock is dry, containing very little or no seepage water, and the veins in it are characteristically weak and unmineralized.

In general the veins cut diagonally across the laminæ of the gneiss, as seen on the plans of the separate levels. The strike of the gneiss is fairly regular, being to the north or the west of north; the veins strike northeast, so that as a rule they quarter across the gneiss at an angle of 45° or more, up to 90°, as seen at a few places in the Ocean Wave tunnel. The relative strike of the gneiss and of the veins is plainly accidental, as the veins depend on strong northeasterly differential movements regardless of the rocks traversed; but in detail the strike of the gneiss is apt to influence the direction and strength of the veins. Where the veins become parallel to the laminæ of the gneiss they are usually weak. In soft gneiss the vein is apt to resolve itself into overlapping parallel lodes instead of continuing as a single strong lode. This is due to the planes of easy fissility afforded by the gneiss, which constantly tend to deflect the vein slip. This is especially well shown where the strike of the gneiss is not greatly different from that of the vein, as in the southwestern part of the 1,000-foot level workings. Here the vein fault is repeatedly deflected in the direction of the gneissic structure, but none of these deflected slips persists far out of the line of general stress shown by the strong unbroken fault vein, its position being taken by a parallel overlapping vein, and the different overlapping veins being stationed at intervals along a general zone parallel to that of the main vein.

Where the vein cuts pegmatitic quartz veins which are phases of the pegmatite and are of pre-Cambrian age this older quartz is crushed and brecciated, and fractures and fissures in it are cemented with crystalline quartz belonging to the vein-forming period and with the metallic sulphides. The typical quartz of the veins is dense, greenish, and impure, and is due chiefly to replacement, whereas the pegmatitic quartz is white and crystalline. Yet this pegmatitic quartz is similar in appearance to the comb quartz of the veins, which characteristically lines open cavities. So where the pegmatitic quartz has been crushed and recemented by vein material, the difference between it and the greenish replacement quartz of a vein is easy to discern, but not that between the pegmatitic quartz and the comb quartz of the vein. Therefore it happens that many specimens of the pegmatitic quartz fractured and cemented with comb quartz and metallic sulphides appear to be really an integral part of the gangue; moreover, where pegmatite has been thus crushed and recemented the resemblance to an original mineral-bearing pegmatite is very close (Pl. XLV).

As in the Bismarck-Pelican lode, the most productive portions of the Colorado veins are near the Central porphyry dike. The only discernible reason is a physical one and is the same as that arrived at in the case of the Bismarck, namely, that the contact of the porphyry afforded a preexisting plane of weakness which governed the subsequent stress and made a single strong and persistent circulation channel; whereas elsewhere, where there was no preexisting governing structure, the fault channel was more apt to branch and so to weaken.

ALTERATION OF WALL ROCK.

ALTERATION OF PORPHYRY.

A specimen of porphyry from the Central dike, Marshall tunnel crosscut, appears hard and fresh in the hand specimen, but under the microscope proves to be altered. It has an altered microfelsitic groundmass. Phenocrysts are numerous and of fair size. Rather large and abundant feldspars are entirely altered to sericite, with some calcite. The plentiful biotite is entirely altered to muscovite, with the separation of siderite. Unaltered minerals comprise rare and small quartz phenocrysts, with accessory apatite and zircon crystals. Small areas of what appear to be specular iron and siderite occur throughout the slide. In many of these areas the siderite is rimmed by the iron. These minerals appear to be pseudomorphous after some original mineral. A thin section of a specimen from the Central dike, obtained on the 850-foot level, shows some fresh sanidine, associated with larger crystals of another feldspar that is completely and uniformly altered to kaolin, with a little calcite.

On the 600-foot level the porphyry is usually much silicified near the vein.

A specimen from the South or Aliunde dike, forming the wall of the South vein on the 600-foot level, shows under the microscope the microgranular groundmass altered to sericite, calcite, quartz, etc. Biotite phenocrysts are entirely altered as above stated. Another specimen shows the feldspar phenocrysts entirely altered to aggregates of sericite, calcite, and kaolinic material. This specimen contains a veinlet of kaolin, apparently deposited in a crack. Specimens from this dike show scattered quartz phenocrysts and the same small areas of probable specular iron and siderite that are characteristic of the other dike.

ALTERATION OF GRANITE.

A specimen of granite which is practically a part of the North vein on the 400-foot level shows under the microscope fresh microcline and orthoclase. Other feldspars are entirely altered to what seems to be a fine sericitic aggregate. This altered feldspar shows fine twinning striæ, but was indeterminable. The biotite is entirely bleached and altered to muscovite, with the development of siderite, much of which is oxidized to reddish ferritic stuff. A few small solid areas are made up of siderite, some of them with a smaller amount of inclosed pyrite. These minerals are perhaps pseudomorphs after original magnetite. Other specimens from the same vein on the same level show broken grains of perfectly fresh microcline, and fragments of granitic muscovite and of zircon with sericitic areas which evidently represent decomposed fragments of feldspar other than microcline, all cemented by vein quartz. In one specimen calcite seams traverse fresh microcline and are probably derived from the alteration of the adjacent soda-lime feldspar. The granitic quartz and muscovite of the granites are unattacked. The alteration products of the feldspar include, besides sericite, abundant carbonates. The fresh microcline wherever studied incloses small idiomorphic crystals of the completely altered feldspar.

ALTERATION OF PEGMATITE.

A specimen of pegmatite from the vein shows under the microscope fresh quartz and microcline crushed to a mosaic and shredded bits of muscovite. Areas of sericite represent original feldspar. The most crushed zone in the section consists of a fine aggregate containing in part fine secondary quartz, abundant siderite or ankerite, and some probable galena contemporary with the carbonate. Even in this zone there are fragments of fresh microcline.

The microcline in these rocks appears never to have been decomposed, though in cases of extreme encroachment by mineralization it seems to be replaced. In one specimen studied microscopically microcline was seen in process of replacement by polybasite with a little pyrite, without decomposition of the feldspar.

COMPOSITION OF VEIN.

The principal metallic minerals are galena and blende, with iron pyrite in small quantities. The blende of this mine has usually a light-yellow color. The galena contains a relatively small amount of silver. The silver values come from richer disseminated argentiferous minerals, of which E. Le Neve Foster[a] enumerates argentite, pyrargyrite, proustite, tetrahedrite, stephanite, and polybasite. The most abundant of these noted by the writers is polybasite, which occurs massive and in cyrstals on the faces of vugs. Next, but much less abundant, appears to be ruby silver (chiefly pyrargyrite). A specimen of massive rich ore examined by W. F. Hillebrand for the writers proved to be mercurial tetrahedrite, and tetrahedrite was determined in two other specimens by W. T. Schaller. The polybasite, as well as the tetrahedrite, is locally known as "gray copper." Native silver is occasionally observed. Only the richer ores, characterized by these silver-bearing minerals, have been worked. According to Foster[b] the average silver content of the ore produced averaged 200 ounces to the ton for sixteen years. Very little gold is present. During the period mentioned above only once was there enough gold to be paid for by the smelter, and that was in a lot of concentrates containing considerable pyrites, which yielded about 0.25 ounce of gold to the ton.[c] An experienced miner states that the only pocket of ore in the mine which carried gold in any amount was the MacCarey stope, on the 850-foot level, much of which carried 0.1 ounce of gold to the ton.

Hematite (specularite)[d] in aggregates of small crystals was found by the writers in the lowest part of the mine (1,050-foot level). This is barren of values.

Siderite or ankerite is rather common, especially in later veinlets. It is probable that various carbonate mixtures are present in the mine. According to J. S. Randall, of Georgetown, W. O. Crosby determined the presence of small quantities of mesitite, an iron-magnesia carbonate, in the Colorado Central.

The principal nonmetallic gangue mineral is quartz, which is locally abundant. There are two distinct varieties—the coarse crystalline, much of it with comb structure, and the fine chalcedonic, much of which under the microscope has a semispherulitic structure. Calcite occurs in and near the veins, very commonly in barren veinlets and in crystals lining the walls of small empty fissures and vugs.

Where the vein is not mineralized the clay "lead" as a rule contains neither metallic sulphides nor gangue minerals.

DEVELOPMENT AND CEMENTATION OF VEIN CHANNELS.

The openings which gave access to the mineralizing waters were formed by sheeting or faulting of the rock along a northeastward-trending, nearly vertical zone. This zone was several hundred feet wide—say, roughly, a thousand feet—and several thousand feet long. The usually parallel fractures and slips which lie in it had variable strength and persistency, and along them veins of strength and size corresponding with the size of the channels were subsequently formed; but the strongest of these channels was probably that now occupied by the main Colorado Central vein, which lies near the center of the zone. This vein follows a strong fault plane or set of fault planes. The principal fault lies along the southeast contact of a northwestward-striking porphyry dike—the Central dike of the above descriptions. The relation is similar to that of the Bismarck-Pelican fault vein to the porphyry dike which it follows, but differs in that the porphyry of the latter dike is soft and decomposed and the slips have been mainly in it or along its contact, whereas in the Colorado Central the dike, though shown by the microscope to be in the main highly decomposed, is usually hard. The contact of this hard porphyry with the gneiss, granite, or pegmatite wall rock presented a plane of weakness which developed into a fault when stress was applied at some time distinctly subsequent to the consolidation of the dike, and where the fault slips do not follow

[a] Proc. Colorado Sci. Soc., vol. 7, 1902, p. 48.

[b] Idem.

[c] Foster, E. Le Neve, op. cit., p. 49.

[d] Determined by W. T. Schaller, of the United States Geological Survey.

the contact they pass away from it into the gneiss or granite, and not into the hard porphyry. Exceptions to this rule are noted at a few places where fault slips and ore pass into porphyry. At one locality on the Marshall tunnel level the ore of the North vein occurs on both sides of the obsidian which forms the quickly chilled border phase of the dike, and a similar occurrence can be seen on the 750-foot and 1,000-foot levels. Moreover, the vein fault, having naturally a more persistently unwavering course than the dike contact, in places cuts through protuberant curves of the porphyry (figs. 92, 93).

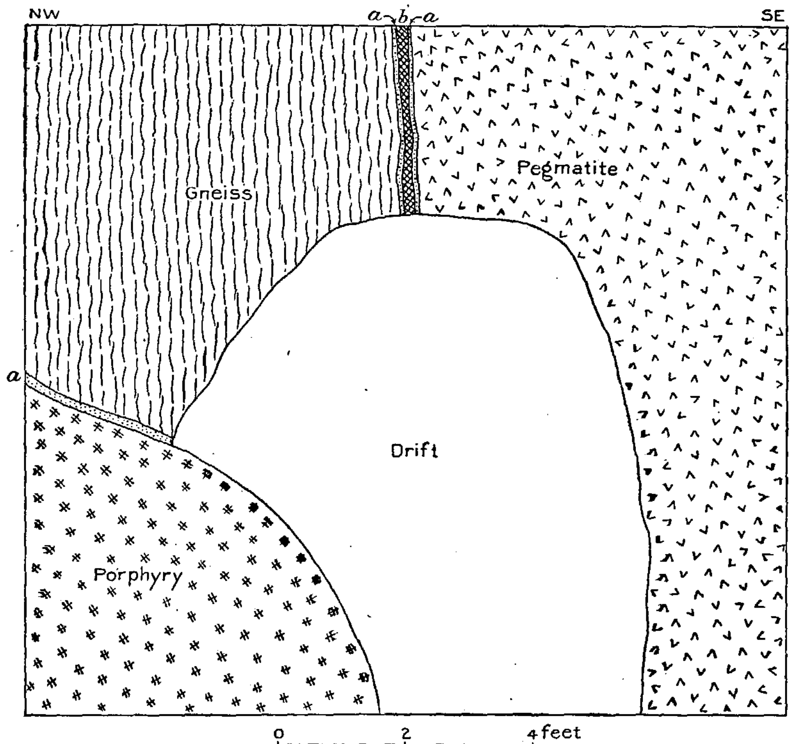


FIG. 92.—Vertical cross section of Colorado Central vein on 1,000-foot level, showing relation of the vein (which has formed along the fault plane) to the undulating intrusive porphyry contact: *a*, Gouge, or kaolinized crushed rock along contacts; *b*, ore in main vein.

The other veins connected with this main vein, being either branches (South vein), parallel or oblique auxiliary veins (New North vein), flat intermediate veins, or imbricating veins, have all a similar origin—they follow fault slips, and a study of their variations resolves itself chiefly into a study of the behavior of fault fractures (fig. 94).

The faults are indicated by ground-up material, by discordance of opposing walls (which rarely can be matched so as to show the exact amount of displacement), and especially by numerous strong striæ which show satisfactorily the direction of movement of one wall on another. The best of these records are tabulated below.

Pitch of striæ in veins of Colorado Central mine.

[Degrees southwest from horizontal on lode.]

North vein:		South vein:	
600-foot level	28, 7, 0	600-foot level	20–25, 45
750-foot level	35	850-foot level	15–25
850-foot level	30, 15, 15, 10, 45, 20	Flat intermediate veins in Aliunde workings:	
1,000-foot level	20	Aliunde No. 2 level	20
Average of observations	22	Aliunde No. 4 level	12, 45

All these observations show unequivocally that the movement of one of the walls on the other was to the southwest at a relatively small angle from the horizontal, varying to some extent locally, but averaging around 20°. These faults were strong and persistent, though the amount of displacement was not great. A maximum of somewhat more than 100 feet may be roughly assigned, this figure being taken from the displacements indicated on the horizontal plan of the North vein of the Ocean Wave level. The displacement as seen on this plan is not far from the total displacement, since the line of movement on the fault is at a comparatively small angle from the horizontal.

These fault openings have become the channels for circulating waters, which have altered the crushed fault material and to a lesser extent the strained wall rocks. Such waters have deposited vein materials, consisting of gangue and ore in some parts of these channels, but by no means at all points. The unmineralized portions of the channels are simply zones of crushing and decomposition in granite, gneiss, pegmatite, or rarely in porphyry, and are marked by clay ("gouge"). Such zones are called "leads," as by following them a mineralized portion of the fault channel can often be reached. As a rule they show no cementation whatever, but only the results of decomposition by the circulating waters. This condition is characteristic of parts of even the strongest fault channels, as that of the North vein, illustrated on the Ocean Wave or 600-foot level (Pl. XLIV).

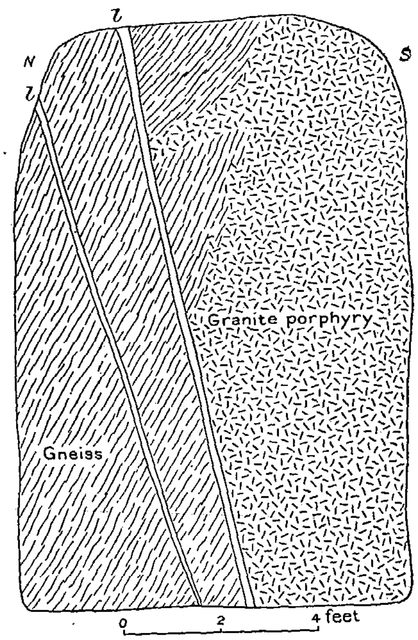


FIG. 93.—Cross section of drift, 600-foot level, Colorado Central mine, showing relation of South vein fault lead (*l—l*) to the contact of the South or Aliunde porphyry dike.

In many places the mineralized portions of the fault channels, constituting the mineral veins, alternate irregularly with the barren "lead" portions, and the dying out of many of the veins is accomplished by the passage from a chiefly mineralized portion to a soft and unmineralized portion, which may lose itself in the rock. Locally, however, the unmineralized "lead" may be very strong, so that it can be followed for many hundreds of feet.

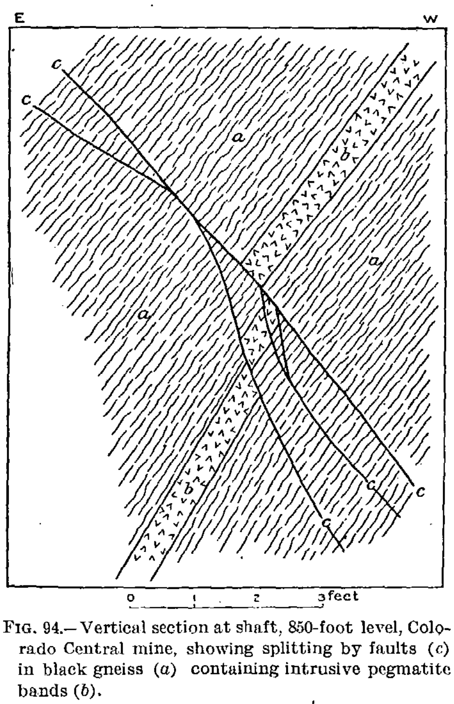


FIG. 94.—Vertical section at shaft, 850-foot level, Colorado Central mine, showing splitting by faults (*c*) in black gneiss (*a*) containing intrusive pegmatite bands (*b*).

The mineralized portions of the veins have, as a rule, been cemented largely by the deposition of silica, forming a dense, greenish replacement quartz, or, in cavities, a white crystalline quartz, usually with comb structure. With the quartz are associated various other nonmetallic and metallic minerals.

The porphyry dikes, which existed before the faulting that gave rise to the veins, were probably intruded along earlier planes of weakness, produced by stress that very likely terminated in faulting. These zones of weakness were cemented by the porphyry intrusion. Renewal of the stress brought about the postporphyry faulting, and these openings were cemented by the vein materials deposited from circulating waters. The movement was not entirely finished, however, but has been renewed, probably several times, since the initial opening of the vein channels. Thus the materials of the earlier mineralization have been brecciated and then cemented with new quartz and metallic minerals. New openings were thus repeatedly formed by movement, and in places they were enlarged by waters through dissolution instead of cementation; and later these cavities became the seats of mineral deposition. The indications are that this process has gone on from the beginning of the faulting and mineralization down to the present day. The number and area of such unfilled openings at present existing in the vein are very large, and it is plain that some of them have been formed at a comparatively recent time by movement, while little vugs have been created along them by dissolution.

A considerable part of the gangue and metallic minerals in the vein has thus been deposited in open cavities, while probably a larger part is due to impregnation and replacement of crushed material.

DISTRIBUTION OF ORE IN VEINS.

All the pay ore contains polybasite and ruby silver. Where these minerals are absent the silver content rarely exceeds 25 ounces per ton. Pay ore has been found down to the bottom of the present workings, but apparently growing less in amount. Much of the first-class ore, sorted out, has averaged 700 to 800 ounces of silver; the second-class ore has frequently averaged 200 to 300 ounces.

The ores are found in irregular shoots which, as a rule, pitch westward on the vein. On the 400-foot level the Central vein splits up into a North and a South branch. It is said that on the North vein, for 200 feet southwest of the junction (Pl. XLIV) extending about 100 feet up and 100 feet down from the level, occurred the richest body of ore in the mine, producing an estimated amount of $1,000,000. The part of it lying below the level included the Carnahan stopes, where from a portion of the vein about 100 feet long and 50 feet high $500,000 is said to have been extracted. There is no particular enrichment at the junction of the two branches here. A similar deposit occurs on the 600-foot level, 200 feet below, at the same or a similar branching (here a few hundred feet farther northeast). On this level many thousand dollars' worth of ore was extracted from the North vein for about 100 feet southwest of the junction: From the next 300 feet of the vein beyond this 100-foot stretch about $300,000 worth of ore is said to have been extracted. The location of these bonanzas indicates that the junction of the veins may have been important in determining ore deposition. A minor but fairly evident instance of the operation of this factor was observed on the Aliunde No. 2 level. Here at the junction of two branching leads a ton or more of rich ruby-silver ore was taken out, but there was no other mineralization in any degree, either of the branches or of the united lead.

PARAGENESIS OF VEIN MINERALS.

DESCRIPTION OF SPECIMENS.

The Colorado Central mine affords an unusual amount of material showing the succession of minerals. Some of the most interesting specimens are described in the following notes:

Specimens from the 500-foot level.—A specimen from the 500-foot level shows (1) medium coarse intercrystallized galena, blende, and jaspery replacement quartz; (2) in irregular geodes, which are probably the result of the eating out of this older ore by percolating waters, are subsequent kaolin, barite, and polybasite, contemporaneous with one another, the last two forming good free crystals. The kaolin, according to the chemical tests of W. T. Schaller, is mixed with zinc and cadmium minerals. There is no zinc carbonate present, and the zinc is probably in the form of sulphide. The relation of this kaolin to the other minerals shows that, like them, it is a deposit from solution, and is not residual.

Another specimen from the same level shows coarse blende, bordering, with large free crystals, on a vug. On these blende crystals have been deposited numerous crystals of polybasite and barite, with less abundant siderite or ankerite and proustite.

Still another specimen from this level shows massive blende, with massive galena cutting across the blende and characteristically later. In vugs in the blende and galena are fine small free crystals of quartz, polybasite, and blende, all abundant and contemporaneous. A fine skin of tiny calcite crystals covers all these minerals, as the latest crystallization. This specimen, it will be noted, shows two distinct generations of blende.

A fourth specimen from the same level shows a first formation of medium-coarse galena, blende, a little pyrite, and jaspery quartz. In geodes which have been formed in this mixture are free contemporaneous crystals of quartz, polybasite, proustite, and argentite.

A specimen from the same locality as the last shows as the first formation medium-coarse galena and blende, with jaspery quartz. On the wall of a cavity in this material are beautiful small free crystals of contemporaneous polybasite and barite.

Specimens from the 600-foot level.—A specimen from the 600-foot level contains massive galena, blende, and polybasite or tetrahedrite, the age relations of the three being uncertain. On small crevices are contemporaneous tiny crystals of barite and pyrite or chalcopyrite. The latter is the thin skim of greenish crystals called "green silver" by the miners and supposed to be rich in silver. As determined by W. F. Hillebrand, however, it probably does not contain any notable amount of silver.

Another specimen from the same level shows massive galena and blende. Subsequent polybasite cuts these minerals and also appears in free crystals lining the walls of geodes, where there also occurs contemporaneous barite.

Another specimen from this level shows veinlets of siderite and calcite, with a little galena. The calcite is locally intercrystallized with the siderite, but is on the whole a later deposit. Microscopic examination of this specimen shows that a siderite-calcite veinlet has been crushed, and the fragments cemented by barite.

On the same level, on the Ocean Wave tunnel, about 700 feet in and 300 feet vertically below the surface, fissures have been lined with siderite, and upon this has been deposited chiefly blende, which in some places has entirely cemented the fissure and in others has only partially filled it, the free blende crystals projecting into the cavity. Associated with these minerals are also free crystals of galena, barite, and siderite or ankerite. Two generations of siderite deposition are shown in this specimen.

Specimens from the 750-foot level.—A specimén from the 750-foot level shows fine galena with some blende. These minerals are cut across veinwise by pyrargyrite. Another specimen from the same level, and 100 feet distant from the first, shows massive blende, cut by seams of later pyrargyrite and some proustite.

Another specimen from this level shows free crystals of various minerals deposited successively on the walls of a fissure, in the following order: (1) Quartz, (2) blende, (3) pyrite, (4) a thin film of calcite. There is here and there a slight intercrystallization of the quartz and the blende, though as a rule the blende is distinctly subsequent. This specimen was found close by others, showing the order of deposition of different minerals in cavities. In one specimen the order was (1) quartz, (2) siderite; in another, (1) siderite, (2) galena. The latter relation is very common, and was observed repeatedly in other localities, both here and on other levels—for example, the 600-foot level. In still another specimen the order is (1) quartz, with intercrystallized pyrite, galena, and blende; this material is traversed by a later fissure, which is lined by (2) chalcedony; and the last deposition consists of small crystals of (3) barite, sitting upon the chalcedony. Another specimen from the same level shows numerous small fissures in pegmatite, lined with quartz which is coated with subsequent siderite or ankerite.

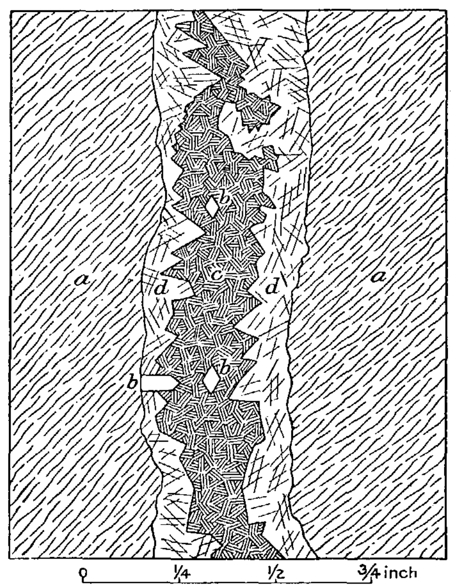


FIG. 95.—Sketch of veinlet on 850-foot level, Colorado Central mine, showing a fissure which has been lined with brown carbonates and filled with fine galena, a single quartz crystal being contemporaneous with both deposits. *a*, Gneiss; *b*, quartz; *c*, galena; *d*, siderite.

Specimens from the 850-foot level.—A specimen from the 850-foot level shows veinlets filling fissures in gneiss. On the walls of the fissures siderite has crystallized. In many of the fissures the center is empty; ordinarily, however, it is filled with fine galena, which is always distinctly later than most of the siderite, though here and there a crystal of siderite may be found embedded in it. There is a very little quartz. In some places a single quartz crystal extends outward from the wall of the vein through both the siderite and the galena deposits, showing that its formation was contemporaneous with both of these (fig. 95).

Another specimen from the same level shows veinlets containing chiefly galena, with some blende, polybasite, pyrite, and chalcopyrite. Druses in these veins are lined with free crystals of blende, polybasite, quartz, chalcopyrite, and siderite or ankerite.

Specimens from the 1,000-foot level.—A specimen from the 1,000-foot level shows the following succession of minerals in a fissure filling in gneiss: (1) Comb quartz, with a little pyrite, lining the fissure; (2) coarse galena and blende; (3) a thin coating of pyrite or chalcopyrite ("green silver" of miners); (4) fine crystalline calcite. Another specimen from the same level shows the following order of deposition in a fissure: (1) Comb quartz lining, with a little pyrite; (2) galena with a little quartz and pyrite; (3) comb quartz, of about the same thickness as 1; (4) crust of white calcite. Another specimen shows, in gneiss, vugs filled with the following minerals, named in their order of deposition: (1) A lining of coarse comb quartz, with some intercrystallized pyrite; (2) galena; (3) polybasite, pyrargyrite, carbonate (probably ankerite), and quartz, in contemporaneous free crystals. Another specimen shows large crystals of polybasite (determined by E. C. Sullivan to contain much arsenic, and therefore to be grading toward pearceite), contemporaneous, in druses, with fine carbonate (probably ankerite) and with chalcedonic quartz. Later than these minerals is a coating of fine pyrite. Another specimen shows quartz, kaolin, polybasite, and galena deposited separately but apparently contemporaneously in vugs.

Specimens from the 1,050-foot level.—A specimen from the 1,050-foot level (the deepest in the mine) shows a gangue of massive quartz and barite. In druses in this material are polybasite, pyrargyrite, galena, and blende. Another specimen shows a vein of polybasite cutting sharply coarse blende and galena. In geodes in a third specimen from this level the following minerals were successively deposited in the order named: (1) Comb quartz, (2) polybasite, (3) a fine coating of carbonates (probably ankerite). A specimen near by shows the following order of deposition in a fissure: (1) Comb-quartz lining, (2) galena and blende, (3) pyrite film. Another shows (1) comb quartz; (2) blende, galena, and pyrite; (3) siderite or ankerite.

On this level specimens were found showing a considerable amount of hematite (specular iron), intercrystallized with quartz, blende, and pyrite (slightly cupriferous ?). These minerals occur cementing the fragments of a breccia of altered granite which contains pyrite, probably the result of alteration of the iron in the rock. The following order of deposition of minerals in the rock openings was noted: (1) Hematite and pyrite, intercrystallized; (2) clean comb quartz; (3) tetrahedrite, pyrite, and galena, intercrystallized, filling the central spaces between the combs of quartz. In other places a carbonate (siderite or ankerite) has been deposited on the quartz.

Specimens from the mine dump.—Specimens taken from the mine dump, their original exact locality being unknown, show similar characteristics to those above described. One specimen shows the following order of events, which is similar to that repeatedly noted previously. The rock is pegmatite—mainly quartz, with a little feldspar. This rock has been crushed and cavities have been formed on whose walls the following minerals were successively deposited: (1) A lining of comb quartz, with some pyrite; (2) coarse galena and blende; (3) barite; (4) pyrite film; (5) carbonate (ankerite or siderite). Another specimen shows the same order of deposition, somewhat simplified, in large open cavities in gneiss: (1) Quartz with some pyrite; (2) blende, galena, and some pyrite; (3) siderite or ankerite. In another specimen tetrahedrite occurs in small fissure veins in gneiss, associated with and in general contemporaneous with pyrite, blende, and galena. In another specimen the following order of deposition was noted, on the walls of a geode: (1) Quartz, (2) siderite, (3) hematite and pyrite, intercrystallized. In another portion of the same specimen comb quartz is younger than massive hematite. Another specimen shows white kaolin occupying the spaces between interlocking crystals of galena and blende, and apparently contemporaneously with them. Another specimen from the dump shows under the microscope a fragment of altered granitic rock surrounded by a fringe of crystalline quartz containing pyrite and a little galena. These materials have been subsequently fissured and then recemented by veins of homogeneous, microcrystalline clear chert (of a greenish color in the hand specimen).

SUMMARY STATEMENTS CONCERNING PARAGENESIS OF MINERALS.

Quartz.—Quartz is characteristic of the whole period of deposition and has been deposited from the beginning of the process to the end. As in the fissure veins of the Terrible group at Silver Plume, the first lining of the fissures in the Colorado Central mine has usually been quartz. Subsequently it is more or less plainly contemporaneous with other materials, and in many places is among the very latest minerals, crystallizing on the walls of geodes, where it has been noted as contemporaneous with siderite or ankerite, blende, polybasite, pyrargyrite, proustite, and argentite. Chalcedony or chalcedonic quartz is not very common, though not rare. As a rule it belongs among the later formations, and has been noted cutting and distinctly subsequent to crystalline quartz. In places it is contemporaneous with galena and blende, while barite, kaolinite, and polybasite have been observed as minerals of later formation.

Barite.—Barite was noted on the 400-foot level, forming free crystals on the walls of a small fissure in crushed and silicified vein material. Both the fissure and the barite crystals are subsequent to the silicification. On the 750-foot level barite was noted in separate crystals embedded in a soft 6-inch seam of clay. In neither of these localities was there any metallic mineral present, and as the crystals lay in the line of circulation of present waters their occurrence suggests that they have been deposited from these waters. In the various specimens studied barite is characteristically among the last-formed minerals, and in many is the latest of all. In one specimen it was noted as younger than calcite, which in its turn was younger than siderite. In various specimens barite was seen to be contemporaneous with siderite or ankerite, kaolin, galena, blende, pyrite, polybasite, and proustite. Its favorite mode of occurrence is in fine crystals coating the walls of geodes, either alone or contemporaneous with free crystals of the above-named minerals, which in such cases usually belong among the last deposits.

Siderite or ankerite.—Iron carbonates, probably comprising both the species siderite and ankerite, are more abundant throughout the Colorado Central mine than in the mines of Silver Plume here described, and are more closely associated with the ore. In many veinlets in this mine siderite takes the place of the lining quartz and forms a barren first deposit on the walls of fissures which may subsequently be filled up by metallic minerals. Other veinlets of siderite are in barren rock, and are not accompanied by sulphides. In this respect the siderite (and ankerite) is like the pyrite and quartz, which have a similar habit, and its origin seems to be probably the same—that is, it represents the crystallization along the walls of cavities of the carbonates abundantly formed by the alteration of the biotite and feldspar of the wall rock. Study of microscopic veinlets in altered rocks from other portions of the district makes it practically certain that siderite veinlets may originate in this way. Much of this earlier siderite is intercrystallized with quartz.

Siderite or ankerite, or more probably both, also forms one of the last and typically the very last deposit on the walls of cavities, coating all the other crystals. In other places siderite is contemporaneous with other of the latest-formed minerals, among which are quartz, barite, galena, blende, pyrite, hematite, chalcopyrite, polybasite, and pyrargyrite.

Accordingly siderite belonging to two distinct periods of deposition may be seen in a single specimen. The fine coating of siderite which forms the last deposit in geodes is most intimately associated with the film of greenish cupriferous pyrite, which usually occupies a similar position. The siderite is as a rule younger than the pyrite, though here and there the two are intercrystallized.

Both seem to be clearly recent deposits and due to ordinary ground waters. The change from an iron sulphide to an iron carbonate may have been brought about by the opening of the mine workings, which artificially introduced oxidizing or semioxidizing conditions to influence the solutions in many places.

Calcite.—Calcite in the form of tiny crystals occurs in numerous places as the very last mineral to crystallize, its habit and probable origin being altogether similar to those of the siderite and ankerite with which it is associated. Calcite forms many barren veins or veinlets in barren rock, where it has plainly collected from the calcite, which occurs abundantly within the rock as an alteration product. Both calcite and siderite form veinlets of this type in porphyry.

The calcite was the very last mineral to form in all the specimens noted but one, which shows, later than the calcite, tiny free crystals of barite. Calcite has not been noted among the constituents of the earlier portions of the vein deposits.

Kaolinite.—Kaolinite occurs, especially in small amounts, on the walls of geodes, where it is among the latest minerals to be deposited. In this mode of occurrence it forms a definite small mass on the geode walls, not interfering with the crystals of other minerals, which are contemporaneous. It is therefore plainly deposited from solution. Under these conditions it has been noted as contemporaneous with quartz, barite, galena, blende, and polybasite.

Galena and blende.—Galena and blende are closely associated, and are usually contemporaneous. In only one specimen was a difference of age noted, the galena being there younger than the blende. These minerals do not belong to a single period of deposition, for although they are characteristic of the older massive vein material, yet they also occur in free crystals in druses of distinctly later age, where they are among the last minerals to crystallize. Frequently both generations can be seen in the same specimen (p. 136). In the latter mode of occurrence galena or blende, or both, have been noted as contemporaneous with quartz, barite, siderite or ankerite, kaolin, pyrite, hematite, chalcopyrite, polybasite, and pyrargyrite.

Pyrite.—Pyrite occurs in fragments of the altered wall rocks inclosed in the veins in disseminated crystals so located that they appear to have been formed from the original iron in the rock. The presence of secondary pyrite, probably due to the alteration of magnetite and biotite, has indeed been determined by microscopic work, though siderite is a commoner form of alteration. Pyrite also occurs intercrystallized, generally in small amount, in the comb quartz which, as a rule (though not invariably, as is practically the case in the veins of the Mendota group at Silver Plume), forms the first deposit on the walls of open cavities in this mine. Where such a fringe of comb quartz carrying some pyrite surrounds a fragment of granite containing probable secondary pyrite all the pyrite has the appearance of having had a common origin. According to this idea this (barren) pyrite has been secreted from the wall rock, to help in forming the first crust to heal the fissure. The comb quartz that is associated with the pyrite, and is usually much more abundant, may then have had a similar origin, its source being the abundant quartz which, together with sericite and carbonates, is among the alteration products of the feldspars. It has been shown that in the Mendota veins, where the same principle which prevails in the Colorado Central is shown more strikingly, the sulphide deposition almost invariably took place during a period distinctly subsequent to the opening of the fissures, and in the meantime comb quartz crystals grew slowly and continuously outward perpendicularly from the walls, covering them everywhere. This action finds its best and most probable explanation in the derivation of the quartz from the adjacent rock.

Pyrite also occurs, though in subordinate amount, as one of the minerals in the massive portions of the veins which are due to impregnation and replacement of the crushed rock along fault zones. Here it is associated and contemporaneous with the jaspery vein quartz, together with galena and blende. It is usually very subordinate, and occurs in many localities in larger amount in the altered wall rock than in the veins, so that the portion which occurs in the veins may easily have been derived from the wall rock.

A thin film of greenish cupriferous pyrite also occurs very abundantly in nearly all vugs as one of the last minerals to crystallize, and of a distinctly later period and generation than that described in the preceding paragraphs. Pyrite of both generations occurs in many single specimens, as described above. The only minerals which as a rule are later than this latest pyrite are carbonates, including calcite and siderite or ankerite, or both. These carbonates commonly form a last coating of tiny crystals on the walls of cavities. The carbonates and the latest pyrite are invariably very nearly contemporaneous, and in places some are fully so, and both seem to be doubtless the work of the present or recent circulating mine waters.

Hematite.—Crystallized hematite (specular iron), though not noted as widespread, occurs in some specimens in considerable quantity. It has been observed contemporaneous with quartz, blende, and pyrite; as a later formation with siderite or ankerite, galena, and pyrite.

Polybasite, tetrahedrite, pyrargyrite, proustite, argentite, and native silver.—Polybasite, pyrargyrite, proustite, and argentite, abundant in the relative order named, may be discussed together. The last two are relatively rare; the first two (especially polybasite) are very common, and their presence substantially determines the value of the ores. In most cases the age relations of these minerals are clear, and in every observed specimen they are among the later minerals to crystallize. Where observed in connection with the galena-blende ores, which form the lean (unworkable) silver ores, these minerals are as a rule distinctly later, cutting veinwise across the older deposits. They are also typically formed in free crystals on the walls of druses. In this mode of occurrence polybasite has been noted contemporaneous with quartz, chalcedony, siderite or ankerite, kaolin, barite, blende, chalcopyrite, pyrargyrite, proustite, and argentite. The only minerals observed as of later origin are the carbonates which have been mentioned as forming the last fine crust in geodes. These include calcite and probable ankerite. Yet in other places polybasite, pyrargyrite, and proustite have been observed apparently contemporaneous with ankerite or siderite of this character, all sitting as free crystals on the walls of geodes.

Tetrahedrite was observed in several localities. Its genesis appears to be much like that of polybasite. Native silver is occasionally found forming films on crevices. It is the last of the silver minerals to form, being later even than the rich secondary sulphides, and its formation seems relatively recent.

GENERAL CONCLUSIONS.

The study of the paragenesis of the vein materials as a whole shows plainly that the deposition of the present vein materials has extended over a long period, which evidently lasted, and during which deposition was constantly though probably not uniformly active, from the formation of the first openings to the present day. The earliest deposits consist of comb quartz with occasional pyrite, which lined many of the fissures before the main deposits of metallic minerals; the latest are the skins of more or less cupriferous pyrite and carbonates which crust the minerals and probably represent extremely recent deposition.

It appears that at no time was the cementation of the openings very thorough and complete, for portions of the fault zones are still soft and decomposed and appear never to have been cemented. Within the cemented portions of the veins, also, new openings have been repeatedly formed by movements in the veins and by the solvent action of dissolving waters that have followed depositing waters. The circulation of waters has always been active along the original openings, and so continues to the present day.

Of the gangue minerals, quartz has been continually deposited from the beginning to the end of the process. The deposition of siderite or ankerite has also been long continued. Barite and kaolinite, however, appear to be characteristic of the later periods, and calcite seems to be only a recent and relatively unimportant formation.

Of the metallic minerals, pyrite, though always in small quantity, is the most persistent, and has been deposited as widely as has quartz. The deposition of galena and blende began as a rule slightly after that of the first quartz and pyrite, but was repeated subsequently. Polybasite, tetrahedrite, pyrargyrite, proustite, and argentite seem to have been deposited only in the later stages and subsequently to the bulk of the older veins containing quartz, galena, blende, and pyrite.

DERIVATION OF CERTAIN VEIN MATERIALS.

DERIVATION OF RICH SILVER SULPHIDES AND ASSOCIATED LEAD AND ZINC SULPHIDES.

Observations show that the highly argentiferous polybasite and ruby silver, on whose presence the workable ore depends, are in general subsequent to massive galena-blende ores carrying a few ounces (say 8 to 30) of silver. As formed during the later epoch of crystallization, marked by these highly argentiferous minerals, are also to be reckoned some well-crystallized blende, pyrite, and galena. Similar last formations of galena and blende in cavities in the Waldorf mines, at Argentine Pass, some miles southwest of the Colorado Central, and belonging in the same geologic district, are reported to be exceptionally low in silver. It seems probable that the polybasite, ruby silver, and other rich silver minerals have been concentrated from the leaner ores by circulating waters, subsequent to the first deposition. Certainly, however, the silver was not concentrated out of the surface zone and brought together in lower levels. The superficial portions of the sulphide vein are as rich as any portion, or richer, and the very thin oxidized zone is the richest of all.

The most probable explanation is that these minerals were concentrated from the older low-grade argentiferous sulphide ores at all depths. Waters circulating through these ores have probably taken them into solution and effected a better separation of their constituents. The galena and blende of the second generation, lining geodes and in many places contemporaneous with the polybasite and ruby silver, may well represent the lead and zinc taken into solution and reprecipitated with smaller silver values than originally. The deposition of the rich silver-bearing sulphides in places more or less separate from that of the secondary lead and zinc sulphides—a separation which has brought about the formation of definite rich ore bodies—is probably due to the differences in solubility of the materials.

To follow this reasoning, considering the amount of silver concentrated in the rich shoots and the quantity of original blende and galena which must have been taken into solution to furnish this silver, it seems probable that a large part of the original ore has been worked over by this process. Indeed, so abundant is the evidence of the continued work of solutions since the formation of the original vein opening that we can hardly be sure as to what is really primary and not rearranged ore.

There appears to be in this mine, moreover, no clue as to the original source of the lead, zinc, and silver. Nevertheless, the presence of ore shoots in certain portions of the veins and their absence in other portions which contain only lead and zinc ores, of low grade in respect to silver, suggests an original difference in these separate portions. On the 600-foot level, for example, the portion of the Colorado Central lode known as the Ocean Wave lode carries zinc ores containing very little silver. Yet these ores also are traversed by later openings, affording the necessary conditions for concentration. It seems probable that such portions of the vein were originally different from the richer portions and had originally a smaller amount of silver. This characteristic difference between veins of predominating blende, with little silver, and veins which carry rich silver ores, characterized by abundant, even though secondary silver sulphides, is striking enough in the Silver Plume area, as between the Mendota and the Terrible veins, for example, which lie side by side and have been exposed to similar conditions throughout; but here in the Colorado Central the two distinct ore types are in different portions of the same lode.

The occurrence of the fresh, clean crystals of silver sulphides, galena, blende, and other minerals, belonging to the later, probably concentrated generation, growing out from the walls of cavities which are full of circulating ground waters, suggests that such waters were the agents of concentration. Plainly at least these descending solutions have no dissolving effect on the crystals, which are as fresh in them as in a mother liquor. On the Aliunde No. 2 level in the zone of the "flat" veins the writers noted a small unmineralized lead, a third of an inch thick. On breaking into this lead a streak of ruby silver was found, with water trickling down over it. There was no more of this above or below. On the level above (Aliunde No. 1) ruby silver was found coating slickensided surfaces in galena ore.

DERIVATION OF QUARTZ, PYRITE, AND SIDERITE FROM THE WALL ROCK.

The wall rocks of the veins are always altered. The chief alteration products are finely divided quartz, kaolin, muscovite (sericite), calcite, and siderite. On the walls of the vein fissures the first deposit has generally been comb quartz, with no evident relation to the deposition of galena and blende, and this has suggested the derivation of the quartz from that in the altered wall rock. The later quartz may well have a similar origin. The amount of silica which has been extracted from those portions of the lead which have not been cemented and are marked by clay zones is probably in itself sufficient to account for the quartz in the cemented portions of the lead.

A similar consideration applies to the rather scanty pyrite, which is in many places more characteristic of the altered rock than of the vein, and the iron for which (though not the sulphur) seems to have probably been original in the rock.

The usual form of iron in the altered rock is siderite, showing that the altering waters were carbonated. Many fissures in such siderite-rich rock are lined with crystalline siderite, as the first deposit, in which case, as in that of the quartz, the derivation of the mineral from the wall rock seems probable, and in such fissures no other origin can be assigned to the subsequently deposited siderite.

DERIVATION OF CALCITE.

The sparse calcite, which is among the last minerals to form, needs no argument as to its formation, in view of the deposition of calcite from waters now traversing the rocks in workings, even crosscut tunnels, in this mine. This calcite has been shown elsewhere to be derived from altered feldspars by ordinary ground waters.

DERIVATION OF KAOLINITE.

Associated with these later carbonates, as well as with the rich silver sulphides and other sulphides of the later generation, is kaolinite, a precipitated mineral whose derivation from the wall rocks seems hardly questionable. This mineral was observed in this mine to be an alteration product of the feldspar in the porphyry, together with sericite and calcite. Kaolinite is generally held to be insoluble,[a] yet in the porphyry it has been found separated from its associated decomposition products and in a pure, transparent crystalline form filling a fissure, being plainly the result of precipitation from solution, as it is where it occurs in vugs in the veins. Its relative insolubility, however, explains the small amount present in the veins as a chemical precipitate.

DERIVATION OF BARITE.

Barite, which is characteristically one of the later minerals and is in many places the very last to form, has been noted as contemporaneous with kaolinite. Barium is undoubtedly present in the feldspars of the wall rock, and some of it may pass into solution by circulating waters when these feldspars are decomposed. The common associate of barite, kaolinite, is frequently formed by the action of carbonic acid in waters, but it has been remarked by Lindgren[b] that it is formed abundantly in the upper zones of many ore deposits, where the action of stronger reagents, such as sulphuric acid, seems probable; and the senior writer has studied occurrences where this observation strikingly applies. Such sulphuric acid in the waters, derived from the oxidation of the sulphides and carried downward, would precipitate barite from solution in some other form, such as chloride, in other downward-moving currents. The occurrence in this mine of separate barite crystals embedded in a seam of clay (see p. 259) calls for some such explanation. At the coal mines of Newcastle-on-Tyne barite is deposited from mine waters in boxes and pipes; these mine waters contain some barium chloride.[c]

SUMMARY.

It has been shown as probable that the gangue minerals are derived from the wall rocks. It has also been shown that a large part of the materials in the veins, both metallic mineral and gangue, are probably immediately due to precipitation from ordinary circulating ground waters. The original derivation of the metals, zinc, lead, silver, copper, arsenic, antimony, mercury, cadmium, gold, etc., and the source of the sulphur remain undetermined.

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[a] For solution of alumina, however, see p. 161.

[b] Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 614.

[c] Dana, E. S., System of mineralogy, 6th ed., p. 903.

DEPOSITION FROM MINE WATERS.

At many places where surface waters enter crosscut tunnels in the rock, such as the Equator and the Marshall tunnels, they deposit iron oxide and calcite. On the walls of the Marshall tunnel a finely banded crust of pure calcite, one-third of an inch thick, was observed. This deposit resembled Mexican onyx in structure and was of a beautiful bluish-green color, owing probably to the presence of some metallic mineral. A similar but brown-banded deposit, over 0.4 inch thick, incrusts the pipe of a mine pump that has been used almost continuously for twelve or thirteen years. This deposit was determined by W. F. Hillebrand to be calcite with a little iron and a trace of manganese.

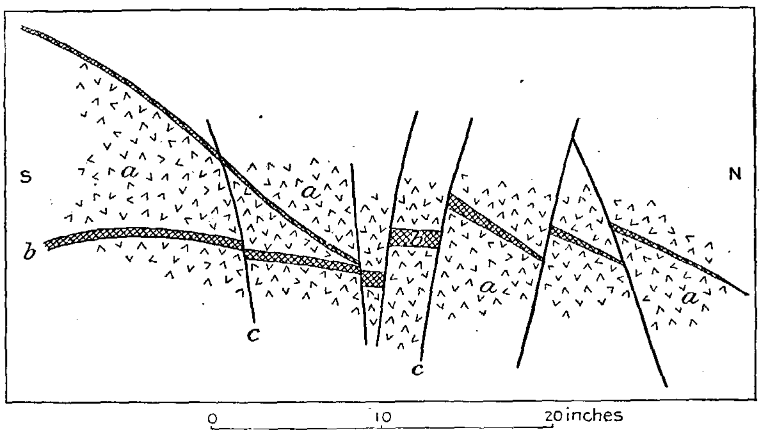


FIG. 96.—Vertical section showing minor postmineral faulting of sulphide veinlets in pegmatite, Intermediate vein, 850-foot level, Colorado Central mine. *a*, Pegmatite; *b*, ore; *c*, faults.

TRANSVERSE POSTMINERAL FAULTS.

Most of the movement since the initial opening of the vein channels has been along the old slips, but occasional ruptures have taken place in a transverse direction, offsetting the veins.

These movements are invariably small, nor are they in general abundant. On the 750-foot level, in one locality, numerous slight faults, striking approximately north, were observed displacing a horizontal streak of galena (figs. 96, 97). These faults have, as a rule, only a few inches displacement. On the 850-foot level (Pl. XLIV) a slight transverse fault, striking west-

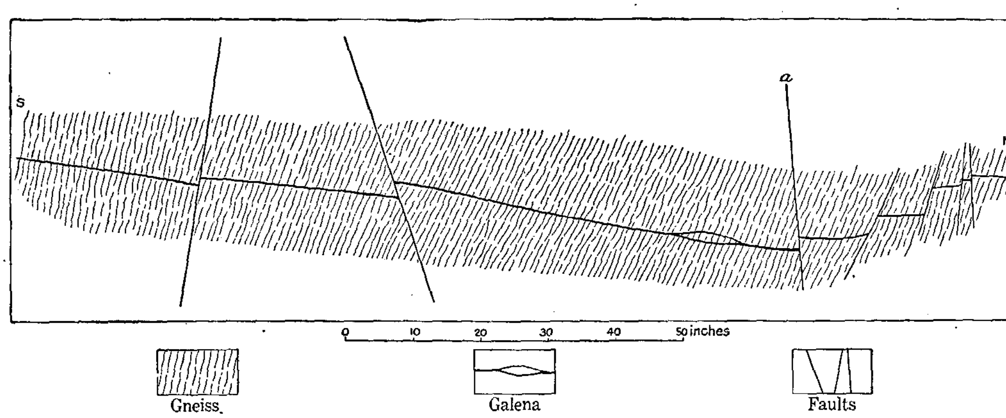
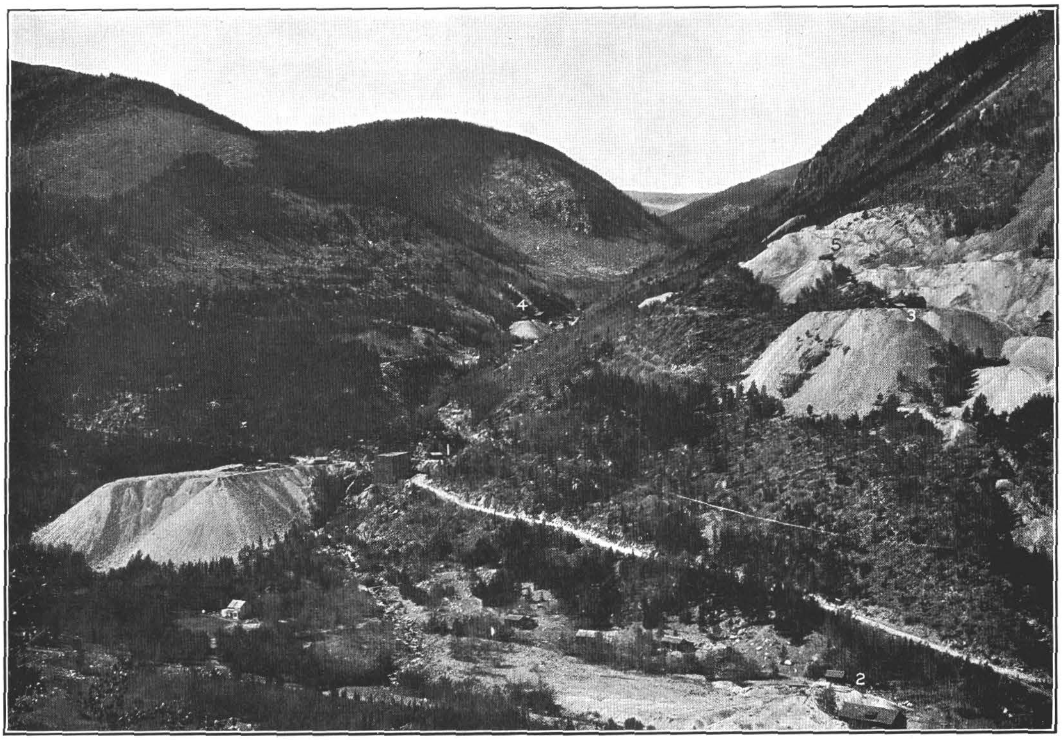


FIG. 97.—Vertical section showing minor faulting of galena veinlet, 850-foot level, Colorado Central mine. Fault marked *a* is somewhat cemented by quartz.

northwest, has a curious effect, shifting the porphyry and the veins about 12 feet to the northwest on the northeast side. This being the exact width of the porphyry, the North vein is here brought against the New North and in apparent continuation with it. At this point, however, the North vein is well mineralized and the New North practically barren, and the true continuation of the North vein was found by following up the fault, which was marked by a heavy sheeted zone.



A. COLORADO CENTRAL AND KIRTLEY MINES, LOOKING SOUTH-SOUTHWEST UP THE VALLEY OF LEAVENWORTH CREEK FROM THE SLOPE OF ALPINE PEAK.

1, Marshall tunnel, Colorado Central mine; 2, Equator tunnel, Colorado Central mine; 3, Kirtley mine; 4, Aliunde tunnel and shaft, Colorado Central mine; 5, Colorado Central surface workings.

B. WIDE WEST MINE, LOOKING NORTHWEST ACROSS THE VALLEY OF SOUTH CLEAR CREEK FROM THE SLOPE OF ALPINE MOUNTAIN.

KIRTLEY GROUP OF VEINS.

GENERAL DESCRIPTION.

The Kirtley group of veins is located on the southeastern slope of Leavenworth Mountain, 500 to 700 feet above the level of South Clear Creek (Pl. XLVI). The group consists of the Kirtley, Stranger, O. K., Tilden, Argentine, Creole, and Gates veins. Of these the Kirtley is the main or master vein from which the other smaller veins branch in both a lateral and a vertical direction. Many of the branch veins successively subdivide until they finally die out.

KIRTLEY VEIN.

The Kirtley vein was intersected by the Kirtley tunnel (fig. 98) about 650 feet from its mouth. It is opened up for a distance of over 1,200 feet on the tunnel level. The eastern

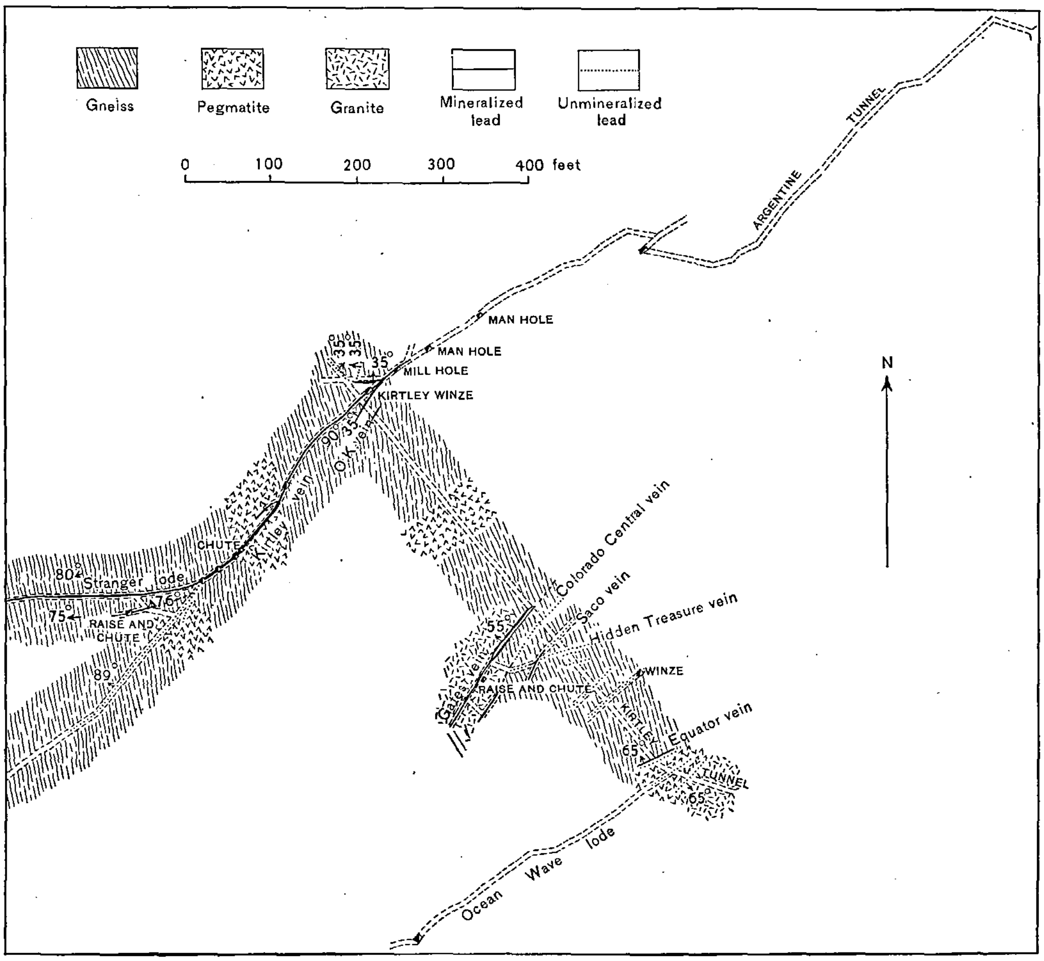


FIG. 98.—Geological plan of Kirtley tunnel workings.

part of this level, moreover, is connected with the workings on the Kirtley vein in the Argentine tunnel. Besides the development on the tunnel level, there are also about 250 feet of workings on the Kirtley vein, on the Marshall tunnel level of the Colorado Central mine, and 100 feet of drifting on a poor lead in gneiss said to be the Kirtley vein near the breast of the Equator tunnel of the same mine. There are practically no workings on this vein at the surface.

The general strike of the vein underground is N. 45° E., but at the northeast end it swerves a little more eastward. The dip is practically vertical on the Kirtley tunnel level, but the vein rolls slightly so as to cause a gentle dip to the northwest in the upper workings and a dip in the opposite direction in the lowest levels.

The Kirtley has formed along a well-developed fault line, as shown by slickensides and by the strong gouge and crushed rock lead forming the portions of the vein where mineralization is wanting or is only slightly developed. Although the vein is strong to the southwest of the point where it is joined by the Stranger vein, it consists entirely of soft gouge and crushed rock, so far as shown by the open workings.

The ore started abruptly at the junction of the Stranger vein and extended rather continuously along the Kirtley for more than 500 feet to the northeast, beyond which the vein again changed to an unmineralized fault lead and gradually became less pronounced. The richest and broadest part of the ore body was immediately northeast of this junction.

In the Dunaway tunnel of the Argentine mine, located about 800 feet N. 28° E. of the Kirtley tunnel, the chief development has taken place on the Kirtley vein. Where encountered by the tunnel and for about 250 feet to the southwest the vein is chiefly a clay or gouge fault lead dipping 65° to 75° NW. and carrying no mineralization except a couple of small bodies of ore immediately at the junction of small branches with the main lead. Farther west the vein is irregular in trend owing to the fact that it follows a series of connecting but differently trending fractures. However, along this part of the vein zone considerable mineralization has taken place and the workings on the Dunaway tunnel level are connected with the stopes of the Kirtley mine, which develop the east end of the long ore shoot resulting from the union of the Stranger and O. K. veins with the Kirtley vein.

STRANGER VEIN.

The Stranger vein, the main branch of the Kirtley, also has a nearly vertical dip and cuts the schistosity of the gneiss wall rocks at approximately a right angle. The general trend of this vein is S. 85° W., but as the vein approaches the main vein it curves around to the northeast and runs almost parallel to the main vein just before reaching the junction. Ore extended along the Stranger vein for more than 200 feet from the crossing, but the best pay ore started 20 or 30 feet from the junction and extended westward for a short distance before it began to grow less in amount as the vein receded from the main vein.

Another but minor branch of the main vein ran somewhat parallel to the Stranger vein and only 15 or 20 feet to the southwest. This minor vein, although it was mineralized for a length of 200 or 300 feet, was not a strong lead. Its dip was about 76° N.

O. K. VEIN.

The O. K. vein was worked from the surface and produced considerable ore long before the Kirtley vein was discovered by the driving of the Kirtley tunnel. In 1872 about 20 men were employed on the O. K. This vein, which from the mine maps is seen to strike about N. 78° E., is a branch of the Kirtley vein and ranges in dip from 55° to 30° N. Where observed in the shaft just above the Kirtley tunnel, however, the vein had a strike of N. 55° E. and a dip of only 30° to 35° from the horizontal. Whether the O. K. vein makes simply a junction with the Kirtley vein, or whether it actually crosses this vein, is not well shown at present because the O. K. becomes much more faint near the point of union, and also because all the workings are not now open. Near the breast of the Kirtley tunnel is a strong lead in granite and gneiss carrying no ore which strikes N. 60° W. and dips 35° NE. The vein where it nears the main vein curves around to the northeast and runs parallel to the Kirtley vein just before it joins it. This vein was decided by a lawsuit to be the "upfaulted continuation of the O. K. vein," which is here supposed to cross the Kirtley. To judge from the dip of the two veins the junction should result in a northeastward-pitching trough. The ore on the O. K. vein near the junction just above the Kirtley tunnel was not only less in quantity but also much leaner in values than the narrow but rich streak found near the surface. Possibly the underground waters circulating in the O. K. vein, however, had a stimulating effect on ore deposition in the Kirtley and helped to cause the formation of the long ore shoot on that vein.

TILDEN VEIN.

The Tilden vein, as shown by the mine maps, trends N. 87° W. and dips about 70° N. It lies intermediate between the O. K. and Kirtley veins and, being somewhat parallel to and steeper than the O. K., makes a junction with that vein. This junction is about 150 feet below the surface. The Tilden vein also joins the Kirtley vein to the west, but what effect the union has on ore deposition is not shown in the present openings.

ARGENTINE VEIN.

The workings on the Argentine vein (fig. 99) were open only for a few feet at the time of visit, and so little could be determined about the relation of this vein to the other veins of the

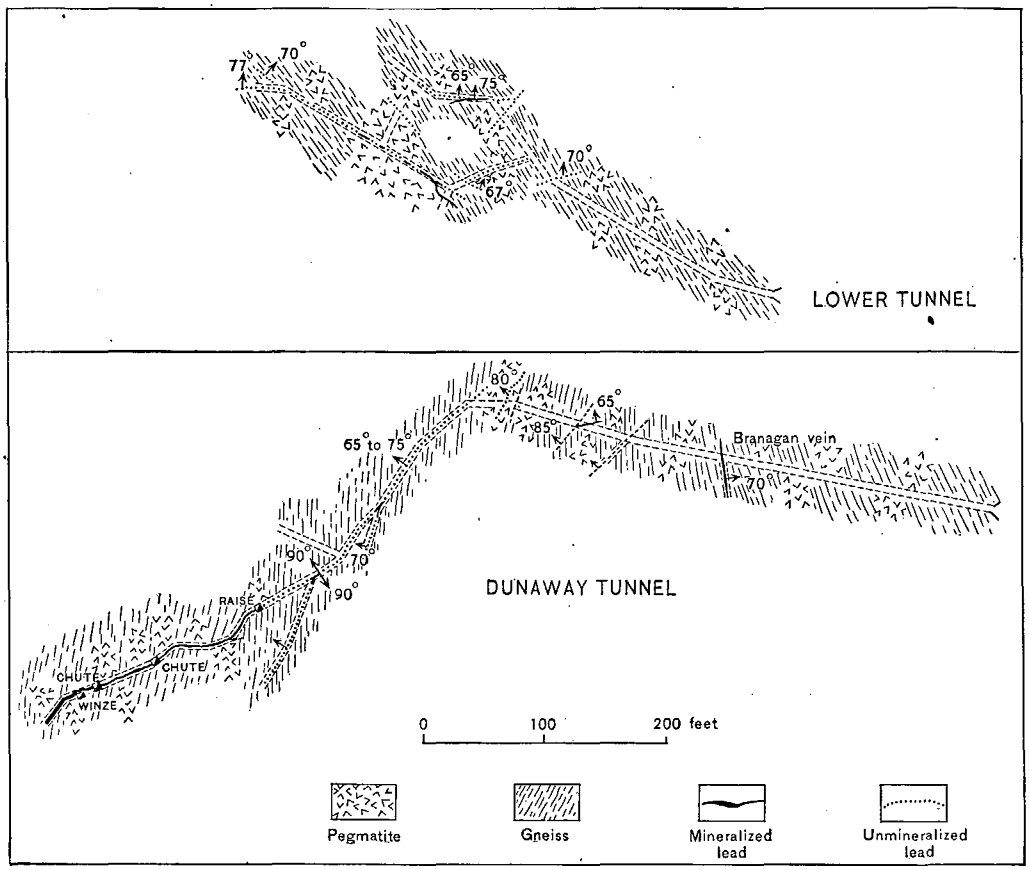


FIG. 99.—Geological plans of levels in Argentine mine.

group. Where exposed near the mouth of the Argentine tunnel it had a dip of 75° SE. and a strike of S. 75° W. On the surface, however, from the point where a branch vein joins it from a S. 60° E. direction, about 100 feet north of the Creole tunnel, the Argentine vein runs S. 52° W. At the junction of this branch there was nearly 2 feet of coarse lead ore, and a mixture of galena and "honeycomb" quartz occurs right at the surface. The Argentine vein, which is considered by some to be an extension of the Kirtley, may be an overlapping or imbricating vein, although it is connected with the Kirtley by minor transverse fractures.

CREOLE VEINS.

The two veins in the Creole tunnel, called the "foot-wall and hanging-wall leads of the Creole vein," are approximately parallel and are probably branches of the Argentine vein.

The Creole tunnel, 150 feet in length, extends S. 78° W. along the south vein, which is a soft crushed granite, pegmatite, and gneiss lead except where a small body of ore was found at the junction of a S. 80° E. branch. A 15-foot crosscut then connects the breast of the tunnel with a drift 35 feet in length along the north vein. Near the breast of this drift there is a junction with a slightly mineralized S. 43° W. vein which dips 70° NW. and may possibly be the Argentine vein. Flat transverse mineralized fractures were noted connecting the north and south Creole veins.

GATES VEIN.

The Gates vein, which was actively worked in the early seventies and in 1874 employed about twenty-five men, has yielded considerable ore. It strikes N. 32° E. and dips about 55° NW., and is a strong fracture zone in gneiss and granite. In places it consists of foot and hanging leads 5 or 6 feet apart, with silicified granite and gneiss or brown-stained quartz between and ore stringers interlacing all through the fractured zone. Both the walls and the rock fragments composing the fractured belt are coated with comb quartz from one-sixteenth to one-fourth of an inch thick, with the quartz crystals radiating into the spaces now occupied by a heavy zinc blende and galena ore carrying some "gray copper" (mainly polybasite and tetrahedrite). The galena is rather coarse textured and much of it shows curved faces, probably due to some mechanical cause. The blende is chiefly of a resinous nature and usually dark brown, though a little of it is greenish yellow. Small vugs lined with drusy quartz are present here and there and many of these are specked with minute tufts of a white mineral, probably calcite or some other carbonate.

About 20 or 25 feet southeast of and parallel to the Gates vein is a strong lead made up of clay and decomposed gneiss and pegmatite, 1½ feet wide, which has a nearly vertical dip and shows some mineralization, especially near its western workings. A cross flat vein dipping about 35° NW. runs parallel to this lead and connects it with the more steeply inclined Gates vein. The cross vein consists of a series of ore stringers in an inclined sheeted zone about 4 feet wide.

OTHER VEINS OF THE GROUP.

In the Kirtley tunnel, about 25 feet southeast of and parallel to the Gates lode, is the Saco vein, which on this level is small, but which, according to Raymond,[a] produced about $55,000 of very rich ore in 1873, during the first five months after its discovery. A short distance to the west of the tunnel the Saco vein makes a crossing with the Hidden Treasure vein, which trends S. 70° W. until it joins the vein south of the Gates vein. The Hidden Treasure also was actively developed in 1873 and produced some ore. At the point of intersection with the Saco, both of the veins carry some quartz and ore on the Kirtley tunnel level.

Another strong vein carrying some rich ore near junctions with branch veins was encountered on the Equator tunnel level of the Colorado Central mine, about 150 feet from the breast. It trends N. 45° E. and dips 70° to 80° N. At the northeast end of the drift the vein is only 75 to 100 feet from the Kirtley vein and trends slightly toward it as if to make a junction with it. However, this vein may not unite with the Kirtley but may be one of a set of imbricating or overlapping veins somewhat similar to the Colorado Central series of veins.

The Branagan vein, which crosses the Dunaway tunnel about 215 feet from its mouth, is chiefly a gouge and crushed gneiss lead which is mineralized in places and has produced a little ore. It is a cross vein which strikes N. 10° W. and dips 70° E.

COUNTRY ROCK.

The country rock, for the most part, is gneiss associated with considerable pegmatite and granite. This gneiss in the southwestern portion of the workings on the Kirtley and Stranger lodes ranges from a hard black rock resembling sheared diorite to a soft biotite gneiss with a strike of N. 15° to 25° E. and a dip of 70° to 80° W. In places this gneiss forms an intimate mixture with pegmatite and granite. The eastern part of the vein on the Kirtley and the western part in the Dunaway tunnel levels consist of a hard granitic gneiss saturated with in-

[a] Raymond, R. W., Mineral resources west of the Rocky Mountains, 1873, p. 275.

jected pegmatite. Pegmatite, besides occurring intimately mixed with gneiss, is found in larger bodies just west of the junction of the Stranger and Kirtley veins, also about 150 feet to the northeast of this point and again on the Marshall tunnel level. Both biotite and muscovite pegmatite are present. The Kirtley crosscut tunnel is mainly in soft biotite gneiss with patches of pegmatite, and these same rocks occur along the eastern part of the Kirtley vein in the Dunaway tunnel of the Argentine mine.

Although the Kirtley and Argentine workings lie near the Colorado Central mine, in which porphyry is commonly associated with the veins, no porphyry whatever has been encountered in the Kirtley workings and only an isolated patch 2 or 3 feet in diameter of intensely altered rock which might be porphyry in the workings of the lower tunnel on the Argentine.

STRUCTURE OF VEINS.

The veins where unmineralized consist of fault fractures filled with crushed rock and clay gouge associated with some quartz and calcite. Although discordances in the wall rocks occur, the movements have caused only slight displacements and few well-marked slickensides were noted. Where ore occurs on the Kirtley vein the streak may consist of a single seam ranging from 1 or 2 inches to several inches of high-grade ore, or to 2 feet or more where low-grade zinc ore comes in abundantly. However, in places the ore streak may widen and consist of several feet of fractured rock with stringers of ore running all through the mass. For example, the Kirtley vein near the intersection of the O. K. contained nearly 3 feet of zinc ore which was of too low grade to pay for extraction, but alongside of this low-grade belt on the south was a zone of fractured rock 6 or 8 feet wide which had seams of high-grade ore scattered throughout and paid well. In places the vein filling consists of a breccia of ore and rock recemented by quartz.

On the Kirtley tunnel dump was found a specimen about 6 inches in width which represents part of the vein filling and shows a barite seam 1½ inches wide, traversing a hard, well-indurated mass which at first appearance seemed to be fine-grained granite or granitic gneiss, but on close inspection proved to be finely crushed country rock containing small fragments of ore and crystals of barite cemented together by silica deposited from circulating waters. (Cf. p. 153.) Narrow tubular crystals of barite radiate out from the seam or barite into the crushed mass and appear to have been formed at a time when the crushed country rock was in a soft, pasty condition with the consistency of mud. On many of these barite crystals is either a layer of comb quartz with the quartz crystals growing out from the barite or a thin coating of colorless quartz which gradually shades into the quartz matrix cementing the crushed rock.

Possibly later barite is associated with this quartz in forming the cementing material to a less extent. Well-formed crystals of barite also occur in long, narrow vugs in the vein filling. The deposition of the barite as a whole seems to be subsequent to the ore deposition (cf. p. 165), for angular fragments of galena and sphalerite are found embedded in the barite or the barite crystals loop about portions of the ore fragments. Particles of ore also occur in the crushed rock mass, which is cut by the seam of barite. Siderite and specularite, which are subsequent to the comb quartz coating the barite, are also sparingly present.

The veins in places show banding to some extent, due to parallel sheeting and subsequent filling of the cracks with ore, both chalcedonic and comb quartz, calcite, and siderite. Much of the ore is probably due to a replacement of the gouge and crushed rock vein filling, though a considerable part is the result of impregnation of the wall rocks immediately adjacent to the fracture, especially in the vicinity of the vein junctions.

COMPOSITION OF VEINS.

Much of the ore from the main vein of the Kirtley group differs considerably in grade from the ore on the branches. Most of the best ore, however, consists mainly of galena with some brownish to yellowish-green resin zinc blende and comparatively large amounts of polybasite and tetrahedrite. Copper-bearing pyrite is also present in very small quantities, and is usually associated with the polybasite and tetrahedrite ("gray copper") or forms a thin coating apparently of slightly earlier origin than these two minerals and may occur as thin films along conspicuous cleavage planes of the galena. Pyrite crystals are also associated with the chalcedonic quartz matrix cementing the crushed and altered rock fragments in the vein. Ruby silver, pyrargyrite, and some proustite are present here and there, but are rare in comparison with the amounts in the ores of the Colorado Central mine. Gold occurs as a mere trace. In one place a thin coating of a sectile metallic dark-gray mineral resembling argentite (silver glance) was found along a crack in silicified crushed rock.

Quartz is the chief gangue mineral, but barite is abundant and some calcite is also present. The quartz is either of the nature of comb quartz coating the walls, rock fragments, and the inside of vugs, or is a chalcedonic quartz cementing the crushed vein materials. Calcite, besides being intermixed with the other gangue minerals, also occurs with other carbonates as clusters of little white specks coating the ores in vugs.

The silver values lie chiefly in the argentiferous sulphides (polybasite, tetrahedrite, pyrargyrite, and proustite) which occur both massive and as well-formed crystals lining vugs and which usually appear to be of later origin than the galena and sphalerite. The richness of the ore depends mainly on the quantity of these silver minerals disseminated through it, for the galena and sphalerite are as a rule lean in silver values. The low-grade ores usually have a high content of zinc blende, although they may consist of a mixture of coarse galena and blende carrying little silver. Fine-grained galena or galena having a fibrous texture carries higher values.

The ores of this mine when sorted usually fall into three classes, as follows: First class, 500 to 600 ounces of silver; second class, 300 to 400 ounces of silver; third class, 100 to 200 ounces or less of silver.

The Kirtley vein itself had the largest bodies of ore and ore of all grades. The Stranger vein produced relatively high-grade ore, and although it was a coarse galena, sphalerite, and barite mixture it belonged almost entirely to the first class. The parallel vein about 20 feet southwest of the Stranger yielded ore belonging to the lower grades.

In the O. K. and Tilden veins the ore near the surface, although it occurred in a narrow streak, contained large amounts of the soft brownish oxidized ore and also of the rich powdery black sulphides that are associated in many places with the oxidized ores, termed locally "sulphurets of silver." On account of these highly argentiferous compounds, the ores at and just below the surface were of much higher grade than those taken from lower depths and are said to have carried a high percentage of lead and from 100 to 1,200 ounces of silver. According to Fossett, the Tilden in 1877 produced richer average ore than any other mine in the district. Just above the Kirtley tunnel level, however, the ore streak on the O. K. vein consisted of 4 inches of galena and blende carrying but small amounts of silver.

On the Argentine and Creole veins the ore, although averaging less than 100 ounces of silver, carries a high percentage of lead. Considerable zinc is associated with the lead and about 0.1 ounce of gold is also present. Cupriferous pyrite is abundant along cracks. Calcite veinlets and also incrustations on faces of fractures, both in the vein filling and in the country rock, are also conspicuous. These calcite deposits, which are normally white, have in places a greenish tinge due to the presence of copper. (Cf. pp. 259–263.)

LOCATION OF ORE.

In the Kirtley group of veins practically every vein junction seems to have had a beneficial influence on ore deposition. As a rule the ore is located immediately at the junction and along the united vein beyond the junction, but may extend along one or both of the uniting veins. For example, where the Stranger vein unites with the Kirtley, the ore started immediately at the junction and extended northeastward for about 500 to 600 feet, and was stoped almost continuously for nearly the entire distance. However, the union of the O. K. and several small veinlets probably also assisted materially in causing the long stope. This ore shoot near the junction of the Stranger vein went up about 150 feet above the Kirtley tunnel but did not reach the surface. To the east the ore did not go up so high. The ore was also followed downward to a distance of about 90 feet below the Kirtley tunnel level. No shoot on the

Kirtley vein itself was ever worked to the surface. On the Stranger vein ore extended from the junction with the main vein for a distance of more than 200 feet (fig. 100). However, the most and best ore was found 20 or 30 feet west of the intersection of a branch veinlet which crossed the Stranger vein about 25 feet west of the Kirtley vein. This branch veinlet connects the Stranger vein with the vein located about 20 feet to the south which runs parallel to the Stranger vein, and, although not an extra strong vein, is mineralized for a distance between 100 and 200 feet.

Both the O. K. and Tilden veins were mineralized from the surface to a point some distance below their junction. The amount of mineralization was greater near and below the line of union, but owing to oxidation and enrichment due to the action of surface waters the ore near the surface was of higher grade and paid better for mining.

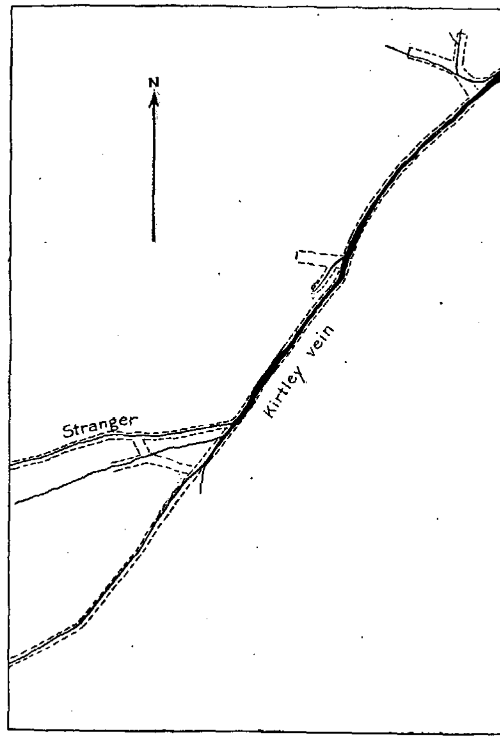


FIG. 100.—Plan of Kirtley vein as shown in Kirtley tunnel. The formation of ores at the junction of branches is here illustrated.

On the Dunaway tunnel level a couple of small shoots occurred on the Kirtley vein to the east of the long ore body, and each of these illustrated well the effect of uniting veins, for these isolated shoots extended for only 10 or 15 feet along the main vein beyond the union of branches, but followed the line of junction up and down for considerable distances. In the Creole and Argentine tunnels where ore was present it was also in the vicinity of vein junctions.

PRODUCTION.

Although the Kirtley vein was not intersected until October, 1877, it began to produce immediately, and up to April, 1880, the Kirtley mine had produced about \$250,000.[a] Of this amount, about \$200,000, according to Mr. Weaver,[b] of Georgetown, the present owner, was taken from the Kirtley tunnel level or just below this level. It is also said that a large amount of ore was taken from the stope running eastward from the Marshall tunnel of the Colorado Central mine.

A good many thousand dollars were obtained from the O. K. and Tilden veins, especially near the surface, for the ore in depth was not as rich as that higher up. The O. K. vein yielded several small lots of very rich ore as early as 1871, and in 1877 the small amounts of ore taken from the Tilden vein were the richest in the camp. The Kirtley vein in the Dunaway and Argentine tunnels also produced considerable rich ore. The Argentine vein was fairly productive, but the ore did not carry such high values. The Creole vein has produced a little low-grade ore.

WIDE WEST LODE.

LOCATION AND HISTORY.

The Wide West lode, which is located mainly on the east slope of Leavenworth Mountain, has been traced from a point just above the large reservoir in the valley of South Clear Creek westward up the slope and over the crest of the mountain ridge separating the two forks of Clear Creek.

This mine (Pl. XLVII), which had previously been worked to some extent, attracted very little attention until the spring of 1881, when a large body of very rich ore was encountered.

[a] Fossett, Frank, Colorado, 1880, p. 402.

[b] Verbal statement.

Since that time the production, which has varied greatly from year to year, has aggregated an amount that is in the hundreds of thousands. Active work has recently been resumed owing to the discovery of another body of ore.

DEVELOPMENT.

More than 8,500 feet of drifts and crosscuts have been driven on the Wide West property, but many hundreds of feet of drifts run during the early history of the mine have since been allowed to cave shut. Most of the development has been carried on through tunnels on the vein and on shafts or raises connecting these tunnels.

NATURE OF WALL ROCKS.

The wall rocks for the most part consist of alternating patches of pegmatite and granitic gneiss (Pl. XLVIII). Granite is also common, especially near the east end of the lowest tunnel level, and a small amount of soft biotite gneiss is present in places. No porphyry is known to occur on the property. Owing to the small extent of the areas of the different kinds of rock the effect of each kind on the vein was not pronounced. The veins usually cut the gneiss nearly at right angles to the schistosity, which was in general slightly east of north.

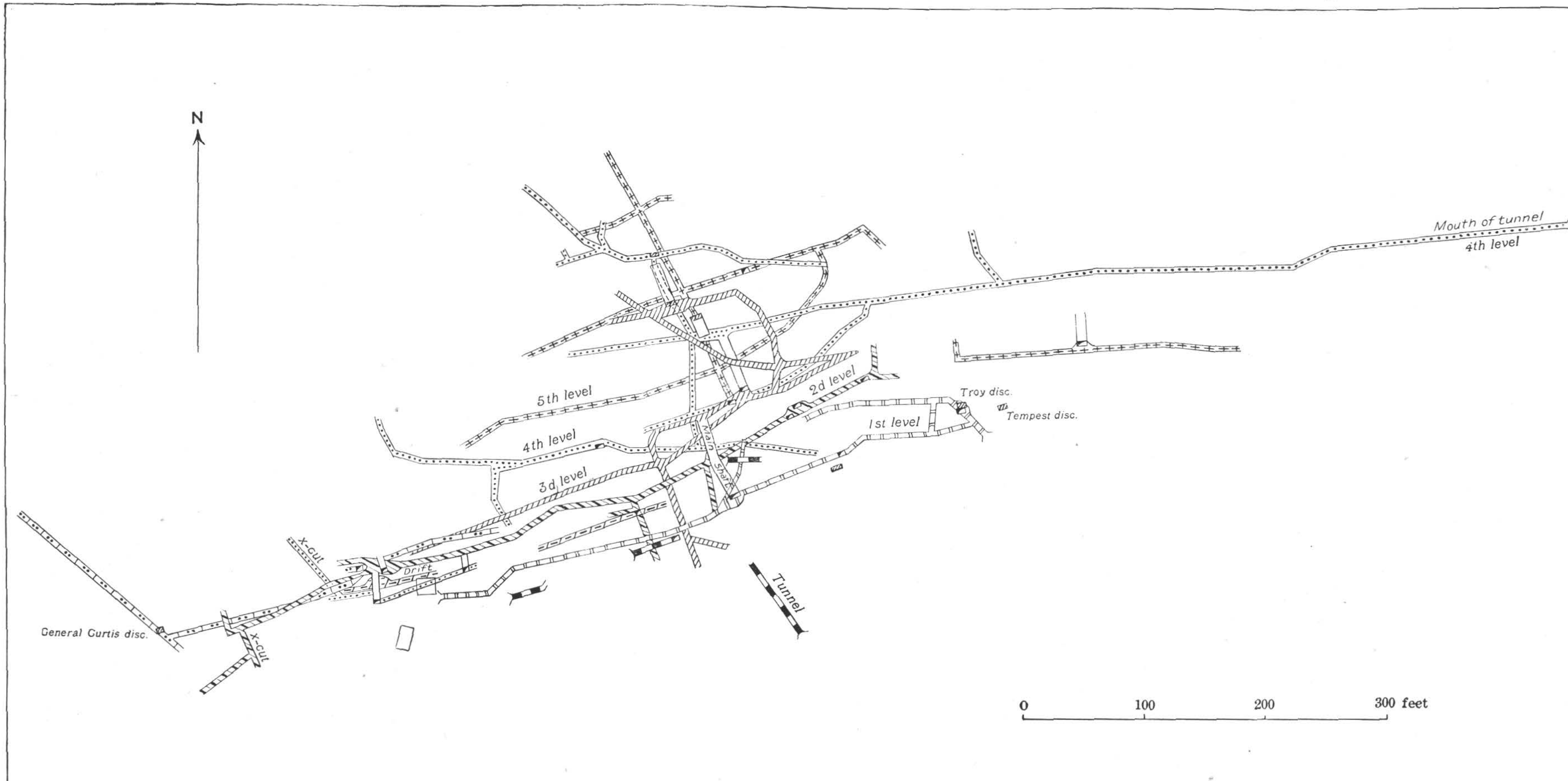
NATURE OF LODE AND LOCATION OF ORES.

This lode has a general strike of S. 82° W. and a dip of 60° to 75° N. The lowest level of the mine shows the Wide West lode made up of two veins only 10 to 20 feet apart, running parallel to each other for more than 1,000 feet. Of these two the south vein has a dip slightly flatter than the north vein, and is also a much narrower and less pronounced lead, owing to the fact that the movement was insufficient to form a continuous single fault, but resulted in a string of connecting minor fractures. The small ore streaks found in places along this southern string of fractures, though only 1 to 5 inches wide, usually contained much richer ore than the broader streaks along the north vein. Extensive movements along this north vein are indicated by slickensides as well as by the 6 inches to 3 feet of soft gouge and pulverized rock which occur continuously along it except where small bodies of quartz ore have occupied their place. However, to what extent the movements caused displacement is unknown, although that there is some dislocation is shown by the discordance of the wall rocks on either side.

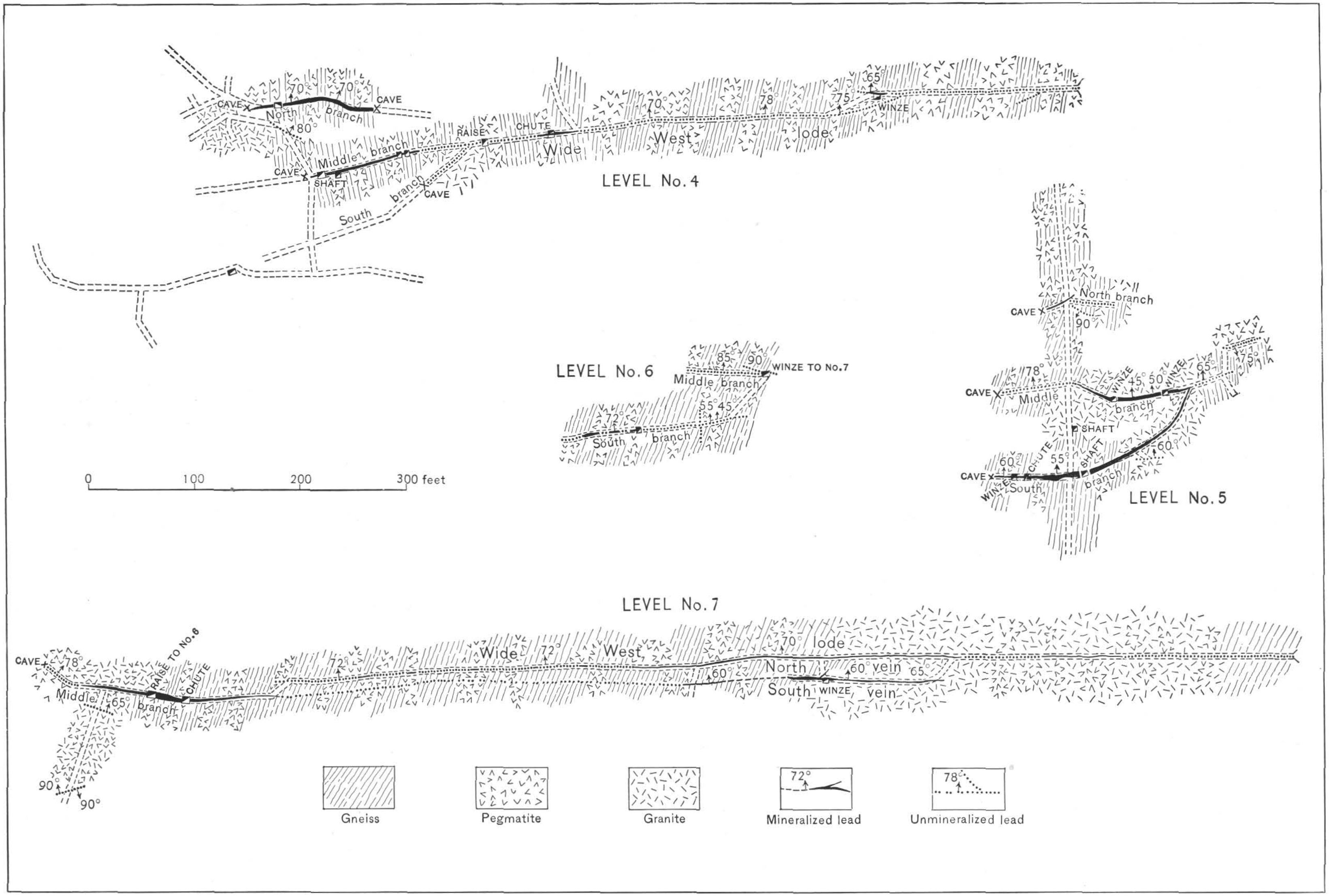
The main lode on level No. 4 is followed westward by the tunnel for about 600 feet to the point where it splits up into three veins that diverge from one another going westward. The "south" and "middle" branches are evidently formed by the splitting of the south vein of the Wide West lode." Each of these three veins carried valuable deposits of ore not only on this level but also on the level above and on level No. 5 below. The largest and richest body of ore in these veins occurred along the "south branch," and according to Mr. Charles Pilz the stope resulting from the extraction of this ore was 200 feet long and had a vertical extent of about 300 feet, pitching slightly to the east. The ore body on the "north branch" was, moreover, larger and richer than that on the "middle branch."

The "south" and "middle" branches near their junction were soft gouge and crushed rock leads 2 to 5 feet wide, showing only the slightest evidence of mineralization. However, both the main vein and the two uniting branches carried ore bodies, but they were formed at a distance of about 75 feet from the junction in each vein. Those in the branches were the more extensive deposits. The point of junction of the "north branch" with the "middle branch" or with the main vein is ill defined, but must exist if the north vein continues its general trend. The obscureness of the junction is possibly due either to the fact that the point where these two veins unite was not mineralized and is therefore not easily detected, or to the fact that the north vein of the main lode may continue as the "north branch."

The ore shoots on the three veins are said to have been cut off on the west by a cross fault or soft lode composed of crushed and badly stained and altered rock mixed with soft clay and scattered angular pieces of ore. This part of the mine, however, was not accessible owing to caving.



HORIZONTAL PLAN OF WORKINGS OF WIDE WEST MINE.



GEOLOGICAL PLANS OF SEPARATE LEVELS, WIDE WEST MINE.

A noticeable feature of the deposits on the three branch veins was the location of the larger ore masses on "flats" or places in the vein where the dip was much less. The regular dip of the vein ranges from 65° to 78°, but in places where the ore bodies were broadest and richest dips as low as 45° were obtained. This flattening of the dip is especially noticeable on the "south" and "middle" branches on level No. 5.

The Bambrick vein is parallel to the Wide West main vein and about 200 feet farther west.

STRUCTURE OF LODE.

The north vein in the lower tunnel levels consists of a single broad fracture filled as a rule with soft clay or gouge and crushed gneiss, pegmatite, and granite, which gives way in places to a gray quartz that in turn becomes ore bearing in spots. The string of minor fractures parallel to this vein, representing the south vein, in general run through comparatively hard rocks, and the ore where it occurs consists of narrow but rich stringers or seams, most of them tightly "frozen" to the wall rocks.

The three branches of the main lode at the west where mineralized consist either of parallel foot and hanging walls with a network of quartz and ore stringers ramifying between two fracture planes 2 to 12 feet apart, or else of a single well-defined wall from the crack along which the mineralizing solutions penetrated the adjacent wall rocks for varying distances and impregnated them with a greater or less quantity of metallic sulphides.

Specimens of vein filling from the openings which are located southwest of the crest of the ridge of Leavenworth Mountain at first sight appear to be angular fragments of galena and blende ore included in porphyry. (Cf. p. 136.) On close examination, however, the matrix inclosing the ore fragments proves to be finely crushed granitic gneiss, granite, or pegmatite, the particles of which are compactly cemented by secondary silica. The nature of the vein filling indicates that movement subsequent to the mineralization has resulted in a fissure filled with rubble comprised mainly of ore, that circulating waters have brought in the finely crushed rock matrix in a pasty condition and filled the interspaces, and finally that the underground waters have brought in the quartz which formed the hard siliceous cement.

COMPOSITION OF LODE.

Quartz, usually gray in color, is the chief gangue mineral. Barite is found sparingly and extends to depths as great as 500 feet below the surface, in general as well-formed crystals lining vugs. Siderite and possibly also ferruginous calcite are common near the surface outcrops, but were not encountered in the lower levels.

The metallic minerals are galena, blende, polybasite, tetrahedrite, and pyrite, the last named generally copper bearing. The blende is usually the yellow, light-brown, or green "resin blende."

The ores are as a rule very rich in silver and there are several records of mill runs which ranged all the way from 1,000 to 2,000 ounces of silver to the ton. A recent mill run on ore from a minor stope showed 236 ounces of silver, 8 per cent of lead, and 4 per cent of zinc per ton. Ore containing fine-grained massive galena commonly carries high values in silver.

CHANGES OF ORE IN DEPTH.

In some of the surface cuts the walls of the vein show numerous blotches or specks of the copper carbonates, azurite and malachite, chiefly the former. These carbonates, which have the nature of stains or thin films deposited on the hard rock walls from solution, were probably derived from the alteration of the cupriferous pyrite, and had apparently been transported for some distance in solution, as casts of dissolved sulphides were entirely lacking in the quartzose vein filling. Blue copper-carbonate stains were also noted in one stope that was more than 300 feet below the surface. A honeycombed porous gossan was found at several points where the vein outcropped.

For short distances below the surface siderite aud ferruginous calcite are common, both as massive stringers and as well-formed rhombic crystals lining small irregular vugs. The ores, which are locally called "sulphurets" and which consist usually of soft brown and black oxidized ores and somewhat similar appearing mixtures of these oxides with sulphide ores of secondary origin, are said to have been common near the surface.

The richest and largest bodies of ore were found between the third and fifth levels. It was from this locality that assays running several thousand ounces of silver to the ton were obtained from picked specimens. Good ore, however, running 200 to 400 ounces to the ton, has been taken from depths of more than 600 feet below the surface.

CENTRAL COLORADO LODE.

LOCATION AND DEVELOPMENT.

The Central Colorado vein, which is located on the northwest slope of Leavenworth Mountain, is developed by a series of tunnels. The main development being carried on at present is through a tunnel about 450 feet in length, which enters the hillside at an elevation of approximately 9,000 feet and intersects the vein about 400 feet from its mouth. About 225 feet of drifting has been done along the vein and some stoping has been begun.

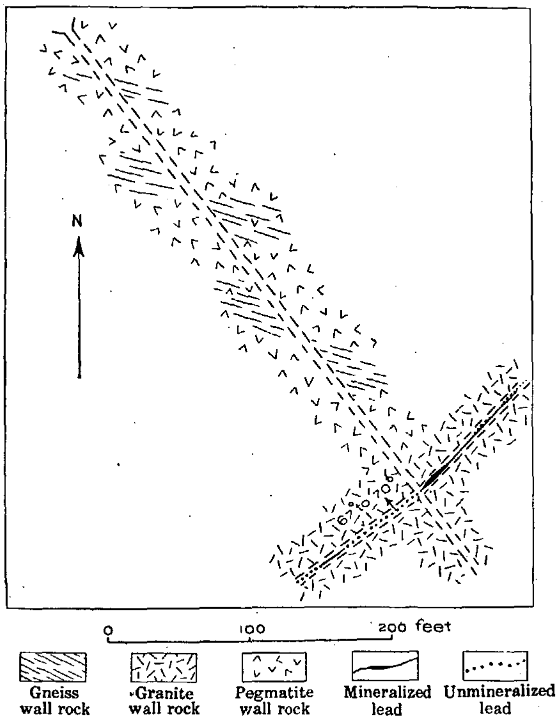


FIG. 101.—Geological plan of tunnel workings, Central Colorado vein.

NATURE OF WALLS.

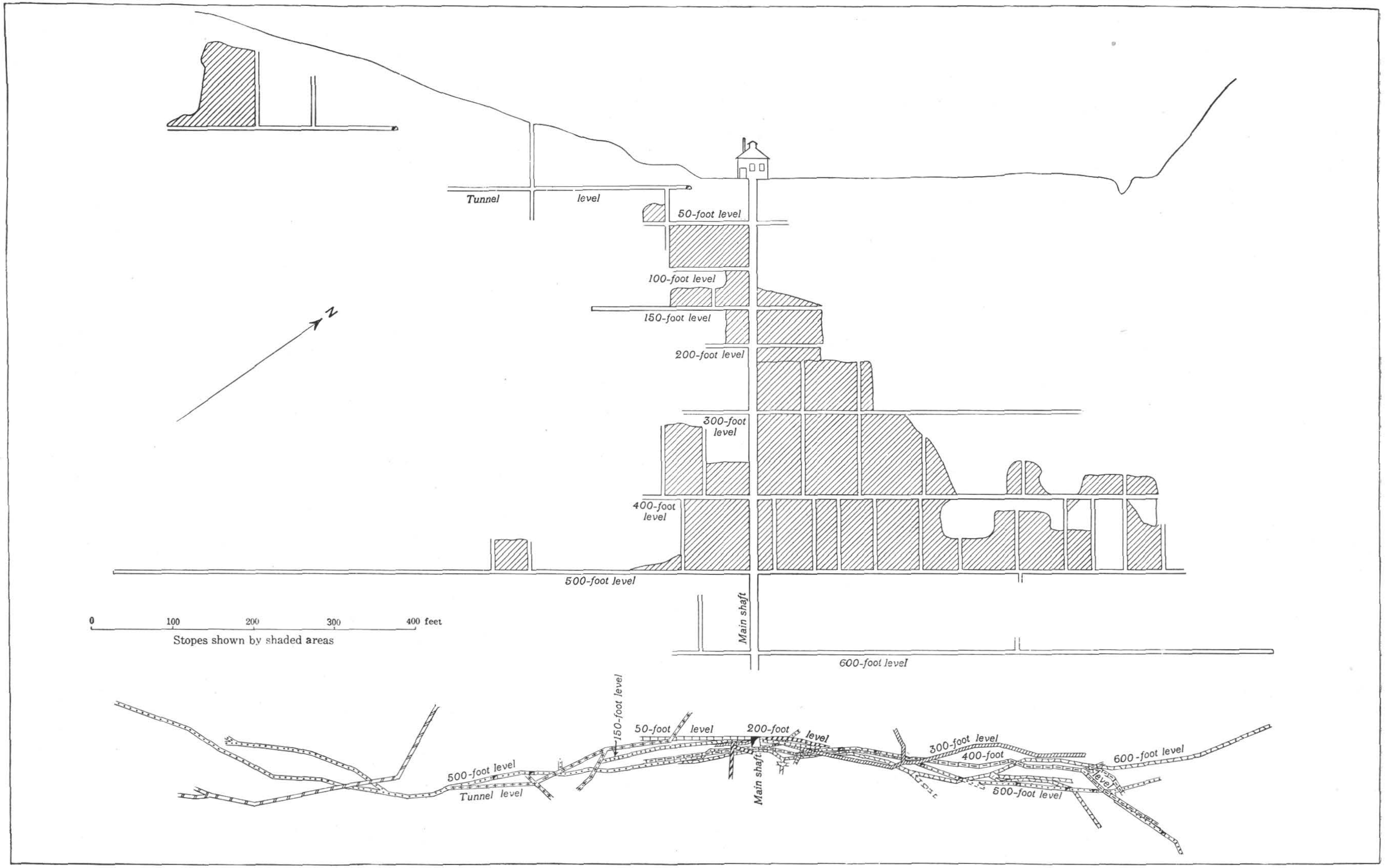
The country rock through which the tunnel (fig. 101) is driven is chiefly pegmatite with small patches of gneiss, usually of a hard granitic variety, inclosed within it. The walls of the vein, however, are mainly hard and comparatively fresh biotite granite. No porphyry was observed in the workings.

NATURE OF VEIN.

The vein usually consists either of a single narrow fracture or of a series of small or tight fractures traversing hard granite in a N. 45° E. direction. Very little movement has occurred along the vein, as gouge, slickensides, and other evidences of faulting and differential movement are almost entirely lacking. Gouge as thin selvage one-eighth to one-fourth inch thick occurs locally between the ore and the wall rocks, but as a rule the ore is "frozen" to the walls. In the vicinity of the small stope from which ore was being extracted the vein had the nature of a stringer lode, and consisted of a series of small mineralized veinlets running parallel to the strike of the vein and in places connected by a network of still finer veinlets.

ORE.

The ore is mainly gold bearing and consists chiefly of pyrite, which is as a rule light in color, but in places carries so much copper that it verges on chalcopyrite. Thin seams or coats of zinc blende occur here and there between the copper-bearing pyrite and the wall rock, as if the zinc sulphide were of earlier origin than the cupriferous pyrite. The ore, which carries from a fraction of an ounce to 2 or 3 ounces of gold and practically no silver, occurs either as fairly well formed crystals of pyrite lining vugs or as massive cupriferous pyrite which adheres



VERTICAL AND HORIZONTAL PLANS OF CENTENNIAL MINE WORKINGS.

tightly to the comparatively fresh wall rocks or is separated from these rocks by a thin selvage. In places where the ore adheres tightly to the walls the boundaries are rather irregular, owing to the replacement of more or less of the country rock adjoining the fracture. The chief gangue mineral is quartz, which in places shows comb structure. Small amounts of siderite and ferruginous rhodochrosite, as well as of barite, are also present.

WELCH LODE.

The Welch vein was actively developed in the early seventies and produced several shipments of very rich ore, but serious difficulty was encountered in exploration work owing to the discontinuous nature of the vein, due either to faulting or to irregularities in the vein fracture itself. At the time of visit no work had been done for years and practically all the workings were caved shut except a short tunnel and shaft located on the upper part of the west slope of the north spur of Leavenworth Mountain.

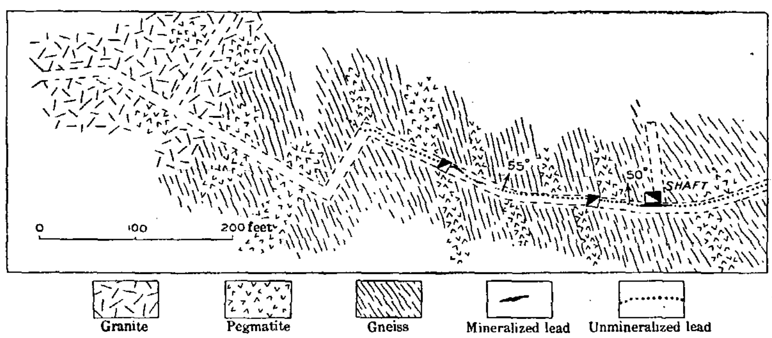


FIG. 102.—Geological plan of tunnel on Welch lode.

The country rock consists chiefly of soft micaceous gneiss with patches of pegmatite and granite. The strike of the gneiss is slightly to the west of north. In the tunnel (fig. 102) above mentioned the vein, which on the surface crosses the crest of Leavenworth Mountain ridge with a strike of S. 85° E., has a curved outline with the concave part of the curve facing north and the strike ranging from S. 62° E. to N. 70° E. It dips northward from 50° to 55° and consists of a clay and crushed rock lead which at certain points is replaced to some extent by quartz or by quartz and ore. Small stopes in the parts of the workings still open indicate that considerable ore was probably extracted from the mine.

CENTENNIAL GROUP OF VEINS.

GENERAL DESCRIPTION.

The Centennial lode and its branches outcrop on the southern edge of the town of Georgetown and pass up over the northwestern shoulder of Leavenworth Mountain. The main or trunk vein, the Centennial, with a general strike of N. 40° E., passes on the northwest under the drift which here floors Clear Creek valley. Near the southwest end of the developed portion it gives off a number of branches, which strike S. 60° to 70° W. These branches are parallel and relatively close together, forming a zone a few hundred yards wide. The best known is the Burrel, on which, not far from its point of junction with the main Centennial vein, there is a shaft. Lying south of and parallel to the Burrel vein is the Big Indian vein, which appears to be a branch of the Burrel and to unite with it at the Burrel shaft. Another lode, lying not far north of the Burrel and parallel to it, joins the Centennial independently of the Burrel. The junctions either have not been encountered or are obscure in the accessible underground workings of the Centennial mine. All these veins are vertical or nearly so.

Taken all together, these lodes have been developed for a linear distance of more than half a mile. The main Centennial lode has been developed underground along a strike extent of upward of 1,400 feet.

The Centennial mine (Pl. XLIX) is reported to have produced ore to the value of $300,000. The Burrel is reported to have produced about $17,000, taken out mainly around the shaft, which is probably at the junction with the Big Indian vein and is not far from the junction of the Burrel with the Centennial.

The Centennial vein is opened up by a shaft more than 600 feet deep, from which run various levels, as well as by some tunnels above the shaft. The Burrel vein was worked principally through a shaft. The Big Indian has a tunnel drift about 300 feet long on the vein.

ORIGIN OF VEIN.

Like the other veins of this region, the veins of the Centennial group have formed along a zone of fracturing and minor faulting. On the northeast end of the sixth level drift, striæ dip to the southwest at an angle of 32° from the horizontal, indicating the direction of differential movement. This fracture zone has been cemented by the vein materials. Little evidence of fissure filling appears. There is, however, much reason to suppose that the fracture zone may have been first decomposed and leached by waters, thus causing it to shrink and become porous, before mineralization. Where not mineralized the vein zone is still soft, but where it is mineralized it is cemented hard with quartz and sulphides.

STRUCTURE OF VEIN.

As seen on the 500-foot and 600-foot levels (Pl. L), the Centennial is a strong vein that branches and weakens at both ends. In the northeastern developed portion the branches open out to the northeast; in the southeastern portion to the southeast. The Centennial is opened up on these levels for about 1,300 feet. On the northeast end the branching and weakening of the vein takes place under the drift of Clear Creek, but on the southwest several of the branches, as above described, are visible on the surface and have been separately located and worked.

The plan of the fifth level (Pl. L) shows, near the southwest end of this level, a branching and reuniting of the vein, the two branches inclosing a horse of country rock. Similar features have been observed elsewhere in the district, as in the Dunderberg and Brown mines (figs. 84 and 81).

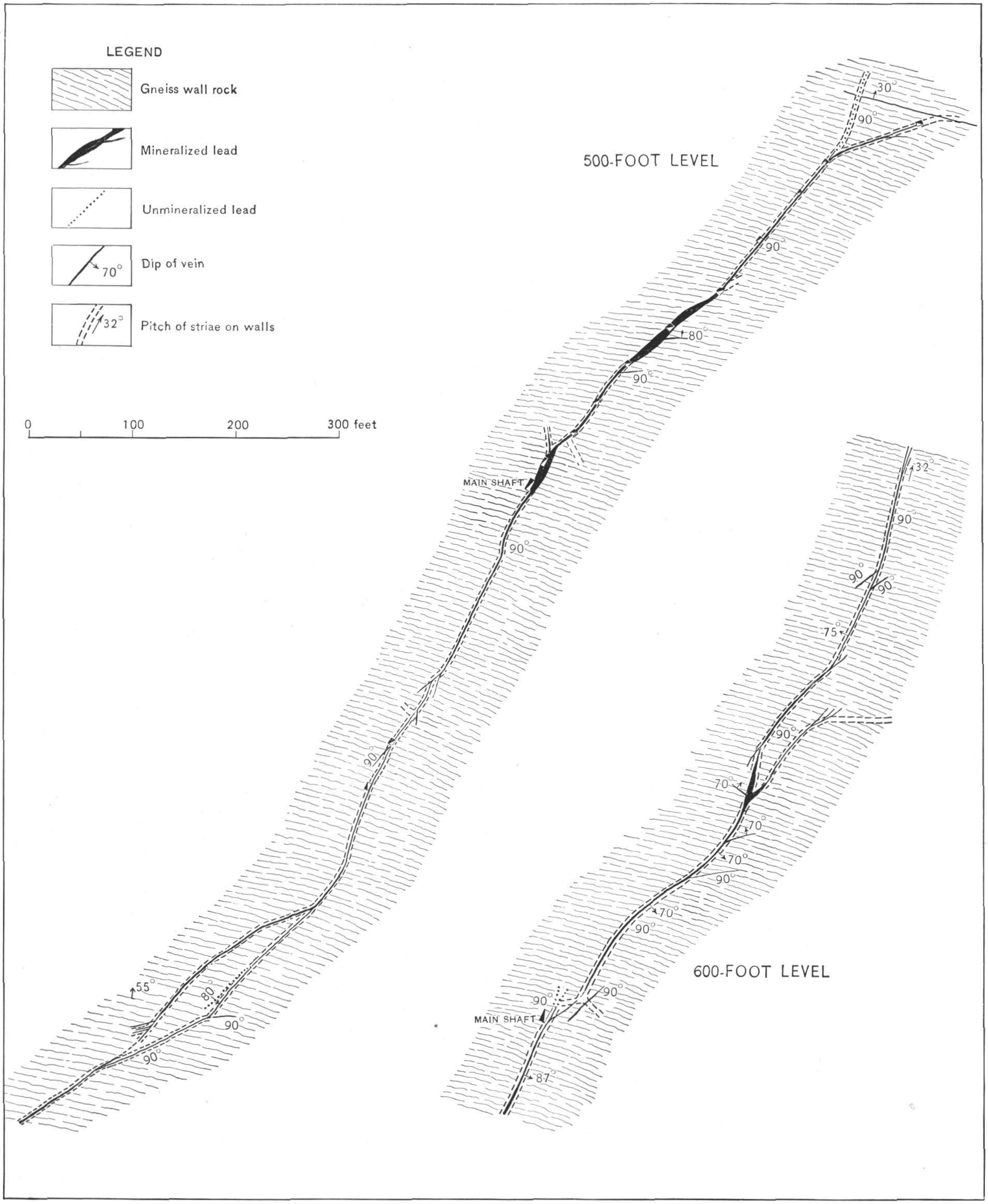
NATURE OF WALL ROCKS.

The country rock of the Centennial vein is chiefly black biotitic gneiss, generally massive, with some pegmatite. There is also a little porphyritic granite. The same gneiss also forms the principal wall rock of the Burrel vein and the other branches of the system which are parallel to it. The southwestern extensions of these branches, however, run into a mass of porphyritic granite. The wall rock of the Big Chief tunnel is entirely granite.

COMPOSITION OF VEINS.

The chief gangue of the Centennial vein is quartz, which is relatively abundant. Here and there the vein is made up mainly of quartz and carries very little sulphides. The principal metallic minerals are pyrite, cupriferous pyrite, chalcopyrite, and tetrahedrite. A little galena and blende occur, but not in sufficient quantities to yield more than traces of lead and zinc in large shipments of ore. The values in the ore consist of gold, silver, and copper, the silver content in the ore produced ranging from 20 to 30 ounces, the gold from 1 to 1½ ounces, and the copper from 4 to 8 per cent. The average value of the ore taken out between the 300-foot and 500-foot levels is stated at $18.60, of which about three-fourths was derived from the gold. The presence of gold in the ore seems to be dependent on that of copper. It is reported that where copper pyrite is present in the ore gold occurs in it and in the iron pyrite, but that where there is no copper in the pyrites they are poor in gold or barren. Some small portions of the ore run very high in gold, one assay of 522 ounces being reported from the 500-foot level. On the 600-foot level a small patch of tetrahedrite is said to carry $3 to the ton in platinum and iridium.

Occasionally druses lined with siderite are found. The Big Chief lode, which is probably a branch of the Centennial, shows different ore from that of the main vein. Here blende and galena are prominent, and chalcopyrite and pyrite are also present. Silver, gold, and copper are



GEOLOGICAL PLANS OF SEPARATE LEVELS, CENTENNIAL MINE.

present in the ore, but in such small quantity that it can not be mined at a profit. The highest grade ore is reported as worth only about $10 to the ton. Fluorite occurs in this ore, being later than the mineralization and coating cavities in the old sulphides.

DISTRIBUTION OF ORE.

On the Centennial vein a definite ore shoot extends from the surface down below the fifth level. The stope map indicates that the extent of this ore shoot along the vein increases continuously to the bottom of the shoot. This downward termination of the ore comes between the fifth and sixth levels. Below this, on the 600-foot level, the vein is strong, but with much less values in silver, copper, and gold, the average value of the ore being from $6 to $10. On the 500-foot level one of the principal portions of the ore shoot seems to be due to the junction of two strong branches, converging to the southwest. At the junction the ore in places was from 10 to 14 feet wide. The branch vein is only slightly mineralized, but the other vein is 4 to 5 feet thick, increasing in thickness toward the intersection. It is reported that ore forms at the same intersection in all the levels from the fifth to the surface. On the sixth level, at the shaft, the same junction of branches is seen, but it carries no ore.

As a rule the ore produced does not contain any appreciable quantity of lead. In one locality, however, on the 500-foot level, where the main vein branches, about 450 feet northeast of the shaft, the southeast branch carries galena in considerable quantity, one mill run yielding 7½ per cent of lead. The other branch shows the usual character. This variation of the mineralogical composition of the vein in different parts and also in different branches emphasizes the fact that rock openings of the same age and adjacent to one another have been penetrated by differing solutions. The occurrence of ore at the intersection of branches noted in this group of veins and elsewhere in the district is probably due to the precipitation resulting from the mingling of such solutions, flowing along distinct channels.

Although the main ore shoot has a definite and somewhat abrupt downward termination midway between the 500-foot and 600-foot levels, at a vertical depth of about 550 feet, yet in the extreme southwest end of the 500-foot level, at the time of the writers' visit, another separate body of ore was being opened up which was reported to be as good as any other that ever came out of the mine. This ore contained copper pyrite and tetrahedrite, like the ore of the main shoot. On account of the depth gained in this southwest drift by passing under the North vein of Leavenworth Mountain, this ore lies at a greater vertical distance from the surface than certain portions of the barren 600-foot level.

PARAGENESIS OF ORES.

The gold content of the ores, as above stated, appears to depend on the presence of copper. The silver also appears to be chiefly associated with copper, probably in the form of tetrahedrite. The very rich assays of gold ore above mentioned are described as occurring in ore resembling tetrahedrite. Silver does not seem to be associated usually with the lead, for the galena ore described above as occurring in a branch vein on the 500-foot level does not contain more silver than the ordinary amount.

The tetrahedrite as a rule is later than the chalcopyrite and is secondary to it, as is shown by its occurrence as definite streaks along fractures in the chalcopyrite. It is also later than the pyrite. No evidence of the relative age of the pyrite and chalcopyrite was noted. The abrupt diminution in the quantity of both chalcopyrite and tetrahedrite between the fifth and sixth levels, however, with the incoming of large bodies of low-grade granitic ore on the sixth level, suggests that both chalcopyrite and tetrahedrite are later than the barren or relatively low-grade cupriferous original pyrite.

CHANGES OF ORE IN DEPTH.

Apart from the abrupt falling off in the principal ore shoot of the values in copper, silver, and gold, between the fifth and sixth levels, no marked variations in depth were noted. It is reported that in the main shoot the grade of ore was nearly the same at the surface as below, although probably the best and most abundant ore occurred near the bottom of the shoot, at the 500-foot level.

Partial oxidation of the ore is reported to extend down 10 to 20 feet or more, but sulphides, chiefly pyrite, extend locally quite up to the surface. Typically there is about 10 feet or more of glacial drift covering the outcrop.

PRESENT WORK OF UNDERGROUND WATERS.

At present water is found dripping in all parts of the workings. This water contains sulphates of copper, as is shown by various occurrences. According to J. S. Randall, of Georgetown, crystallized hydrous cupric sulphate, chalcanthite, is found in the old workings of the Centennial mine. David Kennedy, owner and superintendent of the mine, reports that car rails in the mine get coated with metallic copper precipitated from the waters. The rust scale on the inside of a water pipe in the mine, assayed by Mr. Kennedy, yielded 11 per cent of copper. These facts show that the copper sulphides have been transformed into soluble sulphate by oxidation. Recognition of this fact indicates that a considerable enrichment in copper of some of the sulphides has been brought about by such waters as these, and the downward termination of the richer copper ores between the 500-foot and 600-foot levels suggests that this is the downward limit of the enriched ores, below which are the unaltered or only slightly altered pyritiferous ores. This suggestion, however, should be taken with some reservation. Although the influence of descending waters has probably been considerable in enriching the ore in the ore shoot, yet the irregularity of these ore bodies as shown in all the veins of the district is such as not to exclude the possibility that the ore shoot may have been in part original and formed previous to the enrichment.

MINES OF GRIFFITH AND SAXON MOUNTAINS.

COMET-ÆTNA LODE.

The workings of the Comet and Ætna mines, which lie high up on the northwest slope of Griffith Mountain (Pl. LI, *B*), due east of the town of Georgetown, were undoubtedly driven in order to develop the same lode. At the time of visit, however, none of the workings of the Ætna were accessible owing to caving.

COMET MINE.

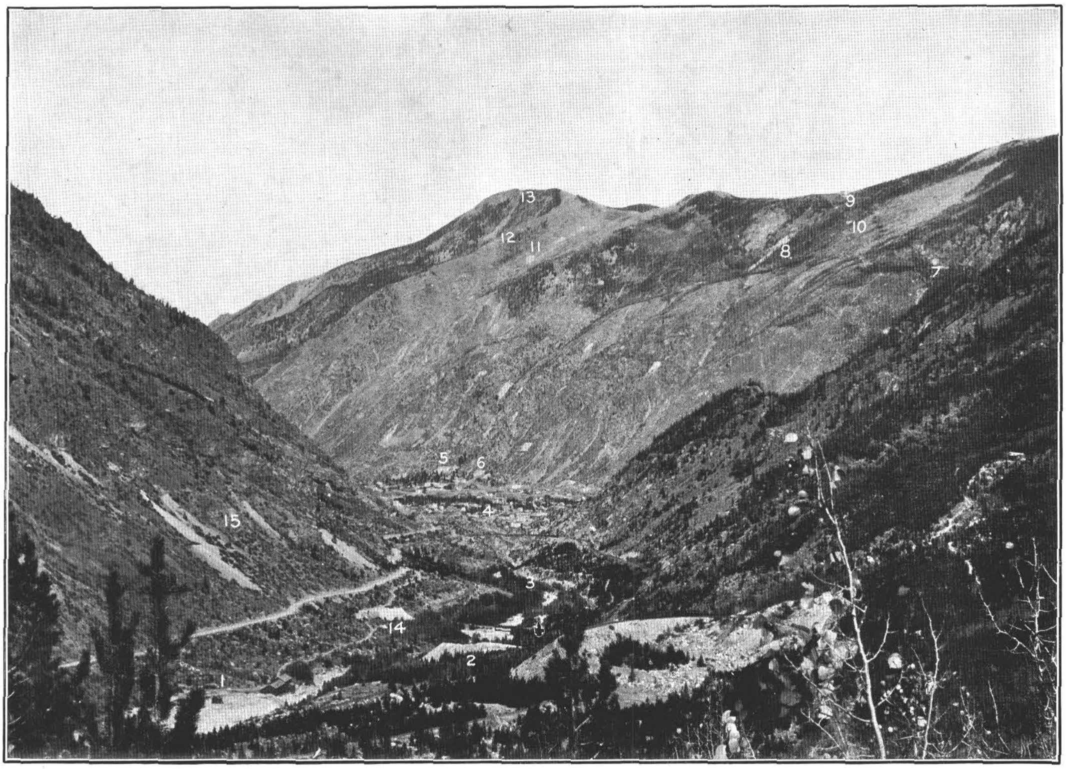
LOCATION, DEVELOPMENT, AND PRODUCTION.

The Comet vein, which was worked extensively even previous to 1871, is developed by three shafts located at an elevation of nearly 11,000 feet above sea level, at the point where the trail from Georgetown to Highland Park reaches the crest of the slope, and also by a tunnel on the west side of Griffith Mountain about 450 feet lower down. This lower tunnel follows the J. A. Hawkes vein (a crushed rock and clay lead dipping 55° to 65° NW. and trending N. 52° E.) for about 500 feet to the point where it connects with a crosscut drift driven S. 65° E. to its intersection with the Comet lode, which lies parallel to the J. A. Hawkes vein and about 600 feet distant.

Not even a rough estimate of the production from the Comet vein was obtainable, but undoubtedly a great deal of ore was taken from the old shafts near the crest of the slope in the early days of mining about Georgetown. It is said that $60,000 was taken from a shoot of ore that was found a short distance above a level run from one of the shafts at a point 275 feet above the tunnel level.

NATURE OF WALL ROCKS.

The wall rocks consist of much altered pegmatite, granite, and gneiss, the last both granitic and micaceous. In the tunnel level the walls of the J. A. Hawkes vein consist chiefly of fairly hard altered granitic gneiss, with irregular patches of pegmatite interspersed throughout. Where distinguishable the strike of the gneiss is about N. 80° W. and the dip 45° N. In the crosscut to the Comet lode (Pl. LII) the first third of the distance was also through gneiss and pegmatite,



A. VIEW OF GEORGETOWN, LOOKING NORTHEAST FROM CEMETERY HILL, NEAR SILVER PLUME.

Lebanon group of mines in left foreground; Griffith Mountain and Saxon Mountain mines in background. 1, Lebanon tunnel; 2, Hall tunnel; 3, Georgetown loop; 4, Georgetown; 5, Annette-Griffith tunnel; 6, Capitol mine; 7, Ætna mine; 8, Comet tunnel; 9, Comet shafts; 10, Ruler tunnel; 11, Magnet mine; 12, Woodley mine; 13, Summit mine; 14, Iris tunnel; 15, Lebanon group of mines.

B. GRIFFITH AND SAXON MOUNTAINS AND MINES EAST OF GEORGETOWN, FROM MOUTH OF CLEAR CREEK CANYON.

1, Annette-Griffith tunnel; 2, Capitol mine; 3, Comet tunnel; 4, Saxon Mountain.

but in places these rocks are soft, from alteration, and are cut by small dikes of the variety of porphyritic granite locally termed "corn rock." The southeast portion of the crosscut is composed chiefly of granite cut by narrow masses of pegmatite and "corn rock." In the vicinity of the Comet lode itself and for a distance of 100 to 200 feet to the northwest of it the country rock is mostly a mixture of pegmatite and gneiss with small amounts of granite and "corn rock." In this belt, however, the alteration has been so intense that in many places it is difficult to distinguish one rock from the other.

Two veinlets of gray jasper-like or chalcedonic quartz intersect the crosscut from the J. A. Hawkes vein and run parallel to the Comet vein. This jasper-like quartz resembles porphyry in both texture and color, and also because of the presence of scattered small whitish rectangular specks that resemble altered feldspar phenocrysts embedded in a fine-grained groundmass. Under the microscope, however, a specimen of this rock exhibits a microgranular texture and appears to be composed chiefly of chalcedony, although a few small streaks cutting through the finer-grained matrix are composed essentially of minute angular fragments of quartz crystals, sericite and talc, and rarely shreds of muscovite and leached biotite. A couple of minute grains of zircon were also noted in one slide. These quartz veinlets contained no ore, although the microscope showed a little pyrite and magnetite. This rock is probably a finely crushed and highly silicified gneiss. No undoubted porphyry was found in the workings.

Small stringers of somewhat similar hard dark-gray jasper-like quartz occur reticulated through the whole belt of softened country rock for a distance of 100 to 200 feet northwest of the main vein, and led to the prevalent idea that the vein here was nearly 200 feet wide. However, the most of this quartz contained no values whatever, although in the vicinity of the Comet vein proper a little mineral occurred in stringers or in small isolated bunches of a quartz of similar appearance, but this probably represented simply a replacement of kaolin or gouge by silica along small slip zones.

NATURE OF VEIN.

The Comet-Ætna vein, which is a strong fracture with 5 to 8 feet of quartz and clayey materials, is isolated from the rest of the veins of the district. The nearest ore-bearing veins are separated from it by 3,000 to 5,000 feet of unexplored or unproved ground. Many people hold that the Comet-Ætna lode is an extension of the Colorado Central vein and this correlation is not without some foundation, for both of the lodes are very strong fractures which have the same general dip and strike. The dip of about 70° NW. could easily account for the northwestward swerving of the surface outcrops of the Comet and Colorado Central lodes as they cross the bottom of the valley of Leavenworth Creek. However, as there is fully a mile of territory between the two recognized ends of the veins, no definite statement to the effect that the two veins are the same can be made. It is possible that the Comet vein represents only one of several branches of the Colorado Central main trunk vein or that the two may be distinct veins which die out by branching as they approach one another.

The Comet lode is very soft, and it is difficult to keep drifts open along it for any length of time. Consequently at the time of visit but little of the vein was exposed for study, as a result of the caving that had taken place during many years of comparative inactivity. From all appearances, however, the lode appears to be a single nonbranching one following two or more parallel planes of movement situated within a few feet of one another. It was not determined to what extent displacement had occurred along the fault planes, but discordances in the wall rocks on the two sides of the fractures were noted. That extensive movements have occurred is well shown not only by polished and slickensided surfaces, but by zones of crushed and pulverized wall rock, by banded friction clays, and by quartzose streaks which consist of well-rounded sandlike grains cemented together by a quartz matrix.

Considerable fracturing of the country rock probably accompanied the faulting which caused the vein fracture, as shown by the zone 100 to 200 feet wide which contains numerous quartz stringers. More or less sheeting of the wall rocks parallel to the main vein has taken place, as can be seen from the number of minor gouge leads occurring between and parallel to both the Comet and J. A. Hawkes veins. Two well-defined open fractures or "water breaks" also occur within this same space. One of these is an open fissure, in places nearly a foot wide, which furnishes a considerable flow of water and whose walls are heavily coated with the soft red and brown oxides of iron.

About 50 to 100 feet northwest of the Comet lode as exposed on the tunnel level is a connected series of leads with different strikes, forming a fairly persistent but irregular lead composed of 2 to 8 inches of crushed rock and gouge which in places grades into quartz or into quartz and ore sufficient in amount to have caused the miners to gouge up on the streak here and there and to put up a raise about 60 feet high in one place near the point where a small branch joins the Stranger lead.

STRUCTURE OF VEIN.

The vein where exposed on a level, connecting with one of the shafts at the crest of the mountain slope and located about 275 feet above the tunnel level, is extremely variable in width. One section of the vein (fig. 103) shows the foot wall, dipping 70° NW., to be somewhat altered granite. Resting upon this foot wall and separated from it by a narrow selvage is from 5 to 6 feet of very highly altered micaceous gneiss; above this is about 1 foot of yellow, brown, green, and blue fine-grained clay in alternating bands. This clay, which is very tough and putty-like, probably represents gneiss, pegmatite, and granite finely pulverized by extensive movements

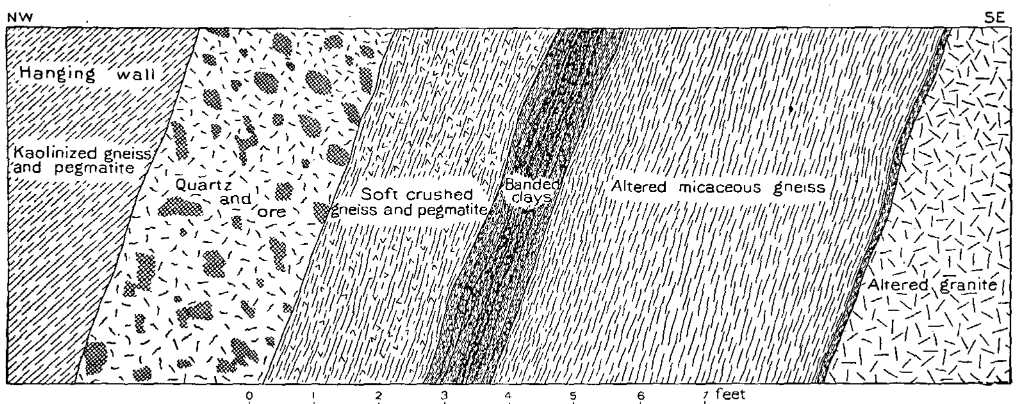


FIG. 103.—Cross section of Comet vein on level 270 feet above Comet tunnel level, showing the structure of the vein zone.

lengthwise of the vein or fault. Embedded in this clay are scattered fragments of pegmatite or granite with their long axes oriented parallel to the clay seams in such a manner as to give the clay belt the appearance of the banded flow structure commonly seen in contact phases of porphyry dikes.

Above and northwest of the alternating variegated clay bands are from 2 to 3 feet of soft, crushed, altered gneiss and pegmatite containing a considerable amount of kaolin or "gouge." Still farther northwest 2 to 4 feet of low-grade ore was noted. This ore zone consists mainly of quartz, which in places either partially or entirely fills cracks in highly fractured gneiss and pegmatite or else coats the fragments of gneiss and pegmatite with a layer of dark-gray jaspery quartz one-eighth to one-fourth inch thick, closely resembling the widely separated veinlets of jaspery or chalcedonic quartz that traverse the belt of altered country rock for 100 to 200 feet to the northwest of the Comet vein.

This dark-gray vein quartz is practically massive, with here and there a small pegmatite or gneiss inclusion that is not so much altered and replaced as to make it impossible to recognize the original rock, although it is highly silicified and its irregular boundaries grade into the mass of jaspery quartz gangue. The ore in this silicified zone occurs mainly in narrow vuglike openings in the partially filled cracks in the fractured gneiss and pegmatite, but also lining irregular-shaped cavities, many of which show crustification but no comb quartz, and which are probably cavities of dissolution resulting from the action of the mineralizing waters. Small bunches of ore are also found sparsely disseminated through the quartz mass.

The northwest or hanging wall, in contact with the quartz and ore belt, consists of a zone of kaolinized and somewhat silicified gneiss and pegmatite 100 to 200 feet wide. The structure of the vein, however, is not constant; for near the shaft, on the level where the above-mentioned section was observed, the ore streak changes to a belt over 10 feet wide of fractured and in places brecciated pegmatite and gneiss, recemented by dark-gray jasper-like quartz which carries practically no ore. Between this broad zone and the putty-like banded clay strip is 6 to 8 inches of rock which appears to be a greenish-gray porphyry, but which on microscopic examination proves to have a groundmass ranging from cryptocrystalline to a fine-grained aggregate of crushed quartz grains with irregular outlines and wavy or undulose extinction. In this groundmass are embedded larger rounded grains of quartz that in the hand specimen look like phenocrysts. This same rock section, moreover, shows that small cracks and rectangular open cavities formerly existed, and that subsequently these were first lined with a coating of carbonates and then the remaining space was filled with kaolin. In some of the stringers filling the cracks, the carbonates, especially where they completely filled the minute veinlets, were associated with small amounts of the contemporaneous ore-bearing minerals, pyrite, zinc blende, and galena, the last appearing to be of slightly more recent origin than the pyrite.

ORE.

The ore noted consisted mainly of well-formed crystals of galena, zinc blende, and a little cupriferous pyrite associated with some siderite or ankerite. This ore occurred generally lining narrow slitlike vugs along fractures or in irregularly shaped dissolution cavities lined with drusy, jasper-like, dark-gray quartz. Some of the blende was of a resinous nature and ranged in color from a light yellow or greenish yellow to a dark brown; other varieties were black and had a dark metallic luster. The ore exposed at the time of visit was of low grade owing to the predominance of the quartz gangue, but a large northeastward-pitching shoot of high-grade ore is said to have been stoped out at a point about 60 feet higher. The ore near the surface was also much richer.

The siderite and ankerite where present have the nature of porous coats on drusy quartz. In places a white earthy substance is found incrusting the crystals of galena and blende in vugs. A chemical analysis by W. T. Schaller shows this to be chiefly an alumina-bearing mineral resembling kaolinite, which contains some zinc but no carbonates. The zinc is probably in the form of a sulphide and the white substance may be either a physical mixture of finely powdered blende with the kaolinite, or kaolinite containing a small amount of the soft white amorphous form of zinc sulphide described by Dana.[a]

ÆTNA MINE.

The Ætna mine, which is situated high up on the west slope of Griffith Mountain, was first located in 1867. The vein is undoubtedly the southwestern extension of the Comet lode, for it has been opened up by three short tunnels, one above another, run into the hillside and extending almost to the limits of the Comet property. At the time of visit all these tunnels were caved shut. At present, however, a tunnel, now 1,900 feet in length, is being run by the Capital Mining and Tunnel Company from a point in the valley just east of Georgetown and south of the Griffith mine, with the purpose of intersecting the Comet-Ætna vein at a depth of about 1,500 feet below the proved surface outcrops. It has been estimated by the owners that this tunnel will cut the vein at a point about 2,600 feet from the mouth. The vein is broad and soft and is said to resemble the Comet lode in every respect. Small shipments of ore that have been made from the mine have carried between 35 and 300 ounces of silver to the ton, but it is said that assays as high as 1,600 ounces in silver have been obtained from picked specimens. The ore consists chiefly of galena and zinc blende, with a small quantity of iron sulphide carrying considerable copper. A specimen of vein material picked up on one of the mine dumps showed specks of galena, greenish-yellow resin blende, and pyrite sparsely scattered through a ground-

[a] Text-book of mineralogy, p. 291.

mass of finely crushed granite and gneiss containing a few larger fragments of pegmatitic milky quartz and vein quartz, the whole recemented by silica. This well-indurated vein material, which closely resembles a solid igneous rock, is very similar in nature to the portion of the Comet lode which resembles porphyry.

SPORTING TIMES MINE.

The Sporting Times mine is located at an elevation of about 9,900 feet on Alpine Mountain, three-fourths of a mile south-southwest of Georgetown. It is developed by two tunnels. The lower one, which is the only one accessible at present, is driven on the vein and is about 850 feet in length. The wall rocks consist almost entirely of micaceous gneiss cut by intrusive pegmatite and granite. At a point about 600 feet from the mouth of the lower tunnel, however, porphyry forms the south wall of the vein for a distance of 50 feet, and a patch of porphyry about 15 feet in length also occurs on the north side. This porphyry mass was too much altered to allow its variety to be determined. The vein (fig. 104) consists of a soft clay, quartz, and pyrite lead, which here and there gives place to quartz, and of sphalerite and galena ore. The

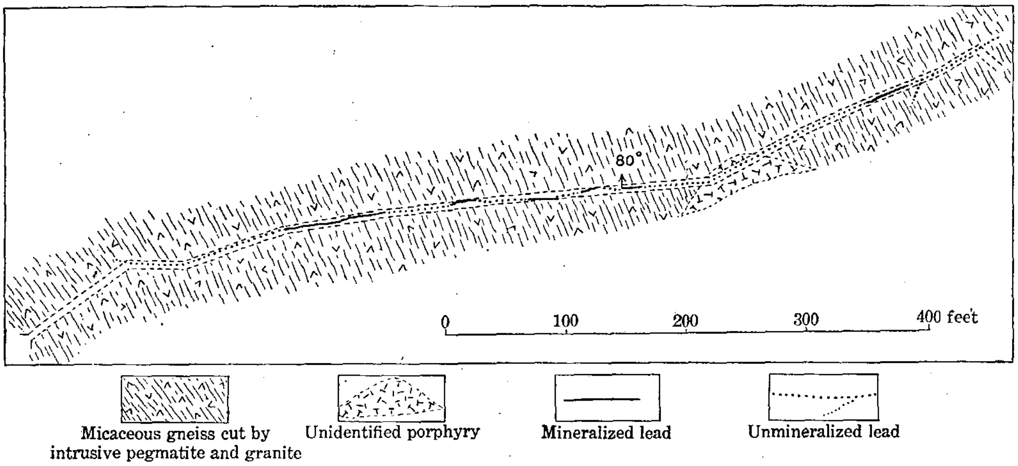


FIG. 104.—Geological plan of Sporting Times lower tunnel.

ore in places is comprised of breccia fragments of galena and sphalerite embedded in a matrix of pyritiferous quartz or silicified crushed rock. No stopes occur on the lower level, but small quantities of ore are said to have been produced by the upper workings.

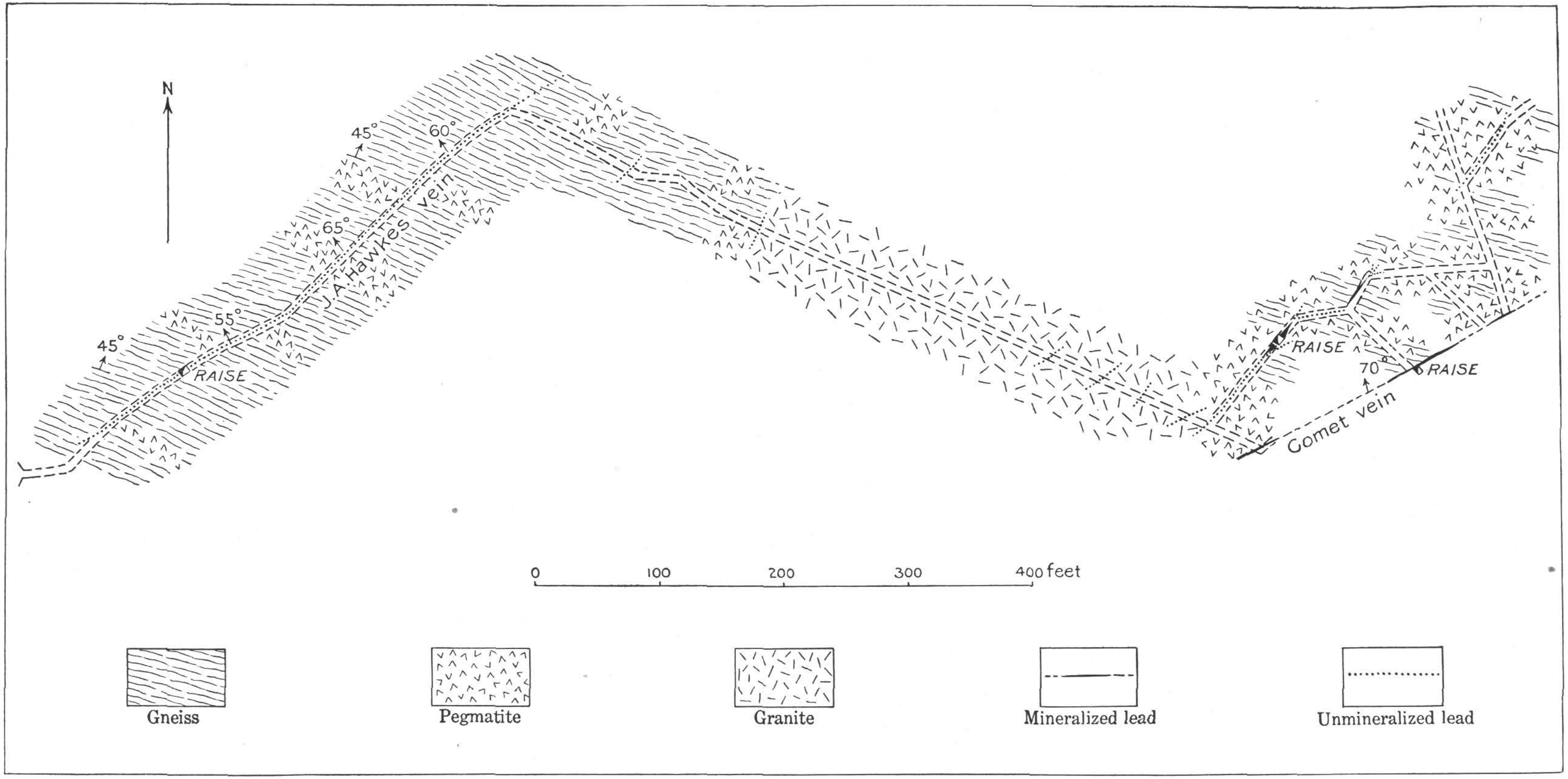
MAGNET LODE.

LOCATION AND DEVELOPMENT.

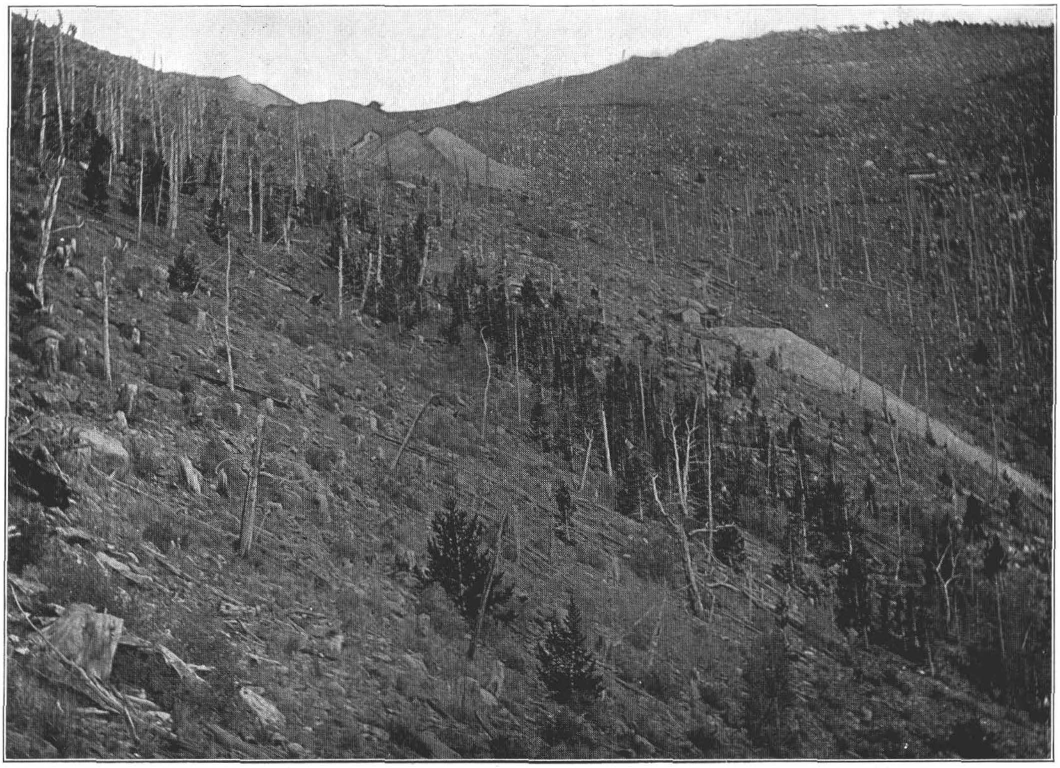
The Magnet mine (Pls. LIII, *A;* LIV), which produced small lots of rich ore prior to 1871, is situated near the head of the steep gulch extending from the valley of Clear Creek to the draw between Saxon Mountain and Woodchuck Peak. The development consists of a comparatively shallow shaft located at an elevation of over 11,000 feet and a series of five tunnels in the gulch to the west, the lowest one of which is more than 500 feet below the collar of the shaft. The tunnels and drifts aggregate over 6,000 feet in length, and although the mine has not been very actively worked for a number of years, yet most of these workings are still open.

NATURE OF WALL ROCKS.

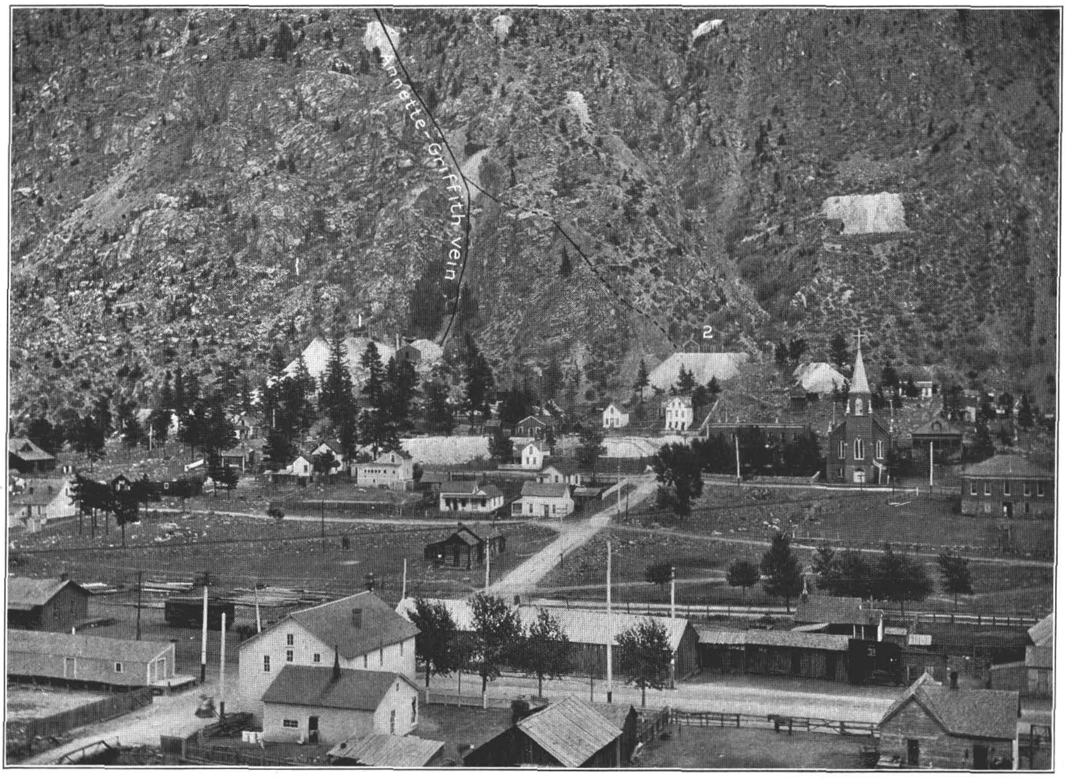
In the vicinity of the principal ore bodies the walls of the vein are comprised chiefly of porphyritic biotite granite. On following the main vein to the northeast, however, a mixture of pegmatite and granitic gneiss is encountered, and still farther northeast soft biotite gneiss with a few small patches of pegmatite. Gneiss also forms the walls of a clay and crushed rock lead,



GEOLOGICAL PLANS OF COMET TUNNEL AND ANGLO-SAXON EXTENSION LOWEST TUNNEL.

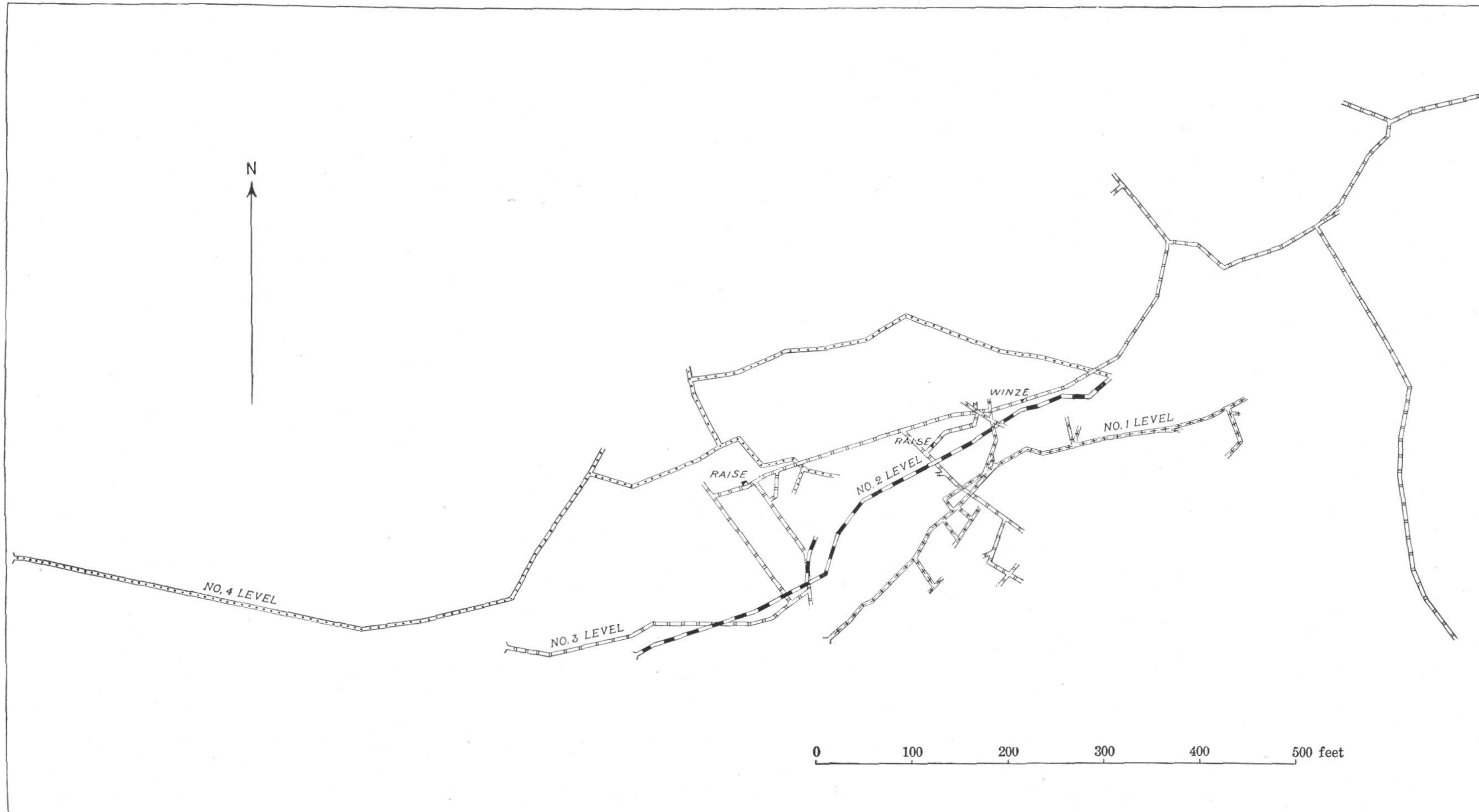


A. MAGNET MINE, ON SAXON MOUNTAIN, LOOKING SOUTHEAST.

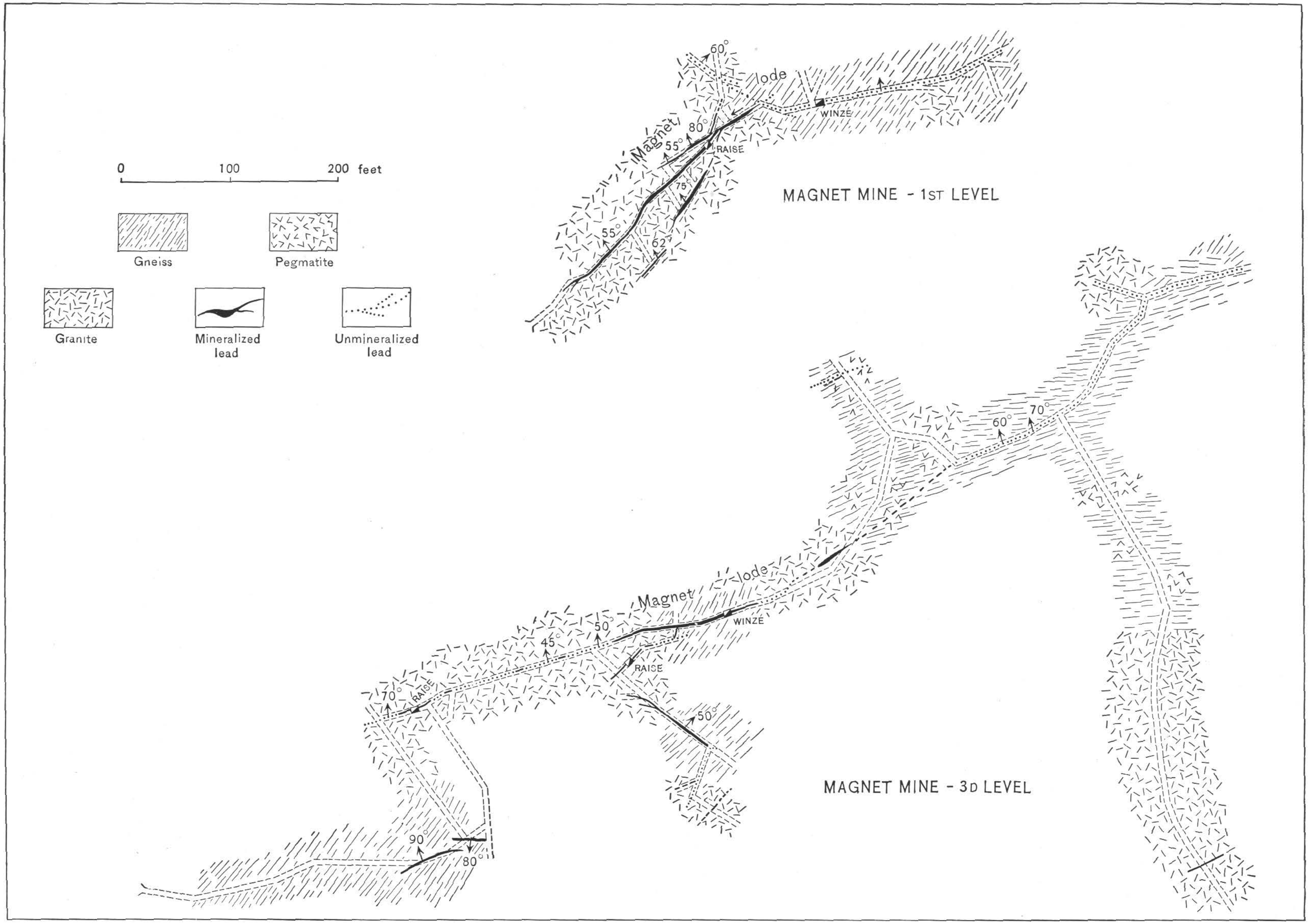


B. ANNETTE-GRIFFITH VEIN AND MINE OPENINGS, LOOKING EAST FROM SLOPE OF REPUBLICAN MOUNTAIN.

1, Annette-Griffith tunnel; 2, Capitol mine.



HORIZONTAL PLAN OF MAGNET MINE WORKINGS.



GEOLOGICAL PLANS OF SEPARATE LEVELS, MAGNET MINE.

followed by tunnel No. 4 for the first 300 feet. The schistosity of the gneiss is variable but as a rule has a strike ranging from northeast to nearly due east. Granite forms the southern half of the long crosscut to the south near the breast of tunnel No. 4.

The wall rocks near the vein are in many places much altered, the gneiss becoming locally soft and kaolinized and the granite changing to a decomposed or friable mass. No porphyry dikes are found in the present workings.

NATURE OF VEINS.

The main vein follows a strong line of movement, marked usually by a single fault line or narrow fractured zone from which a few minor fractures branch. The vein, where unmineralized, is a strong clay, crushed rock, and quartz lead where it passes through granite, pegmatite, or granitic gneiss; but on entering soft biotitic gneiss, as it does toward the northeast, it changes to a much narrower clay and crushed gneiss lead which tends not only to be deflected from its normal trend but to grow less marked and to branch into a series of slips, owing to the fact that the movement was probably taken up in part along the schistosity planes. Besides the evidence of movement furnished by gouge and crushed rock, there are also well-developed movement striæ, which range in dip from 30° to 63° SW. The Magnet vein varies greatly from point to point both in strike and dip, and this characteristic has caused considerable annoyance in exploration, especially on the lower levels (Pl. LV). In the southwest or principal ore-bearing portion of the workings, the vein ranges in strike from N. 45° E. on tunnel No. 1 level to N. 72° E. on tunnel No. 3 level. The strike in the soft gneiss on these levels was N. 77° E. and N. 55° E., respectively. On the main vein the dip was also flatter as a rule in the southwestern ore-bearing portion than at the northeast end. In the southwestern section the dip was about 45° to 55° NW.; at the northeast end it ranged from 60° to 75° in the same direction.

Where mineralized, the vein may consist of a single seam of solid ore, but more commonly it is a stringer lode in granite or other hard rock, or consists of a fractured zone in which most of the rock fragments have been extremely altered and many of them wholly or partly dissolved away and their place taken by quartz or by gangue minerals and ore. However, evidences of the extensive solvent action of the underground waters is still seen in the porous nature of the vein filling and in the numerous irregular openings, which have every appearance of being cavities of dissolution.

In a number of places where the vein has only one wall the mineral-bearing solutions have penetrated for some distance into the country rock on either side of the fracture, and impregnated it with ore minerals in sufficient quantities to make the extraction of the whole mass for a width of several feet pay well. Locally, however, where the vein is broad, the proportion of quartz in the vein filling is so great that, even though polybasite and tetrahedrite are found associated with the galena and blende present, the latter are in such minor quantities that the whole mass yields small values on mining.

About 250 feet from the mouth of tunnel No. 1 two well-mineralized veins converge toward the east and join the Magnet vein, the one northwest of the main vein coming from the S. 57° W. and the other branch from the S. 28° W. These branches, which are rather obscure right at the junction with the main vein, are heavily mineralized a few feet away, but within a short distance diminish in size again as they recede from the main vein.

The Sequel vein is a somewhat parallel vein, also dipping to the northwest, which trends slightly toward the Magnet vein and is thought by some of the miners to make a union with it; but no evidence of such a junction was noted. Several minor, slightly mineralized veins were also observed trending at high angles to the course of the main vein. However, these were rather isolated fractures whose relations to the main vein were indeterminable and which were not recognized on more than a single level.

An unmineralized fault line called the De Meli lode cuts across the Magnet vein on tunnels Nos. 1, 2, and 3. It is a strong barren clay and gouge lead 6 inches to 1½ feet wide which trends N. 58° W. It intersects the Magnet vein on tunnel No. 1 about 300 feet north from the mouth, but is found 50 feet or so farther northeast on No. 2 level, owing to its dip of 55° NE. On tunnel level No. 3 its dip changes to 70° NE.

COMPOSITION OF VEINS.

The gangue material is chiefly quartz, but barite is also common. Carbonates are sparingly present. The quartz is mainly of the dark-gray chalcedonic variety. The barite is most prevalent as well-formed crystals in vugs, but also occurs massive, interspersed through the quartz and metallic minerals.

The metallic minerals consist as a rule of galena, blende, polybasite, tetrahedrite, and some cupriferous pyrite or chalcopyrite.

The ore is relatively high in both silver values and in the percentage of zinc. The amount of zinc present is commonly about twice as great as that of the lead. The zinc, which occurs chiefly as greenish-yellow blende but in part as the brown variety, is in places so abundant as to detract from the value of the ore. The amount of silver as a rule is greater the less the quantity of zinc present in the ore. However, small shipments have been made of ore averaging 400 to 500 ounces of silver per ton in which the zinc content ranged from 15 to 20 per cent. The reason for this is that the main silver values probably lie in the polybasite and tetrahedrite, which are very common in all the best ores of the mine. These two argentiferous minerals occur in the massive form, associated with irregular masses of galena, sphalerite, and chalcedonic quartz, or as rough crusts and poorly formed crystals lining irregular-shaped openings which are probably mainly cavities of dissolution.

The pyrite and chalcopyrite where present are generally associated with the tetrahedrite, polybasite, and chalcedonic quartz.

About 0.05 ounce of gold is usually present. Near the surface considerable soft oxidized ore carrying some copper carbonates was found, and this soft ore was also in many places associated with the soft pulverulent black sulphides rich in silver which are common near the surface in many other parts of the district. Assays from different parts of the vein range from 35 to 600 or 700 ounces of silver to the ton. Some of the small stringers on the Sequel vein gave assays as high as 1,400 ounces in silver. The average ore shipped, however, carries from 150 to 300 ounces of silver to the ton.

OCCURRENCE OF ORE.

On tunnel No. 1 level ore was encountered about 50 feet from the mouth of the tunnel and extended continuously for nearly 250 feet, to a point within 10 or 15 feet of the barren De Meli cross lode. Near its east end the vein is joined on both sides by short but strong branch veins, which diverge to the southwest and contain small but well-developed ore shoots. The southern of these branches is probably represented on the level below by a similarly located vein carrying small streaks of ore. The main ore shoot on No. 1 level pitches about 60° E., and was stoped from the surface continuously to tunnel level No. 3, on which ore also commenced 10 or 15 feet southwest of the De Meli lode, but extended for only about 125 feet. The values in this ore shoot, which was the largest in the mine, however, do not seem to go much below level No. 3, a depth of 235 feet below the surface. An ore shoot due to the junction of minor leads also occurs to the northeast of the De Meli lode, and starts in about 10 feet from the cross lode. This ore body, which was only about 40 feet in length, also pitched eastward and extended between levels No. 2 and No. 3 and for 12 to 15 feet below No. 3. At the time of the visit a crosscut drift to the south was being run toward the vein at this point from a winze sunk to a depth of 65 feet below No. 3 level. A small ore body was also found on No. 3 level on the N. 55° W. vein in the drift located to the southwest of the large ore body west of the De Meli lode.

The Sequel vein carries but few small stringers, and these are composed of very rich ore.

All the main ore bodies seem to be confined to the areas of comparatively hard rocks such as granite, pegmatite, and granite gneiss, rather than to the areas of soft biotite gneiss. The reason for this probably lies in the fact that the rocks first named, being harder and more brittle, under movement would result in more open fractures than the soft biotite gneiss, and so the mineralizing solutions would have a better chance to operate. Vein junctions, although in some cases obscure at the immediate point of union, also probably have a beneficial influence on the ore deposition; and a flattening of the dip of the veins appears to have further influenced the precipitation.

PRODUCTION.

The Magnet vein produced small quantities of ore as early as 1871, and according to Fossett[a] had yielded $50,000 up to 1875. According to some of the old lessees on the property, $70,000 worth of ore was taken from the large stope to the southwest of the De Meli lode, and about $50,000 was obtained from the ore body to the northeast of the same lode. A few sacks of very rich ore were also yielded by the Sequel vein.

GRIFFITH LODE.

GENERAL DESCRIPTION.

The Griffith is a straight and strong lode, at present operated principally by two mines, the Griffith and the Annette, the former exploiting the southwestern portion, near the town of Georgetown, and the latter the northeastern portion, farther into Griffith Mountain (Pls. LIII, *B;* LVI). The vein has in general a strike of N. 50° E. and a vertical dip. In the longest level, the Annette No. 1, the lode is developed for 1,900 feet in a straight line. The older levels, which are higher up on Griffith Mountain, are mostly worked out and are now usually inaccessible. The main levels run into the mountain but little above the level of Clear Creek. The Griffith lode has the same general strike and dip as the Centennial, and the two lodes have certain features in common, together with very sharp differences.

NATURE OF VEIN.

The Griffith lode has formed along a fracture zone, of which some parts are unmineralized, some are slightly altered, with vein and gangue material in thin seams, and others have been mineralized so as to form wide and important ore deposits. The vein shows the usual phenomena of branching, and on the Annette No. 1 level it forks and reunites—a condition which was also observed in the Centennial (Pl. L). The east end of the Griffith lode, as developed underground in the Annette No. 1 level, shows only a weak mineralized slip which at the breast of the tunnel lies in soft gneiss and is barely perceptible. This suggests that the actual end of the lode is very near.

Some of the phenomena of branching at least are probably due, as will be explained, to two distinct periods of vein formation, the veins of the second period being superimposed upon those of the first. The crossing of the main lode by a minor vein zone near the northeast end of the Annette No. 1 level is an unusual occurrence in lodes of this district, and is due in this case to the two periods of vein opening.

Near the southwest end of the developed lode a branch diverges from the south side, opening out to the east. This is called the Sonora vein, and has a southeast strike and a dip of 70° NE. On the surface some high-grade ore carrying from 700 to 800 ounces in silver is said to have been taken from this vein; but where it joins the main Griffith lode, as seen in the Griffith No. 1 level, the vein contains only a small streak of pyrite and has not produced any pay ore.

NATURE OF WALL ROCK.

The wall rocks include gneiss of several varieties, pegmatite, alaskite, and some hornblendite. Usually these rocks are all well mingled, though in some places gneiss and in others pegmatite and alaskite are predominant.

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[a] Fossett, Frank, Colorado, 1880, p. 316.

INFLUENCE OF WALL ROCK.

A mixture of gneiss with alaskite and pegmatite has resulted in a rigid rock that has fractured well and formed a good medium for the slips along which the vein has formed. Locally, where soft gneiss predominates, as in the outer or southwestern part of the Griffith No. 1 level, the vein becomes weak or pinches out almost entirely and is unmineralized. Where the vein fracture passes into granite, on both sides of the gneiss, the vein immediately becomes strong again.

COMPOSITION OF VEIN.

The character of the ores in different parts of the vein is very different, largely on account of the two distinct periods of ore deposition. To take all parts of the vein together, it may be stated that the vein materials include considerable pure galena, some blende, pyrite, and chalcopyrite, with brown carbonates, including siderite, rhodochrosite, and magnesite, as the chief gangue minerals. Pure kaolin occurs in the vein at many places and is locally abundant. It is evidently a chemical precipitation, as was determined to be the case in the Colorado Central mine. A peculiar feature of this mine, not determined in other mines of the district, is the presence of gold and silver telluride. This mineral has been described by Richard Pearce,[a] who notes that C. A. Martine, of Georgetown, discovered the presence of tellurium in the mineral and sent it to him for investigation. Doctor Pearce found that the mineral occurred in small quantities, associated with pyrite, galenite, and chalcopyrite, in a matrix containing a little magnesite.

The color is dark gray, with a bright metallic luster; hardness about 3. An analysis was made by Mr. F. C. Knight on carefully selected material, but, owing to its intimate association with the minerals named above, it was impossible to obtain the mineral in a pure form. The result of the analysis is as follows:

Ag	50.65
Te	18.80
Pb	9.34
Cu	4.65
Fe	4.00
Bi	1.16
S	8.06
$MgCO_3$	1.95
Alloy of Au and Ag	.48
Insoluble residue	1.07
	100.16

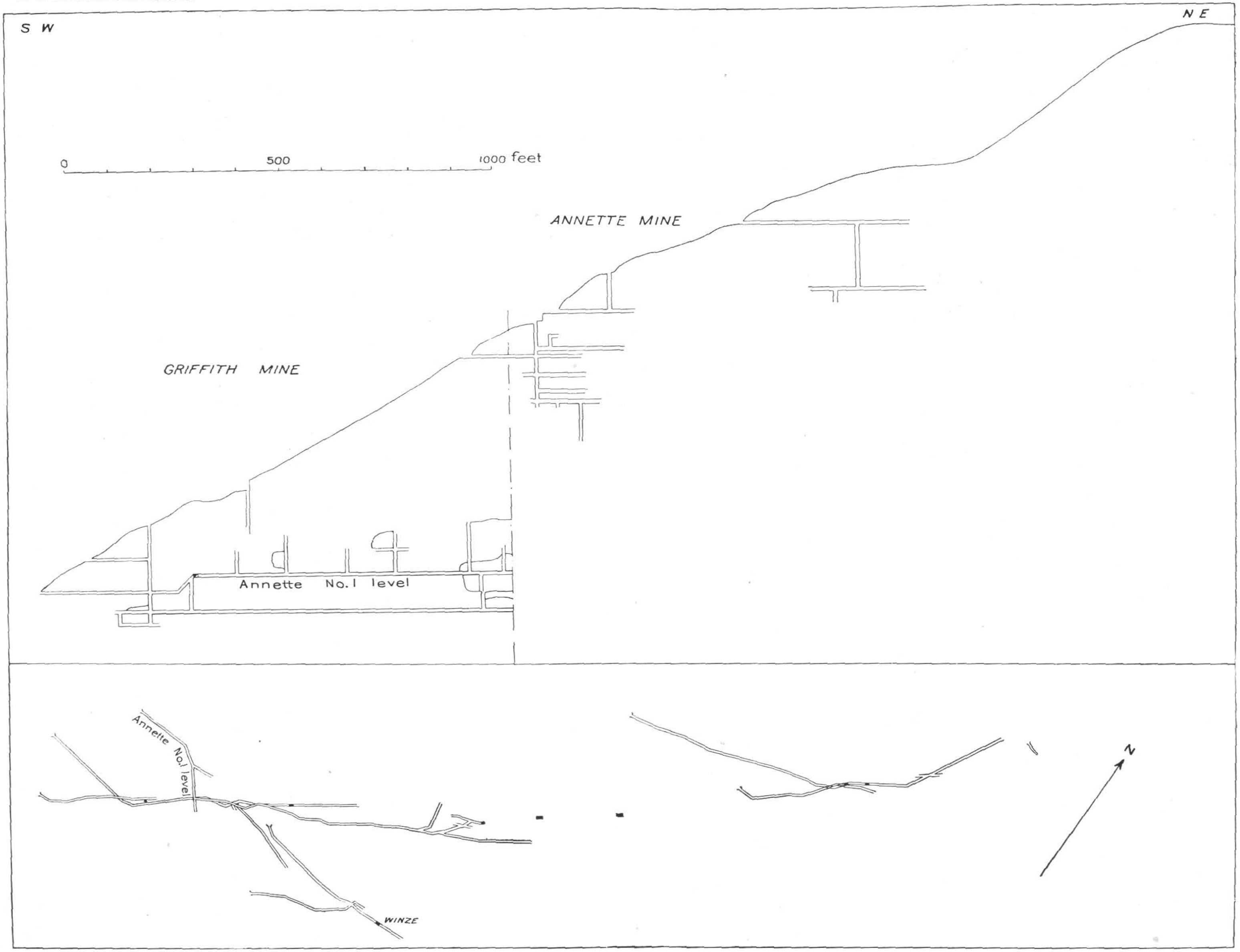
It was supposed by Mr. Martine that the gold present in the mineral was combined with tellurium; the results of my investigations show, however, that the gold exists in the form of a rich alloy of Au and Ag. One small piece of the mineral showed distinctly a coating of gold and silver alloy on its cleavage plane. On treating the powdered mineral with nitric acid the residue showed no indication whatever of brown sponge gold, which would have been the case if this metal was combined with tellurium. On the other hand, the residue contained the gold only in the form of a bright pale-yellow alloy which proved to be 0.725 fine, the rest being silver.

The mineral, judging from the above analysis, may be said to consist of a mixture of hessite and argentite, Ag_2Te and Ag_2S, associated with other minerals in the following proportions:

Hessite	51.22
Argentite	20.93
Cu_2S (chalcopyrite probably)	5.82
FeS (chalcopyrite probably)	6.28
PbS (galenite)	10.78
Bi_2S_3	1.42
Au and Ag alloy	.48
$MgCO_3$	1.95
Insoluble residue	1.07
	99.95

It is interesting to note that the relation between the hessite and the argentite corresponds closely to the formula $2(Ag_2Te) + Ag_2S$.

[a] Proc. Colorado Sci. Soc., vol. 5, 1894-1896, pp. 242-243.



VERTICAL AND HORIZONTAL PLANS OF WORKINGS ON GRIFFITH VEIN COVERED BY GRIFFITH AND ANNETTE MINES.

Annette workings incomplete; other workings less so.

A specimen of this telluride was assayed by H. K. Miller, of Georgetown, who found 17.478 ounces of silver and 1.970 ounces of gold to the ton, with 13.75 per cent of lead and 5.80 per cent of copper. Another specimen given to the senior writer by the owners of the Griffith mine was submitted to W. F. Hillebrand, of the United States Geological Survey, who found in it qualitatively the elements reported by Doctor Pearce, and remarked that the evidence afforded by a partial analysis supported his conclusion as to the presence of a mixture of hessite, argentite, and other minerals. This telluride occurred in the Griffith vein, in a shoot of ore which extends from the surface downward almost vertically.

In general the ores of the mine may be divided into two groups—the galena ores associated with blende, chalcopyrite, and some pyrite, and the carbonate ores associated with pyrite and some barite. These two classes of ore were deposited at distinctly different periods. In general the carbonate ore is not profitable for mining, the average content being stated at $2 to $3 in gold and 10 to 12 ounces in silver, with little or no lead. It is, however, reported that one stope of carbonate ore containing pyrite yielded 20 to 25 ounces in silver and $6 to $10 in gold. A specimen of typical carbonate-pyrite ore was taken by the senior writer from the more northern of the two branches near the northeast end of the Annette No. 1 level, 60 to 70 feet from the breast of the branch. A seam of ore here was a few inches thick, with no traces of galena, but the ore was rather soft and crumbling, as if decomposed by circulating waters. An assay made by R. H. Officer & Co., of Salt Lake City, yielded 0.16 ounce of gold and 63 ounces of silver to the ton.

In the ores of the galena class in the Griffith mine the values are chiefly in lead, next in silver, and $4 to $5 in gold. It is reported that farther into the mountain on the same vein, in the Annette mine, the values run more in gold, silver, and copper and less in lead. In both mines it is these masses of galena ore which are sought for and mined. These lead ores are subordinate in quantity to the carbonate ores above discussed. They are reported to contain on an average about 40 ounces of silver and $8 to $9 in gold. As a rule the copper is not present in large enough quantity to be paid for by the smelter, although one shoot yielded the exceptional amount of 1 to 1½ per cent of copper.

Owing to the origin of the two classes of ore at different periods, mixtures of the two generations of vein materials in all proportions are found at many places. Such mixed ore was seen, for example, in the Annette No. 1 level a few hundred feet from the entrance and was reported to yield 20 ounces of silver and 0.05 to 0.10 ounces of gold. Similarly, about 300 feet in on the Griffith No. 1 level is a small body of rich ore in a low-grade vein. This ore is reported to yield 300 ounces in silver, $2 to $3 in gold, and some copper. A specimen of this ore taken by the senior writer and examined by E. C. Sullivan, of the Survey, was found to contain a sulphantimony compound of silver.[a] Sphalerite was also present and smaller quantities of copper, cadmium, lead, arsenic, etc.

STRUCTURE OF VEIN.

The vein shows plainly two distinct periods of fissuring and cementation by vein materials.

The result of the first dislocation of the rocks along this line was a strong fissure, in part open for a considerable width, as is shown by the angular fragments of wall rock that occur in and are cemented by the vein materials which were deposited subsequent to this dislocation. These angular fragments of wall rock indicate an original rubble-filled fissure, like that now occupied by portions of the Mendota and similar veins. The filling of this fissure was also similar to veins of the class mentioned. The first deposition was a line of comb quartz, and the interior of the fissure was filled with solid sulphides, practically without gangue, consisting of galena, blende, pyrite, and chalcopyrite. The abundance of chalcopyrite is distinctive of this vein, in contrast with the Mendota and other similar veins referred to.

Subsequent to the formation of this sulphide vein there was another dislocation, resulting in much larger openings than the first disturbance produced. The new fissure in general

[a] Probably tetrahedrite or polybasite.—J. E. S.

followed along the line of the old one, splitting the older vein and breaking it up in various ways. On account of the greater brittleness of the original sulphide filling, as compared with that of the wall rocks, the new fissure split the vein in the middle at many points, leaving a layer of sulphides clinging to each wall, a result which, after the new fissure was cemented with the carbonate ore of the second period, gave a false appearance of crustification. In numerous other places the older vein was broken into angular fragments, which rested in the new-formed fissure in the shape of rubble (fig. 105), precisely as the fragments of country rock had filled the original fissures. These angular fragments of sulphide ore now appear as inclusions in the later carbonate ore in varying amounts and degrees of coarseness.

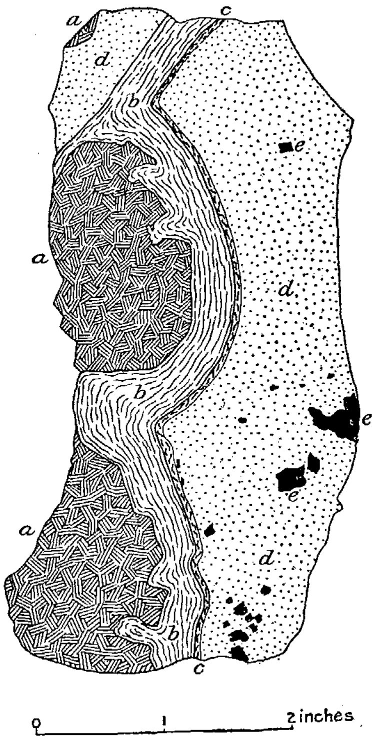


FIG. 105.—Sketch of specimen from Griffith vein, showing cementation of fragments of galena (a) belonging to the first period of deposition by a crustified material belonging to the second period and deposited in the following order: 1, Finely banded (crustified) brown carbonates (b); 2, a thin crust of quartz with sulphides (c); 3, mingled brown carbonates and fine quartz (d) containing some pyrite (e) and a little galena (a).

Elsewhere the new fissure departed locally or completely from the course of the original one (fig. 106). Thus on the Annette No. 1 level, where the composite Griffith vein splits and reunites, the two branches inclosing a horse of country rock, it is probable that one of the branches was formed during the first period of vein deposition and the other after the second period. It seems highly probable also that certain of the branches diverging from the trunk vein were formed entirely during the second period of vein deposition. Near the northeast end of the Annette No. 1 level are two branches separating from the trunk vein on the north side and striking almost due north. The ore in these branches is entirely the carbonate-pyrite ore characteristic of the second period. The more northeastern of the two branches crosses the trunk vein and has been explored for a considerable distance in both directions. The probability that this branch is due to the subsequent period of fissuring explains the otherwise unusual phenomenon of crossing.

Where, as is usual, the path of the earlier and the later fissures practically coincided, the proportion of the vein filling belonging to the two periods varies greatly (fig. 107). In general, however, the spaces afforded by the reopening of the fissure, and consequently the amount of ore now present in the vein as a result of cementation of this reopened fissure, are estimated to be many times as great as in the first period. In places the earlier sulphide ore may form the bulk of the present vein, constituting what is locally (though perhaps not correctly from a technical standpoint) known as an ore shoot.

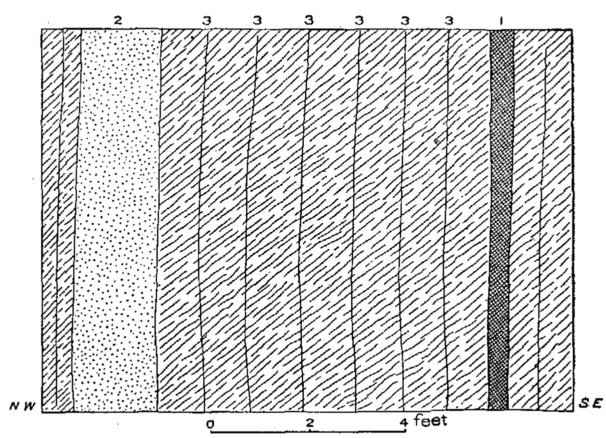


FIG. 106.—Vertical cross section of Griffith vein, Griffith No. 1 level, showing veins of two distinct periods running side by side and parallel in the same drift. 1, Vein of earlier period consisting of blende, galena, and a little pyrite; 2, vein of later period consisting of brown carbonates with pyrite; 3, sheeting in gneiss country rock, parallel with vein.

PARAGENESIS OF MINERALS.

The principal minerals of the ores belonging to the first period are galena, blende, chalcopyrite or cupriferous pyrite, and some iron pyrite. Copper-bearing pyrites seem to be invariably associated with this earlier vein material, but nowhere in any quantity with the material of the second period. Examinations of hand specimens and thin sections of this earlier sulphide ore show that the various sulphides are almost contemporaneous, but in detail they have crystallized out in the following order: (1) Pyrite, (2) chalcopyrite, (3) galena. The relative age of the blende has not been observed, though it seems to be very nearly contemporaneous with the galena. In various places galena was noted filling cracks in chalcopyrite. The earliest formation in the veins of this first period was comb quartz, which lined the open spaces. Tetrahedrite was noted along cracks in chalcopyrite and distinctly subsequent to it.

In the vein material belonging to the second period of deposition the pyrite, which is abundant, is contemporaneous with the more abundant carbonates, whereas the sulphides of the first formation, where they are included in the carbonate gangue, occur in broken and angular fragments. Microscopic examination, however, indicates that a small amount of chalcopyrite, galena, and blende was deposited contemporaneously with the carbonate gangue.

A specimen of the carbonate in the later ore, submitted to E. C. Sullivan, of the United States Geological Survey, proved to be mainly ferriferous rhodochrosite, with some magnesite and traces of calcite. Doctor Pearce, quoted above, mentions magnesite as a gangue material. According to J. S. Randall, of Georgetown, the carbonate gangue of the Griffith mine is largely siderite, with some magnesite. It is probable that the brown carbonate is a mixed carbonate of iron, magnesite, manganese, and lime, as in other mines of the region.

Typically small contemporaneous crystals of quartz are scattered in the massive carbonate. As a rule also the deposition of quartz has persisted longer than that of carbonate, for abundant geodes and druses, which are found in the carbonate ore, are lined with crystals of quartz. With this predominant quartz there is also here and there some lesser amount of brown carbonates, and even small and scanty crystals of sulphides, such as chalcopyrite, galena, and blende. Barite also is very commonly found lining the druses as the last mineral to crystallize, and kaolin occurs under the same conditions.

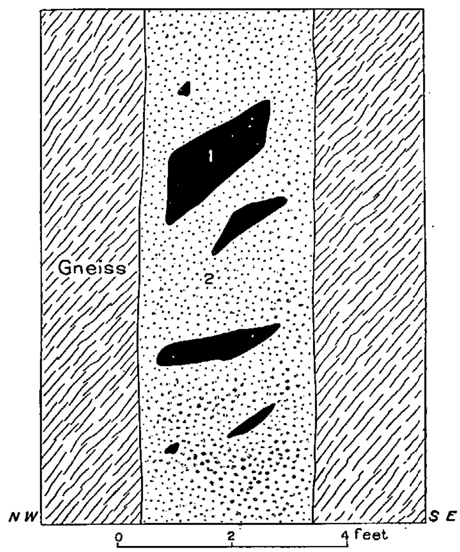


FIG. 107.—Vertical sketch section of Griffith vein, Annette No. 1 level, about 1,600 feet from mouth, showing ore of two periods of vein formation. 1, Coarse galena ore of first period; 2, carbonate-pyrite ore of second period inclosing broken angular fragments of No. 1. The wall rock is gneiss.

In some places the gangue may be mainly quartz, with a subordinate amount of intercrystallized carbonates. In other mines of this region, such as the Mendota, Dunderberg, Bismarck, Wisconsin, Pay Rock, and Colorado Central, brown carbonates of iron, manganese, etc., with contemporaneous pyrite, have been found to be in general later than galena and blende, but nowhere on such a scale as is found in the Griffith mine. In the other mines mentioned also this carbonate-pyrite ore has usually a very evident connection with the present topographic surface, but the somewhat similar ore of the Griffith has no such connection.

INFLUENCE OF DEPTH.

On considering the influence of depth on the ores of the first period, it appears probable that the action of surface waters has brought about some local concentration and impoverishment. As is usual in mines of this district, the surface ores were very rich, and according to Raymond[a] contained sufficient gold to repay sluicing. It is reported by those familiar with the mine that there was more copper on the upper levels than in those more remote from the surface. The occurrence of tetrahedrite along cracks in chalcopyrite, like that noted in the Centennial mine, suggests the secondary nature of the tetrahedrite and descending ground waters as the depositing agency. It is also reported that these upper ores contained more silver and gold and less galena.

[a] Mines and mining west of the Rocky Mountains: Ex. Doc. No. 207, 41st Cong., 2d sess., p. 368.

It appears probable that this action of shallow descending waters had some enriching influence on the subsequent carbonate-pyrite ore, for it is reported that in the upper levels much of the ore of this class was rich enough to pay.

POSTMINERAL FAULTING.

On the Griffith No. 1 level, 100 feet from the mouth, the Griffith vein is cut by a transverse fault striking N. 43° W. and dipping 76° NE. At the point where the lode is cut it is a composite lode, the result of the two periods of vein cementation. It is offset about 10 feet to the northwest on the northeast side by the fault. It is reported that this same fault is found all the way down from the surface, but that the offset diminishes in depth. For example, 60 feet above this level the offset is 15 feet, but 25 feet below it is only 5 or 6 feet. Near the surface the fault is marked by a water course filled with bowlders.

PRESENT UNDERGROUND WATERS.

In the southwestern, or outer, portion of the Annette No. 1 level coatings were observed on the drift walls, in some places stained with copper. Water drips from the rocks and vein at intervals all along these drifts. On the Annette No. 1 level water was observed from the mouth for 1,200 feet in, to a point having an estimated vertical distance from the surface of 650 feet. From this point to the end of the level, which is about 1,900 feet from the surface, at an actual depth of about 1,050 feet, the rocks were quite dry.

ANGLO-SAXON LODE.

ANGLO-SAXON MINE.

HISTORY, DEVELOPMENT, AND PRODUCTION.

The Anglo-Saxon lode is located on the northwest slope of Saxon Mountain and runs north-northeastward up the slope to an elevation of 10,500 feet. In 1867 it caused much excitement on account of the extremely rich ore found along it. The developments consist of four levels with numerous crosscuts and shafts, but all these workings are at present caved shut.

According to Burchard[a] the Anglo-Saxon mine had yielded about $700,000 previous to 1883. But little ore has been extracted since that time, although small quantities of rich "float ore" are at present occasionally found scattered through the loose surface material along the trend of the vein.

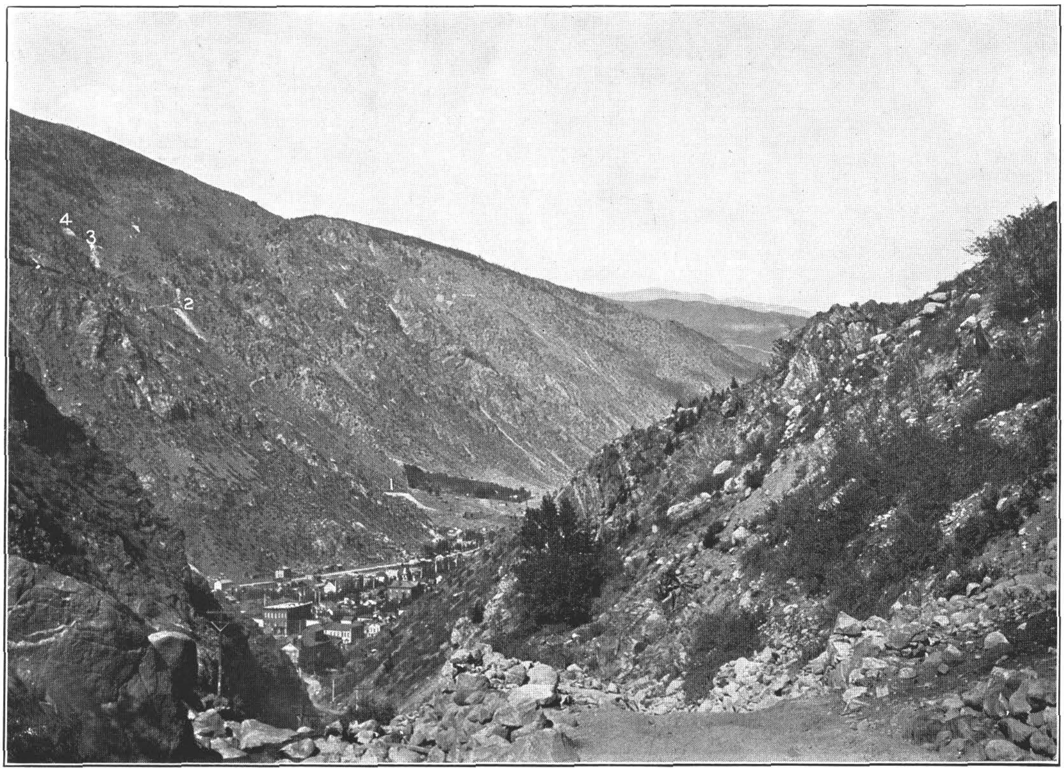
NATURE OF ROCKS.

As all the workings were closed by caving, the exact nature of the rocks occurring along them is unknown, but the surface rocks in the vicinity of the vein consist chiefly of much-altered friable granite and pegmatite. Granitic and biotitic gneiss also occur. The gneiss has a general strike of N. 40° W. and a dip of 20° NE.

VEIN AND ORE.

The Anglo-Saxon vein on the surface has a general strike of N. 70° E. and a dip ranging from vertical to a slight inclination toward the north. Where the vein crosses a spur of Saxon Mountain, at an elevation of about 10,300 feet, the wall rocks for some distance on either side of the vein consist of yellowish altered and friable granite. Running through this soft granite, much of which is probably not in place, are irregular branching seams of loose material in which are embedded here and there nodular masses or nuggets of very rich ore. These masses consist either of yellowish and greenish light-colored oxidized ore, or of rounded lumps of a black sectile waxy substance, high in silver values, which W. T. Schaller found by chemical analysis to be argentite (Ag_2S), or silver glance. Argentite occurs also as small stringer-like masses in the sandy matrix, which resembles loose surface material. These stringers may represent the portions of displaced surface croppings of the vein, for the seams have been successfully followed for only a few feet in depth.

[a] Burchard, H. C., Precious metals in the United States, 1883, p. 277.



A. GEORGETOWN AND REPUBLICAN MOUNTAIN, LOOKING NORTH IN SILVERDALE CANYON TO SOUTH CLEAR CREEK.

1, Kelly tunnel; 2, New Boston mine; 3, Beecher mine; 4, Muscovite mine.

B. REPUBLICAN, DEMOCRAT, AND COLUMBIA MOUNTAIN MINES, LOOKING WEST FROM DUMP OF MAGNET MINE.

1, Kelly tunnel; 2, Moline tunnel; 3, New Boston mine; 4, Spartan tunnel; 5, Beecher mine; 6, Mineral Chief mine; 7, Muscovite mine; 8, Sceptre mine; 9, Queen mine; 10, Astor tunnel; 11, Cliff lowest level; 12, Junction lower level; 13, Edgar tunnel; 14, Buckeye tunnel.

In all probability the rich sulphide ore is the result of the secondary action of surface waters and has originated since the formation of approximately the present topography. These sulphides which are residual in the oxidized ores are much the richest of the ores in the mine and in respect to their high content of the precious metals are very similar to ores noted at Monte Cristo, Wash.,[a] by Spurr, and also at Leadville[b] by Emmons, who stated that it was "evident that the action of the surface waters has been to concentrate the silver in the sulphide ore, not in the oxidized product."

Small shipments of high-grade ore obtained near the surface have brought returns ranging from 1,000 to several thousand ounces in silver to the ton.

No active work has been done on this mine for years, although at present a few sacks of ore are being obtained from surface pits by picking out the rich pieces of ore which are sparsely scattered as nodules or irregular seams in the friable granite and wash.

ANGLO-SAXON EXTENSION VEIN.

LOCATION AND DEVELOPMENT.

The Anglo-Saxon Extension vein, which is probably either the continuation of the Anglo-Saxon vein or one of its branches, is located to the west and south of the old Anglo-Saxon workings and is opened by a series of tunnels which aggregate over 2,500 feet of drifting. Most of the upper workings are inaccessible. The lowest, or seventh, level, the longest one in the mine, was about 825 feet in length at the time of visit, but was being extended. The first part of the lowest tunnel, the mouth of which is located 600 or 700 feet above Clear Creek, is a crosscut run through fractured biotite granite and pegmatite. The rest of the level and the vein itself are entirely in gneiss, which as a rule strikes to the northwest.

VEIN AND ORE.

The vein on the lowest level has a strike of N. 73° E. and a slight dip to the northwest. It is for the most part a crushed gneiss and clay lead, from a few inches to 2 feet wide, which is in many places highly colored by iron and copper salts. That the vein is along a fault line is well shown by the gouge and the putty-like clay, which represent country rock finely pulverized as a result of movement, and also by slickensides and movement striæ dipping 65° NE. In a few places the clay and crushed rock lead changes to quartz or to a low-grade ore, or "mill dirt," consisting of a mixture of quartz and decomposed pegmatite and gneiss over a foot wide with specks of galena all through the mass, which also carries a little lead carbonate and some copper compounds, as shown by the presence of copper sulphate, and the carbonates, azurite and malachite.

This lean ore is said to carry values ranging from $10 to $18 per ton. Some portions of the vein nearest the surface carry a porous or honeycombed mass of quartz which shows leaching by descending surface waters. The presence of iron oxides in abundance shows that the lower workings are still in the oxidized zone.

Most of the ore produced by this mine was found between the Blacksmith Shop level and the seventh level, which are about 225 feet apart. The greater part of the ore was from shoots which are said to have dipped to the northeast.

PRODUCTION.

Little information was obtainable about the production of the Anglo-Saxon Extension mine, but the Director of the Mint reports the production for 1889[c] as $2,017.60, divided as follows: Gold, $880; silver, $768; lead, $250.80; copper, $118.80. In the report for 1890[d] the yield was given as $3,955, divided thus: Gold, $1,100; silver, $2,246; lead, $609.

[a] Spurr, J. E., Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 2, 1901, p. 777-865.
[b] Emmons, S. F., Secondary enrichment of ore deposits: Trans. Am. Inst. Min. Eng., February, 1900, p. 7.
[c] Leech, E. O., Production of gold and silver in United States, 1889, p. 144.
[d] Idem, 1890, p. 130.

MINES OF REPUBLICAN, DEMOCRAT, AND COLUMBIA MOUNTAINS.

REPUBLICAN MOUNTAIN GROUP.

EXISTENCE OF A ZONE OF MINERALIZATION AND INTRUSION.

The so-called Republican Mountain group of veins occupies a definite east-west zone which extends from Clear Creek on the east westward up the valley of Silver Creek nearly to the summit of the mountain ridge. (See Pl. LVII.) The difference of elevation of the surface along various parts of this zone amounts to about 3,000 feet. The separate veins in this zone have a generally eastward trend corresponding with that of the zone as a whole, but also vary from that direction to the southeast and the northeast.

This vein zone is also a zone of porphyry intrusion. The principal dike runs east and west along the Sunburst-Sceptre vein. Farther east, what may be the same dike is encountered near the Boston vein, in some places forming one or both of the walls of this vein. Smaller dikes have also been noted in this zone. The porphyry is definitely earlier than the formation of the vein zones.

It is evident that an east-west zone of weakness existed here previous to the intrusion of the porphyry. The first dislocations were probably followed by the igneous intrusion. Subsequently, the stress continuing, renewed movement took place, producing fault zones which in part followed along or near the older dike. These later openings were in part cemented by vein material. Later still movement was again resumed, also on an important scale. The result was that the principal vein of the zone, the Sunburst-Sceptre, was reopened and fissured in the same way as the Griffith vein on Saxon Mountain. The fissures in the reopened veins of Republican Mountain were subsequently cemented by the same materials as in the Griffith vein, namely, brown carbonates with pyrite. Subsequent to this cementation the Sunburst-Sceptre vein was again reopened and the fissures were cemented with chalcedonic quartz. Thus fissuring and subsequent cementation have taken place repeatedly during a period of time probably beginning in the late Cretaceous[a] and lasting to a recent date, or very likely to the present day.

PRINCIPAL VEINS OF THE GROUP.

The principal vein in the western portion of this zone is the Sunburst-Sceptre. The Queen lode is a smaller vein near and parallel to the Sunburst-Sceptre, and the Astor is a similar nearly parallel vein. At the east end of the zone the chief veins are the Boston and the Mineral Chief, with a number of smaller ones, such as the Muscovite, Spartan, and Beecher. The connection between these veins has not been well established, but it is possible that some of those which go by different names may be in reality parts of the same lode. For example, the Spartan is probably the northeastern continuation of the Mineral Chief, and the western continuation of the Mineral Chief is commonly held to be the Smith & Wesson. Similarly it is possible, as is held by many, that the Spartan-Mineral Chief vein may be the continuation of the Boston vein. The Muscovite vein may be the continuation of the Beecher, which is a branch of the Boston, although no connection has been traced either on the surface or underground.

CHARACTERISTICS OF VEIN FILLING.

The lodes of this zone contain ores which possess characteristic distinctions from those of other groups of veins. Those near the foot of the mountain or at the east end of the zone, such as the Boston, Mineral Chief, Beecher, Spartan, and Muscovite, all contain ore of the same kind, marked in many places by large amounts of pure galena, a variable amount of very dark blende, and considerable pyrites, with a low content of silver and very little gold. Siderite and a little kaolin also occur. When sorted this material forms a good grade of commercial lead ore. It resembles in many ways the Griffith ore of the first period of deposition, even containing the same peculiar dark-colored zinc blende. The lodes farther up the mountain, at the west end of the zone, are similar to the others, being usually of low grade in respect to silver. However,

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[a] See p. 109.

they contain relatively more silver and less lead than the group of veins first mentioned. As a whole, the Republican Mountain ores are distinguished from those of the so-called Democrat Mountain group of veins in that the latter are high-grade silver ores.

KELLY TUNNEL.

Like nearly every other group of lodes in the region, this group, chiefly worked out near the surface, has been the object of one of those tunnel projects for which the local topography is so favorable. The Kelly tunnel (Pl. LVIII) was started on the west side of Clear Creek, near the north end of the town of Georgetown, to run under both the Republican and the Democrat Mountain groups of lodes and tap them at great depth. It was driven for 2,680 feet in a northwest direction, at a reputed cost of $160,000. A number of minor veins were first encountered, and, farther in, the Boston vein, at the point where it is joined by its principal branch, the Beecher vein. This junction at the surface and in the upper workings had been responsible for an important ore shoot. Where the same junction was encountered in the tunnel, however, at a depth of about 1,000 feet, it was absolutely barren, and the vein zones, though well marked as faults, showed practically no mineralization. The tunnel undertaking was therefore given up, at least temporarily.

In the Kelly tunnel, for the first 750 feet or thereabouts, abundant water drips from the roof and deposits iron ocher in the same way that has been described for other underground workings in the region. Farther in, however, as far as the breast of the tunnel, the rocks are practically dry and there has been no deposition of iron or lime. A small pool of water backed up near the breast by the fall of material from the roof of the tunnel shows that these deeper rocks are not entirely dry, although relatively much drier than those of the superficial zone.

One of the lodes cut in the outer part of the tunnel, the Deming lode, at a vertical distance of 300 feet from the surface, shows 3 or 4 feet of silicified material cementing the fault zone, with local sulphides. Farther in the tunnel the lodes cut at depths ranging from 500 to 1,200 feet are nearly all soft fault zones with only traces of cementation, even silicification being almost absent. In some of these lodes the superficial portion for a few hundred feet below the surface shows strong silicification, resulting in the formation of quartz veins, some of them several feet thick, with accompanying sulphides. Such, for example, were the conditions in the upper portion of the Boston and Beecher lodes. Moreover, where these soft lodes, which are cut at greater depths underground, are at all silicified, there is a relatively thin quartz streak, in some places containing pyrite, which invariably, so far as noted, lies upon the foot wall of the soft, decomposed zone. These two circumstances indicate that the silicification is probably the work of descending surface waters and that the sulphides which accompany the quartz have probably a similar origin.

BOSTON AND BEECHER VEINS.

DESCRIPTION.

The Boston vein has a northeasterly strike and a steep southerly dip. It is opened underground by three tunnels, of which the uppermost, the New Boston, also called the Kelly No. 2 level, is about 170 feet below the outcrop. Below this is the Moline tunnel, also known as the Kelly No. 1 level, which is 400 feet below the outcrop. Still below this the Kelly tunnel cuts the vein at a depth of somewhat more than 1,000 feet. The chief branch of the Boston vein is called the Beecher. It diverges from the main vein on the north side, opening up to the west and striking approximately east and west. Like the Boston, it has a steep southeast pitch.

In the Moline tunnel a zone of slight mineralization occurs on the south side of the porphyry dike, which is here 200 feet or more south of the Boston vein and has an east-west trend. This mineralized zone is called the Galena vein. It is marked by tight seams of galena, pyrite, and blende carrying a little silver. The same slightly mineralized lead is said to have been recognized at the surface. On the Kelly tunnel level, at the same porphyry contact, a similar lead was noted, also slightly mineralized. As the trend of the porphyry contact is diagonal to that of the Boston vein, this so-called Galena lode runs into that vein and is to be considered as a branch of it. The junction was actually observed on the Kelly tunnel level (Pl. LVIII).

ORIGIN AND STRUCTURE OF VEINS.

The main Boston vein and its branches follow fault zones marked by bands of crushed and decomposed country rock, in many places by contortions of the gneiss against the fault planes, and also by the striæ, which in this region afford a reliable indication of the direction of movement. Such striations along the Beecher lode in the Moline tunnel have a pitch of 30° E. Along the Galena lode in the Kelly tunnel they pitch 20° E. These zones of crushing have locally been cemented by cherty quartz and sulphides. A study of the veins and the vein material leads to the conclusion that the process of mineralization has been largely replacement and interstitial filling rather than fissure filling. As a rule different hard slices of the lode are separated from one another by bands of soft gouge which are apparently the result of renewed movement subsequent to the first cementation.

CHARACTER OF WALL ROCKS.

The principal wall rock of the vein is a black biotite gneiss. Here and there, however, there is considerable granite. In the Moline tunnel it was noted that the rock on the north side of the vein was chiefly granite, whereas that on the south side was mainly gneiss, as if the vein had been localized near the contact.

A dike of porphyry 30 to 35 feet thick goes down perpendicularly from the surface, and has been cut in both the Moline and the Kelly tunnels. Locally, as in one place in the Kelly tunnel, the thickness of this dike increases to 150 feet. In the vertical section taken along the Kelly tunnel the dike is at some little distance from the vein, but as the trend of the two is diagonal they come together as shown in the Kelly tunnel, where the junction occurs a short distance southwest of the main tunnel. On this level the main Boston vein pursues its course, passing diagonally through the porphyry dike to the opposite or southern contact, but the Beecher vein on encountering the north contact of the porphyry appears to follow it westward.

ALTERATION OF WALL ROCKS.

It is characteristic of the altered gneiss in the vicinity of some of these veins that it has assumed a peculiar bright-green color. Some of this gneiss examined microscopically was found to consist chiefly of quartz and a pale-green mineral, evidently a mica. Analysis by W. T. Schaller showed the coloring to be due to chromium, so that the mineral is a chrome-bearing muscovite (fuchsite). Other specimens of the altered gneiss showed, besides these alteration products, abundant cloudy carbonates with original sphene and ilmenite. Through the Kelly tunnel it was shown that the black gneiss contains veinlets of brownish carbonate which have the appearance of being derived from the neighboring wall rock.

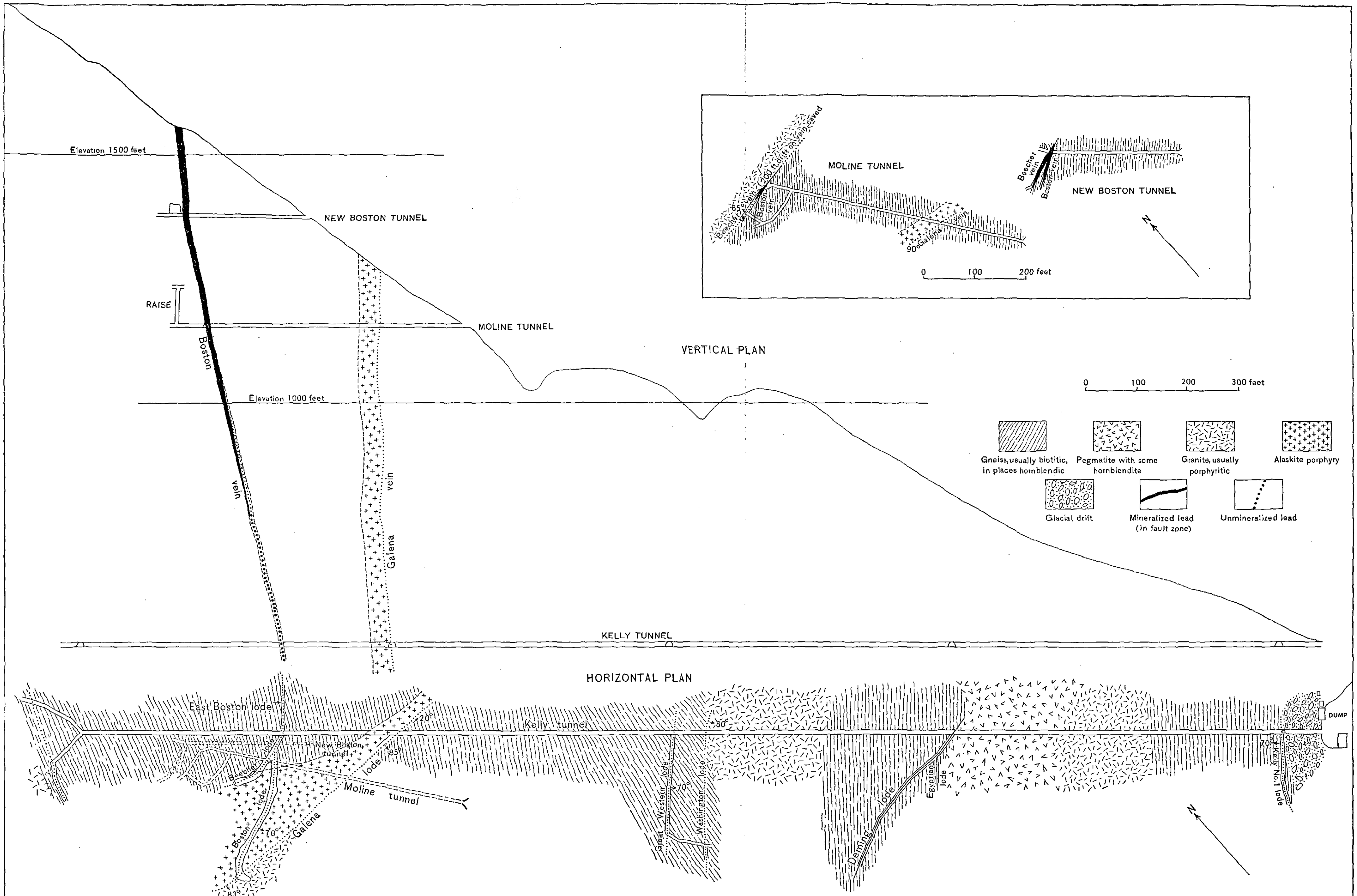
In some hand specimens the porphyry appears decomposed and in others hard and fresh. Microscopic examination, however, indicates that it is all decomposed. A specimen from the Kelly tunnel showed phenocrysts of quartz and others of feldspar entirely altered to sericite and brown carbonates. The groundmass was a fine body of secondary quartz, sericite, and a little brown carbonate, the section containing a small veinlet of brown carbonate and another of fine crystalline quartz. In the other veinlets the two minerals were crystallized together. Another specimen of altered porphyry from the wall rock of the Beecher vein in the Kelly tunnel was so thoroughly decomposed as to show under the microscope only a confused mass of brownish carbonates with sericite and quartz. In general, the porphyry as seen in the Kelly tunnel contains numerous small calcite veinlets apparently derived from the altered rock.

RELATION TO WALL ROCK.

The Boston vein where it enters the porphyry dike on the Kelly tunnel level becomes wider and stronger and shows more mineralization than where it lies in the gneiss.

COMPOSITION OF VEIN.

The vein contains considerable quartz and pyrite, and these two materials are the chief constituents of the poor ore. There is also some siderite, which is probably contemporaneous



VERTICAL AND HORIZONTAL PLANS OF KELLY TUNNEL AND ASSOCIATED MINE WORKINGS.

with the pyrite. The ore of the better quality carries large quantities of massive pure galena, with abundant pyrite, considerable blende, and a little chalcopyrite. This ore contains a small amount of gold and silver. Picked ore from the Moline tunnel is reported to yield 50 to 60 per cent of lead, 14 ounces of silver, and 0.1 of gold. Tetrahedrite is practically absent, only one or two small fragments of it having been reported.

LOCATION OF ORE BODIES.

Only a single ore shoot has been found on the Boston vein, and this is located at the junction of the Boston with the branch called the Beecher. The Boston vein has been traced on the surface eastward nearly to the foot of the mountain without any other discoveries. Except for this shoot, the vein is practically unmineralized, as is shown not only at the surface but in the underground workings. In the Moline tunnel a drift which is now caved was run along the Boston vein for 200 feet east of the ore shoot. The lead as developed in this drift showed neither ore nor quartz, but only a zone of crushed and decomposed rock. Near the junction on this level the quartz and ore are several feet wide, but along this drift the quartz dwindled in thickness to 3 or 4 inches, lying upon the foot wall of the fault zone and containing nothing but a little barren pyrites.

The ore shoot was worked downward from the surface. At the surface it was worked for 50 feet east of the junction along the united veins, and for 100 feet west of the junction along the Boston. On the New Boston tunnel, which cuts the shoot about 170 feet below the outcrop, the body of quartz and sulphides is situated at the exact junction of the main vein with the branch vein and is 8 or 9 feet wide. From this junction the thickness and strength of the vein diminish rapidly on both of the uniting veins and on the trunk vein. On the Moline tunnel level, 400 feet below the outcrop, the principal ore has formed from the junction of the Beecher with the Boston on the west, eastward along the united vein for 75 to 80 feet. Here there is a large body of ore, consisting of a gangue of jaspery white and dark quartz carrying large quantities of sulphides.

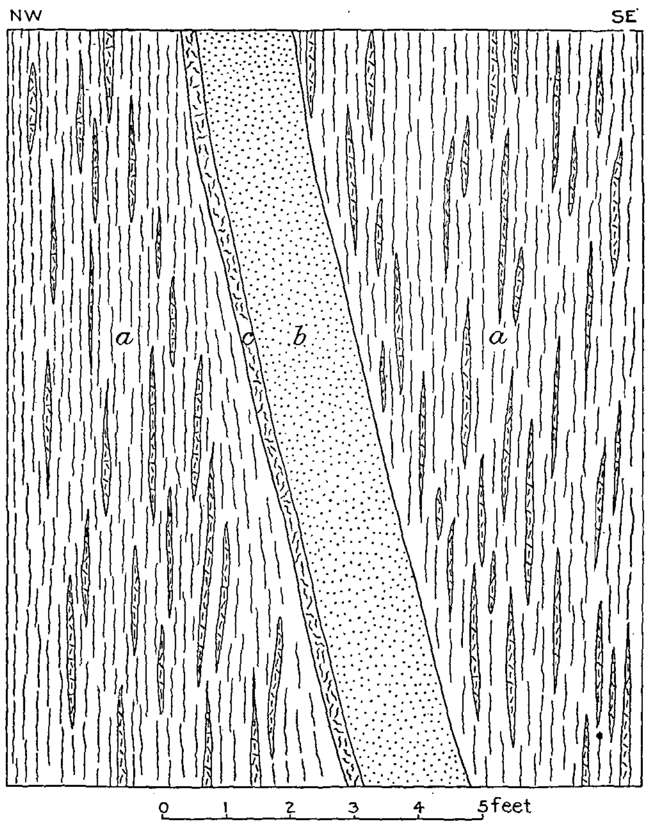


FIG. 108.—Vertical cross section of New Boston vein. Sketched from breast of drift in Kelly tunnel. Shows quartz streak on foot wall of clay lead (watercourse). *a*, Gneiss with pegmatite streaks; *b*, soft clayey gouge; *c*, quartz with specks of pyrite.

INFLUENCE OF DEPTH.

The principal ore shoot of the Boston vein was followed from the surface downward below the Moline tunnel, to a depth of more than 400 feet, but at the point where the same junction was encountered in the Kelly tunnel at a depth of 1,000 feet it was almost entirely unmineralized, being marked only by a thin silicified streak which locally lies upon the foot wall of the fault zone, and by local bunches of iron pyrite and cupriferous pyrite carrying a little silver and a trace of gold. Usually, however, there is no mineralization at all. This soft fault zone in the Kelly tunnel has no resemblance to the strong, wide vein formed at the same intersection in the upper levels.

The Beecher vein, which unites with the Boston to form the ore shoot in the upper levels, appears stronger in the New Boston tunnel, where it extends as a hard definite vein for some distance away from the junction, than it does more than 200 feet deeper in the Moline tunnel, where, at a distance of not many feet away from the junction, it turns into a soft uncemented fault zone. Still deeper, in the Kelly tunnel, the Beecher branch is represented only by a mere slip.

This noted diminution in depth of strength of the ore shoot and of the veins which unite to form the ore shoot suggests the conclusion that the increasing barrenness is necessarily due to increasing distance from surface influences and that the veins have been formed by descending surface waters. Although this conclusion is probably in the main true, it is not unequivocally demonstrated by the above-mentioned occurrences, for when followed laterally the veins which in the region of the principal shoot in the upper levels are strong and well mineralized, become soft and unmineralized, just as they do when followed downward. Certainly the mineralized region here has been limited laterally as well as in depth, and the ore deposition has been due to waters circulating or uniting along the junction named and not mineralizing other portions of the vein channel.

Another circumstance, however, which bears on this problem is that where the soft decomposed fault zones carry a small streak of quartz containing specks of sulphides, this streak almost invariably runs on the foot wall of the zone, as if deposited by waters which sink through the porous material and flowed along the foot (fig. 108).

MUSCOVITE VEIN.

The Muscovite vein has not been traced very far on the surface. Underground it has been opened up in different places by tunnel workings, of which the most extensive has a drift following the lode for 300 feet (fig. 109). The wall rocks of the lode are mixed gneiss and porphyritic granite. The marketable ores consist of pure galena containing some pyrite and approximately 12 ounces per ton of silver. There is some chalcopyrite but no tetrahedrite. Blende occurs very rarely; as a rule the ores do not contain any appreciable quantity of zinc.

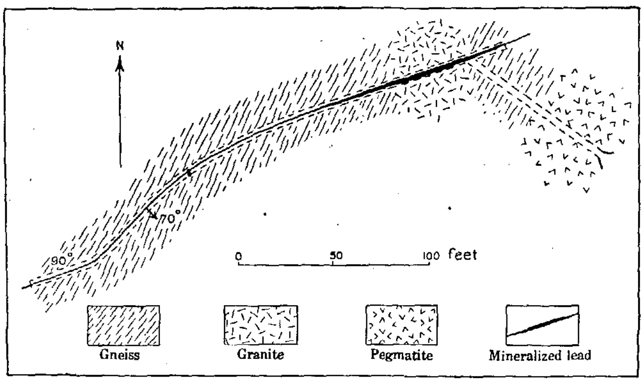


FIG. 109.—Geological plan of Muscovite tunnel.

MINERAL CHIEF VEIN.

The Mineral Chief vein, of which the Smith & Wesson is generally held to be a continuation, is opened up by tunnel drifts of considerable length. A plan of the most extensive of these tunnels now open to observation is shown in fig. 110.

The vein is of irregular thickness, being strong in many places but not very continuous. The wall rocks consist of gneiss and porphyritic granite in about equal proportions. The gneiss is typically silicified near the veins; much of it has been altered so that it has the same green color as that noted in the walls of the Boston vein. The ores are of exactly the same kind as those of the Boston and Spartan workings, the veins in which, as previously mentioned, may possibly have some connection with the Mineral Chief. The picked ore contains large blocks of pure galena with some pyrite and a little chalcopyrite. It is low grade in silver. The characteristic feature of this vein, as well as of others in the same general district, is the soft gouge which occurs in bands along it.

SPARTAN VEIN.

The Spartan tunnel runs in from the bottom of Silver Creek from a point directly northeast of the mouth of the opening on the Mineral Chief vein, of which it is very likely a continuation.

This tunnel shows a vein 2 or 3 feet thick, consisting of mixed silicified country rock and quartz with considerable clean galena containing pyrite. Blende occurs also in streaks and bunches and is of the same dark color as in other lodes of this group. A 6-inch streak of soft gouge follows the vein. The wall rock is gneiss.

MINOR VEINS OF THE NEW BOSTON-MINERAL CHIEF REGION.

The other lodes of this group have not produced any ore of importance. Many of them are strong fault zones which may be traced for some distance on the surface and are well marked when tapped by tunnels underground, but they are slightly or not at all mineralized. The Deming lode is recognizable on the surface. A little ore was taken out here to a depth of 25 to 30 feet. This ore consisted of galena and pyrite, containing approximately 35 ounces of silver and $4 to $5 in gold to the ton, although some of it went higher. This lode is cut in the Kelly tunnel at a distance of 700 feet from the mouth. It strikes east and west, and like most of the other lodes dips steeply to the south. At the point where the tunnel intersects the lode a cubic yard or so of ore showed wire gold associated with galena. This was at a vertical depth of about 300 feet. This vein forks just west of the tunnel on this level. The south branch is called the Egyptian lode and is silicified for a width of about 1 foot. The lode from its forks back to the tunnel is strong and is marked by quartz, galena, blende, and pyrite containing silver and a little gold. The wall rock is of different varieties, including hornblendite, black biotite gneiss, pegmatite, and granite. This lode, wherever developed on this level, is not soft, but shows 3 or 4 feet of hard silicified material and quartz.

The Washington lode, shown on the plan of the Kelly tunnel, is also said to be recognizable on the surface, where, however, it yielded no ore of importance. Very small quantities of ore found on this lode in the Kelly tunnel assayed from 10 to 30 ounces of silver, 4 to 5 per cent of lead, a little zinc, some pyrite, and a very little gold. The wall rock is black biotite gneiss and some pegmatite.

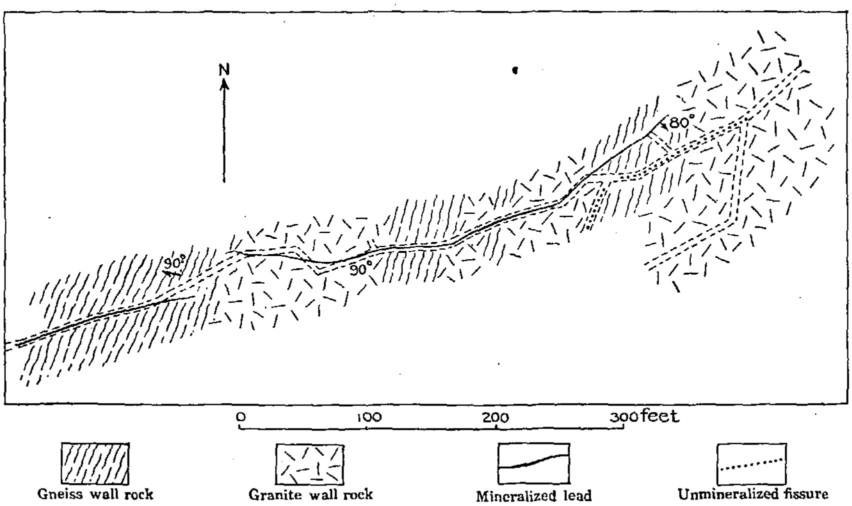


FIG. 110.—Geological plan of Mineral Chief tunnel.

The Great Western lode, shown in the Kelly tunnel plan 60 to 70 feet northwest of the Washington lode, is reported not to have been recognized on the surface. It follows a fault zone marked by a layer of gouge materials and smooth slip surfaces showing striæ dipping eastward at an angle of 20° to 32° from the horizontal. For a distance of 20 to 30 feet along the drift on this lode there is a little quartz and pyrite, from 1 to 2 inches thick and resting upon the foot wall of the fault zone. The remainder of the lode, as exposed by the drift on this level, shows no quartz or mineralization save for a few specks of pyrite.

The Tennessee lode is reported to have been recognized at the surface, but it shows there only soft decomposed material without mineralization. It is opened up only by a prospect hole. Where cut in the Kelly tunnel, at a depth of 1,200 feet or more, it exhibits the same characteristics, being entirely unmineralized.

SUNBURST-SCEPTRE VEIN.

SCEPTRE MINE.

LOCATION AND DEVELOPMENT.

The buildings and tunnel mouth of the Sceptre mine are located in Silver Creek gulch on the east side of Republican Mountain, at an elevation of about 10,700 feet. The vein is opened by a single tunnel, approximately 2,300 feet in length, all on the vein. On the western portion of the same vein are the Sunburst mine workings. (See Pl. LIX.)

COUNTRY ROCK.

Gneiss and pegmatite with local patches of "corn rock" are found on both walls, except where the porphyry dike that extends the whole length of the vein on the southwest side comes into direct contact with the vein material. The gneiss, especially that toward the northwest end, is a highly micaceous biotitic variety.

The porphyry dike, which has a width of 15 to 18 feet, is undoubtedly a continuation of the dike which holds a similar relation to the vein in the Sunburst mine. It is made up chiefly

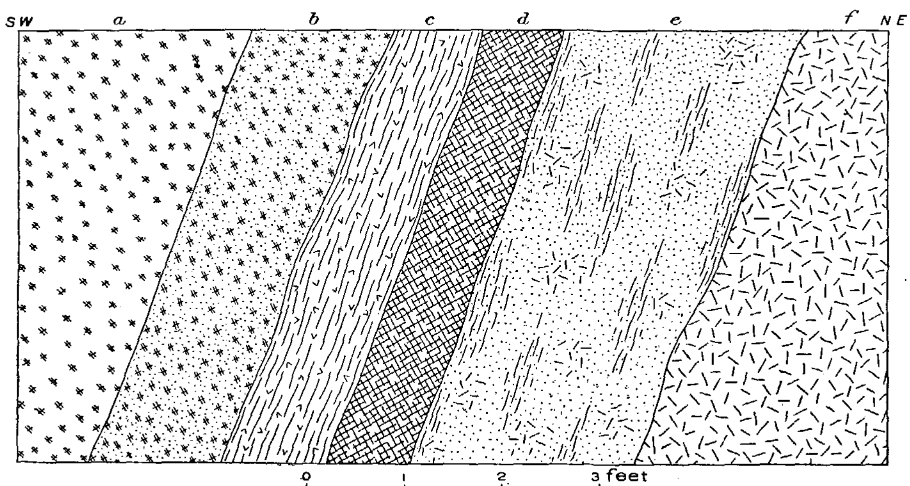


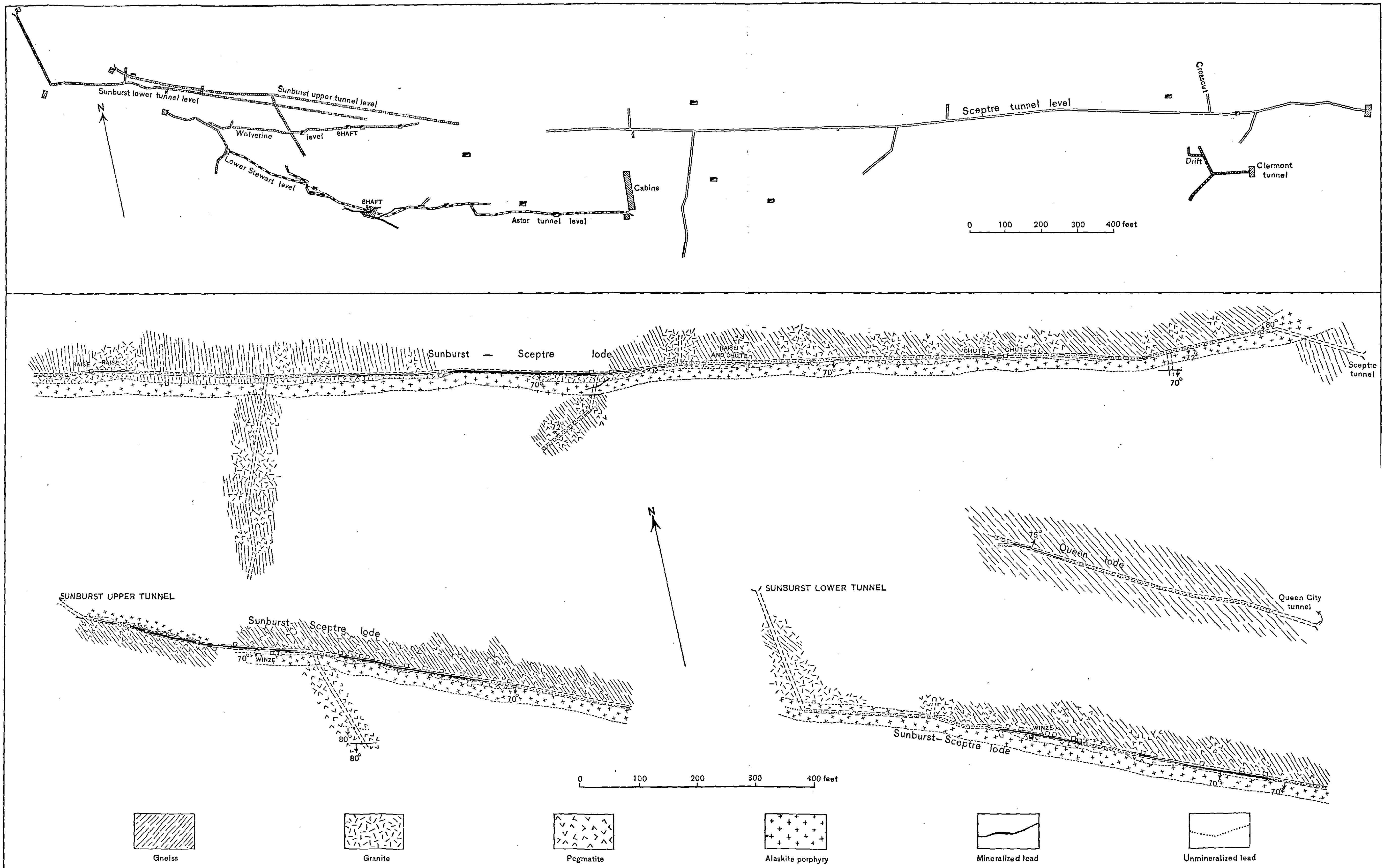
FIG. 111.—Cross section of Sceptre vein, showing the vein structure. *a*, Alaskite porphyry; *b*, silicified alaskite porphyry; *c*, silicified gneiss and pegmatite; *d*, ore and rock breccia; *e*, gouge and crushed rock lead; *f*, granite.

of dark-gray porphyry with phenocrysts of feldspar up to 0.1 inch in length, especially well developed toward the northwest end; but nearer the mouth of the tunnel it changes in places to an almost white rock with biotite phenocrysts up to 0.2 inch in length. The vein, which is considerably altered and silicified in the vicinity of the vein, is probably an alaskite porphyry dike corresponding to one recognized on the surface.

DESCRIPTION OF VEIN.

This vein has a general trend of N. 73° W. and a dip of 70° SW. Through the entire length of the tunnel, about 2,300 feet at the time of visit, the porphyry dike, with the same dip as the vein, is on the southwest (hanging wall) side of the lode, either in direct contact with the vein or separated from it by masses of granite or gneiss up to 18 feet in width.

The vein (fig. 111) is usually accompanied by a zone of dense clay or crushed rock, from 6 inches to 4 feet wide, located just above the foot wall. Immediately above this rather impervious layer lies the ore or mixture of ore and quartz of brecciated country rock, ore, and quartz. In some places the quartz and ore streak or the ore breccia is entirely absent; in others it reaches a width of several feet. Above the ore-bearing band is usually a gray jaspery quartz seam from 1 inch to 4 feet wide, or a more or less silicified belt of crushed gneiss, pegmatite,



MAP OF MINE WORKINGS AND GEOLOGICAL PLANS OF SEPARATE LEVELS, SUNBURST-SCEPTRE GROUP OF MINES.

or granite, of varying width, which separates the ore from the porphyry dike. Nearly midway on the tunnel about 1 foot of crushed quartz and white clay occur between the porphyry dike and the 4 to 5 feet of quartz which lie just above the clay lead.

MINOR VEINS.

About 1,300 feet from the mouth of the tunnel a crosscut runs for 70 feet or so to the west of south, where it intersects a drift on a lead trending S. 69° W. This lead, which is of clay and crushed rock, is 6 inches to 2 feet wide. It dips 75° N. and shows traces of vein quartz and in some places specks of ore. The wall rocks consist of gneiss with patches of pegmatite and "corn rock."

About 550 feet farther in on the tunnel another crosscut extends 325 feet to the west and south, but does not cut any important leads and is not extended far enough to cut the vein mentioned immediately above.

At 300 feet from the mouth a crosscut of 25 feet to the south encounters a mineralized lead trending N. 75° W. and dipping 70° S. This lead shows a streak of brecciated quartz and sphalerite ore from one-half inch to 5 inches wide.

Some small stringers of ore consisting of galena, sphalerite, and pyrite were found at the contact of the porphyry and the country rocks on the southwest side of the porphyry dike, on the contact opposite from that where the Sceptre vein is situated; however, no "pay ore" has ever been discovered, though a few stringers of ore were found running from the main vein and entering the porphyry. Fig. 112 is a vertical section across one of these stringers in the porphyry.

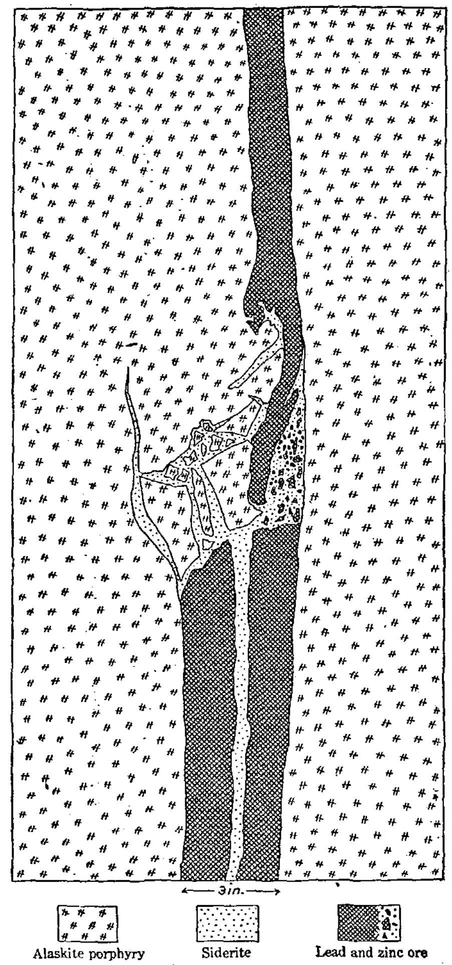


Fig. 112.—Cross section of veinlet running into Sceptre vein, showing reopening of a fissure filled with galena and blende ore and subsequent deposition of siderite.

THE ORE.

The ore of this vein, like that of the rest of the group of veins in the same locality, is of low grade. That is, although the veins are strong and the quartz and ore streak where present is comparatively broad, yet the best assays rarely show more than 200 or 300 ounces of silver and the average is far below this. Besides the silver content, the ore carries from 3 to 5 per cent of galena, 5 to 12 per cent of sphalerite, and 0.08 to 0.12 ounce per ton of gold. Traces of polybasite and gray copper occur here and there, but as a rule the silver is carried mainly by the galena and to a less extent by the sphalerite, which is usually of the black variety. The ores, especially toward the southeast end, carry more or less pyrite, which is locally copper bearing.

The notable features of the ore of this mine are the characteristic siderite gangue, the small percentage of galena, and the fairly constant content of 0.08 to 0.12 ounce of gold. For the most part the ore is a breccia, in which fragments of galena, sphalerite, siderite, and country rock have been recemented by gray jasper-like quartz.

SEQUENCE OF ORE DEPOSITION.

The sequence of events and the order of deposition of the minerals composing the ore breccia is probably as follows:

1. Formation of fracture and brecciation of wall rocks.
2. Cementation of angular fragments of wall rocks by quartz or by pyrite and sphalerite.
3. Deposition of galena.
4. Brecciation of above.
5. Deposition of siderite.
6. Deposition of small stringers of sphalerite-galena ore.
7. Deposition of pyrite.
8. Brecciation.
9. Deposition of finely granular crystalline to coarsely chalcedonic vein quartz.
10. Deposition of pyrite.
11. Deposition of very fine chalcedonic quartz.

The evidence for the foregoing conclusions is based on the following observations from thin microscopic sections and hand specimens and the study of ore in the vein itself:

(1) The vein contains angular fragments of gneiss and pegmatite.

(2) The vein shows broad ore belts, in which black sphalerite is the matrix inclosing the angular fragments of wall rock and quartz. A small amount of contemporaneous pyrite accompanied the sphalerite.

(3) In microscopic sections galena is seen to fill interstices between the sphalerite crystals, to line cracks in the sphalerite, and to form a fringe about the sphalerite crystals.

(4 and 5) In places along the main vein, as well as in some of the branch stringers which here and there leave the main ore streak, siderite forms a cementing material for angular fragments of the sphalerite and galena ore of Nos. 2 and 3, and also fills reopened fissures in this older ore.

Fig. 112 represents a small branch veinlet in porphyry which shows predominant blende, with galena and pyrite bordering the sides of the old fissures, and siderite filling the later opening in the center of this ore; or, where the galena-sphalerite ore has broken away from the sides, the siderite forms the matrix cementing the angular fragments of porphyry and sulphide ore. The pyrite in this veinlet occurs more abundantly near the borders of the other sulphides. In other parts of the vein angular fragments of country rocks or quartz, with a border of siderite surrounding them, are found inclosed in later chalcedonic quartz.

(6) Microscopic examination revealed also some small stringers which showed contemporaneous comb quartz and toothlike crystals of siderite lining a small opening, with later galena and sphalerite filling the center. The second period of sulphide deposition, however, was probably only locally developed, and was not of much economic importance.

(7) Pyrite crystals were noted on top of siderite crystals which lined vugs. Thin sections of the ore also showed pyrite along the cleavage planes of siderite and forming a coating about siderite crystals. This pyrite was contemporaneous with some quartz.

(8 and 9) The brecciated fragments of the ore formed by the foregoing processes were inclosed in the finely granular crystalline quartz of No. 9, as seen in rock sections.

(10) In thin sections forking stringers of pyrite were noted which cut through the quartz crystal aggregates of No. 8 and the rock fragments.

(11) Very fine chalcedonic quartz stringers were found cutting all of the above-described ores as well as including angular fragments of them. This observation was noted both in hand specimens and in thin microscopic sections.

LOCATION OF ORE BODIES.

Two important ore bodies were noted. The main body, about 320 feet long, was about 1,250 feet northwest of the mouth of the tunnel and had a pitch of about 16° SE. The second body of ore was about 150 feet in length and carried a larger percentage of low-grade ore (30 ounces silver), containing considerable sphalerite. This mass of ore was encountered about 1,700 feet from the tunnel mouth.

SUNBURST MINE.

LOCATION AND DEVELOPMENT.

The Sunburst mine (see Pl. LIX) is located at an elevation of about 11,300 feet on the northwest slope of Republican Mountain, a short distance below the ridge connecting Republican and Democrat mountains.

The vein is opened by two tunnels. The upper tunnel, which is 132 feet above the lower one, is about 1,000 feet in length and follows the vein all the way. The lower tunnel consists of a crosscut of 225 feet and a drift of about 900 feet on the vein.

Besides the two drifts on the vein, a single exploratory crosscut about 200 feet in length runs a little east of south from the lower tunnel level, at a point about 450 feet from the mouth of the tunnel. At the time of visit two faint leads had been intersected by this crosscut, one with a strike of S. 72° E. and the other of S. 81° E. Both of these leads had a dip of 80° S.

COUNTRY ROCK.

The Sunburst vein runs parallel to and is found immediately in contact with or within a short distance of the porphyry dike that holds a similar relation to the Sceptre vein, of which the Sunburst is the westward continuation. The rock forming this dike is in the main dark gray, and has a compact groundmass and conspicuous phenocrysts of feldspar up to 0.1 inch in diameter. In some places, however, the porphyry is white and has hexagonal plates of biotite, and elsewhere it forms a light-colored, finely granular, altered mass. The dike, which dips 70° SW. and is approximately 18 feet wide, lies in general on the southwest side of the vein, where it is either in direct contact with the lode material or is separated from it by lenses of gneiss and pegmatite or altered porphyritic granite.

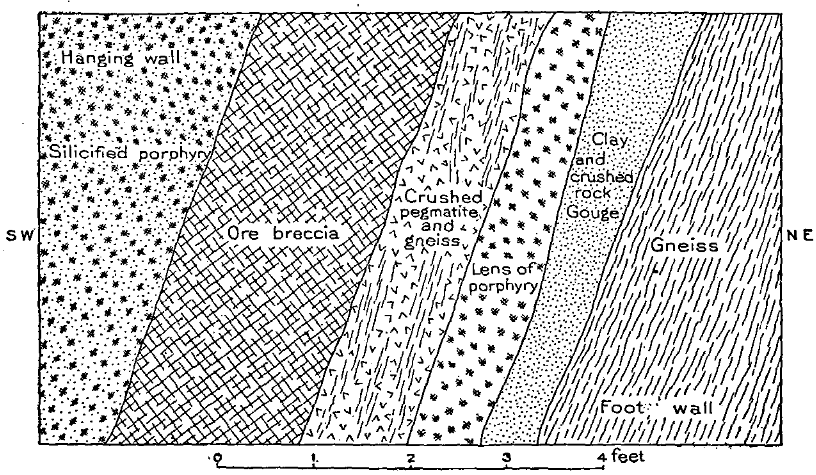


FIG. 113.—Cross section of Sunburst-Sceptre vein in stope 80 feet above lower Sunburst tunnel showing lens or horse of porphyry within the vein zone.

The northeast wall consists principally of micaceous biotite, gneiss, and pegmatite, with small patches of porphyritic granite or "corn rock." Southwest of the porphyry dike the country rock, where exposed, was coarse pegmatite with a small amount of gneiss.

DESCRIPTION OF VEIN.

The vein has a general strike of N. 70° W. and a uniform dip of 70° to the west of south. A band of white clay gouge or a mixture of clay and crushed and kaolinized gneiss and pegmatite separates the ore or quartz streak from the northeast or foot wall of the lode, and silicified porphyry occurs on the hanging-wall side with a belt (horse) of silicified gneiss and pegmatite between it and the ore in many places. Fig. 113 illustrates a vertical section across the inner stope above the lower level, where a lens of porphyry about 1 foot wide comes in between the foot-wall "gouge" lead and a belt of crushed and kaolinized pegmatite and gneiss farther southwest. In places, especially near the breast of the lower tunnel, the soft white "gouge" lead changes to a very tough grayish putty-like clay belt.

That the relation between the vein fracture and the porphyry is purely physical, depending on the fact that a zone of weakness exists either in the porphyry dike itself or in the rocks adjacent to the dike, is shown not only by the belt of gneiss, pegmatite, or granite, from a few inches to 17 or 18 feet wide, which generally occurs between the vein proper and the porphyry contact, but also by the fact that toward the west end of the upper tunnel the vein crosses to the north side of the dike, whereas in the lower tunnel the vein fracture runs along in the porphyry dike itself and almost entirely disappears within the dike by fracturing.

Except where the vein runs through porphyry, the clay and crushed rock lead next to the foot wall is continuous throughout the length of the vein, but ranges from a few inches to 4 or 5 feet in width. Between this clay streak and the hanging wall, in the barren sections, occur small irregular lenses or discontinuous strips of dark-gray quartz. As ore-bearing areas are approached this quartz strip becomes continuous and more and more speckled with metallic minerals, grading into an ore shoot in which the quartz and ore streak may reach a width as great as 4 feet.

NATURE OF ORE.

The ore streak, although broad, rarely yields what would be called high-grade ore in the Georgetown district. Assays have shown the values in silver to run as high as 300 ounces, but these are exceptional. The mill runs probably average about 100 ounces of silver, 4 to 5 per cent of lead, and 8 to 10 per cent of zinc, with a small but rather constant content of gold (0.08 to 0.1 ounce). The ore for the most part is a breccia, in which angular fragments of galena, sphalerite, siderite, and country rock have been recemented by a later gray jasper-like quartz.

The sequence of the deposition of the various constituents of the ore is similar to that of the ores in the Sceptre mine. (See p. 300.) The Sunburst ores differ from the Sceptre ores in having less pyrite and cupriferous pyrite.

Small masses of semioxidized ores are found in places down to a depth of 150 feet from the surface. They usually consist of rather porous masses of poorly formed crystals of black sphalerite and galena, covered by a reddish or brownish coating of oxidized minerals, probably for the most part iron and manganese oxides derived from the oxidation of siderite, rhodochrosite, and pyrite. The oxidized and semioxidized ores (locally called "sulphurets") are said to carry values but slightly higher than the unoxidized ores.

Native silver in the form of "wire silver" was found intimately mixed with sphalerite in the innermost stope above the lower level, at a distance of 200 feet from the surface, along a postmineral plane of movement. Small quantities of tetrahedrite (gray copper) and polybasite occur here and there in the quartz and ore streak.

The characteristic feature of the Sunburst-Sceptre ores is the abundance of ferruginous rhodochrosite occurring as a gangue mineral. It is found in considerable quantity even in the highest grades of ore. The ore in the upper parts of the shoots was usually of a little higher grade than that at greater depths.

LOCATION OF ORE BODIES.

The ore appears to occur in two distinct ore bodies. The first one, which is encountered about 125 feet from the mouth of the upper tunnel, has a width of about 200 feet and extends from the surface to the lower level, with a vertical to steeply inclined westerly pitch. The second ore body, which lies about 490 feet southeast of the mouth of the upper tunnel, is 275 feet wide and extends from a point 115 feet above the upper level to the lowest level also. This ore body pitches toward the northwest.

QUEEN CITY LODE.

LOCATION AND DEVELOPMENT.

The Queen City mine is opened by a single tunnel, the mouth of which is located in the valley of Silver Creek, at an elevation of about 10,700 feet and at a distance of 250 to 300 feet south of the mouth of Sceptre tunnel. The tunnel has followed the vein for 525 feet.

COUNTRY ROCK.

The country rock consists almost entirely of micaceous biotite gneiss, with seams or patches of pegmatite.

DESCRIPTION OF VEIN.

The vein strikes N. 65° W., being thus nearly parallel to the Sceptre, and dips about 75° NW. It consists of a single crushed rock and clay lead from the mouth to a point about 380 feet in, where this lead is replaced by a narrow quartz streak that gradually increases in width up to 2 feet at a point 480 feet from the mouth, where a branch vein enters from the northwest (striking N. 75° W.). This quartz streak carries some specks of galena and sphalerite, although up to the time of visit it had yielded no pay ore. Its existence is undoubtedly due to the union of the branch vein with the main vein, for it narrows up again beyond the union.

ASTOR MINE.

The Astor mine is located at the head of Silver Creek Valley, near the summit of the ridge extending between Republican and Democrat mountains, at an elevation of nearly 11,500 feet above sea level. This mine, which was worked extensively previous to 1868, formerly had more than 2,500 feet of underground workings, but at present access can be had to practically none of these on account of excessive caving. The total yield of this mine up to 1880, according to Fossett,[a] was between $60,000 and $100,000, and was due to numerous small shipments of comparatively rich ore. Most of this ore was obtained near the surface and from a stope about 150 feet in length, which was reached by a crosscut tunnel 450 feet long and a drift extending 75 feet along the vein.

The W. B. Astor vein, which runs approximately parallel to the Sunburst-Sceptre vein, is a rather broad, soft vein, striking N. 75° W. The mine workings on the west side of the ridge are partly on the Astor vein and partly on the Wolverine vein, both of which are supposed to have been encountered also in the workings of the Sunburst mine. The Astor vein is considered to have been cut in the Sceptre workings, too, but its identity could not be established.

The ore, which consisted chiefly of galena, zinc blende, and traces of pyrite associated with a quartz-siderite gangue, is said to have averaged between 75 and 300 ounces of silver to the ton, but assays as high as 1,200 to 1,600 ounces of silver per ton have been obtained from picked specimens.

DEMOCRAT MOUNTAIN GROUP OF VEINS.

GENERAL DESCRIPTION.

The so-called Democrat Mountain group of veins (Pl. LX) occupies an area of irregular extent, a few thousand feet in diameter, situated on the very summit of Democrat Mountain, and extends from the ridge of the mountain a short distance down the slope both to the east and to the west. When the veins of the group are plotted together, there is a noticeable general east-west trend, more or less parallel with that of the Republican Mountain zone of veins. To speak more accurately, however, the veins represent two distinct systems—a northeast system and a northwest system.

There was considerable activity in this district about thirty years ago, and it is estimated that approximately $2,000,000 worth of ore was produced, but for many years past the mining operations have been of an unimportant character.

NATURE OF VEINS.

The relations of different veins to this group are unusual as compared with those of neighboring districts in that the veins can be referred to two distinct systems striking in different directions and running into or crossing one another.

One set of veins has a northwest strike and is represented chiefly by the Emma-Galie, Polar Star-Junction, and Fletcher-Silver Cloud veins. Another set has a northeast strike and is represented chiefly by the Rogers and Cliff veins. There are also minor veins belonging to these systems. Veins having strikes transverse to one another may run into each other without

[a] Fossett, Frank, Colorado, 1880, p. 387.

crossing or they may cross, but where they cross, so far as noted, there has been no appreciable displacement of one vein by another. Some of the relatively weaker lodes have an irregular and curving trend, as if wavering between the two principal strikes. This is characteristic—to take the best examples—of the Nyanza and Silver Glance lodes, whose course is curving and in part oblique between the trends of the two systems, but which on their east ends conform entirely in strike to the northwest system and on their west ends curve around so as to be parallel with the northeast system. (See fig. 114.)

From these different relations it is probable that one set of vein fractures is not later than the other, but that both were formed contemporaneously and were the results of a single stress. The character of the vein filling is similar in both systems, indicating a contemporaneous mineralization of the vein zones.

The main lodes are usually well-defined zones of crushed and altered rock of varying thickness. These zones are locally cemented with vein material, including quartz and sulphides. Except where these ore bodies occur, the lodes are in general soft and barren looking,

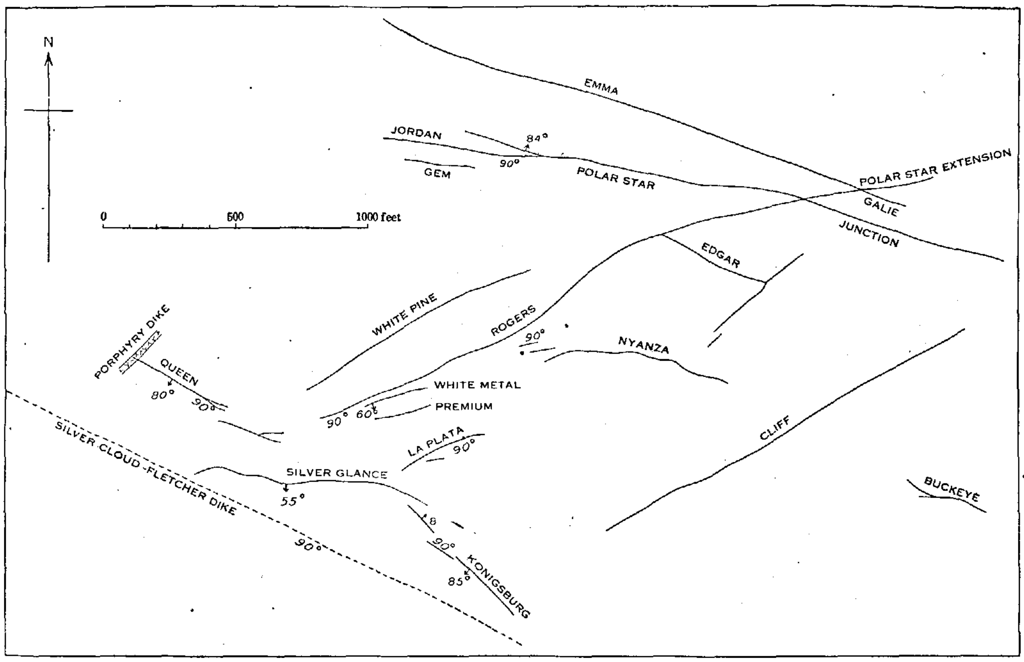


FIG. 114.—Horizontal sketch plan of developed veins (so far as known) in Democrat Mountain group. At the west end of the developed portion of the Queen vein is the only porphyry dike noted in the district. The wall rocks are principally mixed gneiss and granite.

hardly resembling mineral veins at all—a particular in which they resemble the veins of the Republican Mountain group.

In the Buckeye mine evidence of movement subsequent to mineralization was noted. In one place the vein filling consists of angular fragments of ore embedded in a matrix of crushed country rock, which has been indurated by a silica cement filling the interstices. This recalls a similar phenomenon in the Mendota lode, near Silver Plume. (See p. 229.)

NATURE OF WALL ROCKS.

The principal wall rock of the Democrat Mountain group of veins is biotite gneiss, with considerable granite, much of which is porphyritic, and some pegmatite and diorite. & single porphyry dike was noted in the Queen tunnel (fig. 114). This dike is about 30 feet wide and entirely decomposed. It has a strike at right angles to that of the Queen of the West vein, which runs into it in the tunnel workings, and parallel with that of the veins of the northeast system, such as the Rogers and Cliff. However, so far as noted, it has no connection with any vein of importance.

MAP (INCOMPLETE) SHOWING MINE WORKINGS OF DEMOCRAT MOUNTAIN DISTRICT.

ALTERATION OF WALL ROCKS.

The rocks adjacent to the veins of this group are commonly altered in the usual way characteristic of wall rocks in this general region. A specimen of the porphyry dike in the Queen tunnel above mentioned, when examined microscopically, proved to be entirely altered to fine sericite and quartz, with a little iron oxide.

INFLUENCE OF WALL ROCK ON VEINS.

The favorite wall rock of the miners in this district is the porphyritic granite, which is frequently called "corn rock." The reason appears to be, here as elsewhere, that this rock has much greater rigidity than the biotite gneiss and has lent itself better to the formation of strong and persistent fractures. It was noted in several places that lodes on passing from granite into gneiss have a tendency to split and scatter, passing between the laminæ.

COMPOSITION OF VEINS.

The chief gangue material is quartz, which is found in two varieties—one having a typical crystalline texture and the other having the dense, fine texture of chert. Specimens from the Rogers vein in the Edgar tunnel and from the Jordan vein in the Bonanza tunnel show fragments of strained crystalline quartz, cemented by chert containing fine crystalline siderite and areas of sericite. The chief sulphide is galena. More or less blende is present, especially on the eastern slope of the mountain—as, for example, in the Cliff workings. This blende is typically dark colored, like that in the mines of Republican Mountain and in the Griffith mine. Scarcely any iron pyrites is present, but there is locally some chalcopyrite. In the Cliff mine brown carbonates, probably of iron or maganese or both, were noted.

The most characteristic ores of this district have been high-grade silver ores. They are distinct from those of the Republican Mountain mines in that they are high in silver and contain no gold and less lead, iron, and zinc. The best ore has run up to several hundred ounces in silver per ton, and the amount of low-grade ore is not very great. Native silver has been frequently found in these mines.

PARAGENESIS OF VEIN MATERIALS.

It was noted that in a veinlet containing quartz and galena which was observed in the Rogers vein zone in the Edgar tunnel workings the two minerals were of distinctly different ages, the quartz being first, coating the walls of the fissure, and the galena being later, filling the remaining space. In the Cliff mine it was noted that in some places brown carbonates (probably carbonates of iron or manganese or both) had the same age relation to the sulphides as the quartz just mentioned, constituting the first crust which formed upon the walls of the vein cavity.

As already noted, specimens from the Rogers and Jordan veins indicate a crushing of the original crystalline quartz and a cementation of the breccia thus formed by fine chert. Similarly it was noted in the Buckeye mine that the sulphides of the original deposition had been brecciated and the interstices between the fragments of ore filled with crushed country rock, which in turn was cemented by fine silica.

LOCATION OF ORE BODIES.

The ore bodies encountered in this group of veins have been relatively small in proportion to the amount of exploration that has been done, but as a rule have been of high grade. Apart from these ore bodies the veins are in many places very little or not at all mineralized, or even not cemented by silica.

Most of the old workings are at present inaccessible. According to reliable reports, however, the chief ore occurred in the vicinity of the principal crossing or intersection of the main lodes in the region, where the powerful Rogers vein runs into the Polar Star and Emma veins, the Rogers belonging to the northeast system, and the other two to the northwest system. It is reported that around this junction, within a horizontal area having a diameter of several hundred feet, a million dollars' worth of ore was extracted. In this region nearly all the intersecting lodes had ore shoots, of which that of the Rogers seems to have persisted farther away (southeast) from the junction than any of the others. It is reported, however, that at the exact crossing of the lodes as a rule there was little ore, only leads extending to ore shoots at a little distance being present. This productive area is situated on the very top of the Democrat Mountain ridge, in a little saddle. It is reported that the ore shoots here dip both ways, according to the slope, the pitch on the eastern or Clear Creek slope being to the east, and that on the western or Bard Creek slope being to the west, thus saddling the ridge.

Outside of this principal field of mineralization, lesser pockets of ore were found on the Jordan, Silver Glance, Silver Cloud, Queen of the West, Cliff, Buckeye, and other veins. In some of these places the intersection of two veins has evidently had a stimulating effect on ore deposition. For example, in the Buckeye the main vein trends N. 85° W. and is intersected by a branch striking N. 55° W. From the junction of this branch, which is practically unmineralized for 40 feet along the united vein, high-grade ore has been taken out and low-grade ore extends for 80 feet farther. At another junction, however, there is no increased mineralization whatever.

The ore bodies which have been worked out in this region are characteristically shallow, most of the ore having been taken out within 200 feet of the surface. Locally the ore has been found to a depth of 400 feet or more, but as a rule the lower workings, including the long tunnels, have encountered mainly barren and soft unmineralized lodes beneath the well-mineralized superficial portions.

ORIGIN OF ORES.

The proximity of the known shoots to the surface and especially the conformation of their pitch with the surface slopes, together with the characteristically almost unmineralized nature of the same lodes at the depth of a few hundred feet, suggest that the ores were deposited by waters which descended from the surface.

DESCRIPTIONS OF SEPARATE VEINS.

The principal lodes of the northwest system are the Emma-Galie and Polar Star-Junction on the north side of the district, and the Silver Glance and Silver Cloud-Fletcher on the south side. Minor veins, which, from the best information known to the writers, seem to form with the Silver Glance lode a northwestward-trending zone of imbricating veins, include the Queen of the West, Konigsburg, Edgar, Nyanza, and Buckeye.

The Emma-Galie lode probably crosses the Rogers lode, the portion on the east side of the Rogers being known as the Galie and that on the west side as the Emma. The workings are not now accessible, so that this conclusion could not be actually proved. It is reported that the chief ore shoot on the Emma occurred where a minor diagonal lode styled the Little Emma intersected the main vein and ran with it for some little distance before crossing and leaving it on the opposite side. The ore in this shoot was of high grade. The Galie vein, on the east side of the intersection, is reported to have contained a body of relatively low-grade ore near the field of intersection.

The Polar Star lode is probably the same as the Junction, the former lying on the west side of the intersection with the Rogers and the latter on the east. All these workings, however, are now inaccessible, so that only the probability can be stated. The Polar Star-Junction, when considered as one, has been developed by underground workings along its strike extent for about 2,200 feet. The ore on this lode was taken chiefly from the superficial portions. The Bonanza tunnel, which has a long drift for about 1,400 feet on the vein, shows a little ore in it, the lode being soft, semisilicified barren material 3 or 4 feet wide and underlying the zone where the rich pockets were present. In the workings of this tunnel the Polar Star divides into two branches opening out to the west, the more northern retaining the name Polar Star and the southern, which appears to be the stronger, being called the Jordan. A small body of ore was found on the Jordan branch not far from the junction. A small lode cut by the Bonanza tunnel about 80 feet south of the Jordan is parallel to it, and is probably either a branch or an auxiliary vein.

The Edgar lode as opened up in the Edgar tunnel runs transversely across from the Rogers lode on the northeast to a minor lode parallel with the Rogers on the southwest. It shows no ore of importance.

The Nyanza tunnel is on the same level with the Edgar tunnel and connects with it, the former starting from the west slope of the hill and the latter from the east. The Nyanza tunnel runs along the Nyanza lode, which is of irregular strike and is in most places of no importance.

The Buckeye vein has a general strike of N. 85° W. and a dip of 60° to 80° S. It is opened up by two tunnels, of which only the upper was accessible at the time of examination. (See fig. 115.) The country rock is gneiss with a little pegmatite. The vein follows a fairly strong but rather irregular fracture which tends to break up toward the east into a number of branches. The most important branch strikes N. 55° W. and joins the main vein about 275 feet from the

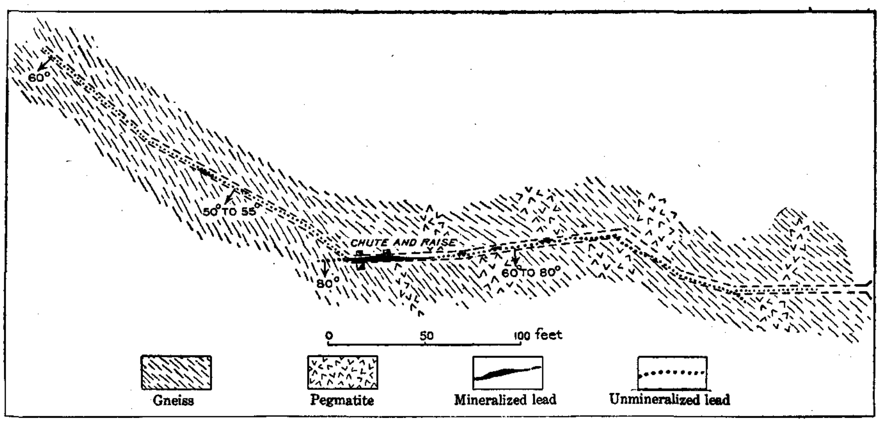


FIG. 115.—Geological plan of tunnel on Buckeye vein.

mouth of the upper tunnel. This vein is very slightly mineralized, but just beyond the junction with the main vein the chief body of ore was formed, extending from the junction for a distance of about 40 feet to the east, along the main vein.

The Queen of the West lode strikes northwestward and dips steeply to the southwest or is vertical. As opened up in the Queen tunnel it is fairly strong, but weakens at both ends of the development work. It contains a little ore.

The Silver Glance is a somewhat curving and oblique vein, belonging on the whole distinctly to the northwest system. Its dip is flatter than that of most of these veins and in the lowest level, the Queen tunnel or seventh level, was noted to be about 55° SW. This lode is developed by underground workings along a strike extent of more than 1,000 feet. It was principally exploited through the Silver Glance shaft. Six levels were run on the vein, the seventh level being run in from the Queen tunnel. Considerable ore in bunches has been taken out from this lode.

The workings on the Fletcher vein were all inaccessible at the time of examination, on account of caving. On taking the general course of the dumps which were reported to be up the line of the Fletcher, it appears that this vein is one of the northwest system. It is stated that this lode has yielded three distinct pockets of ore, and has had a fairly good production. The dip is said to be nearly vertical. The Fletcher vein is reported to run on the northwest into the Silver Cloud, which has approximately the same strike and dip and is currently supposed to be practically the same vein.

But little is known of the Konigsburg vein, whose workings are mostly caved shut and of which no maps were obtainable. It is reported to have been traced for a long distance on the surface, and to have yielded a little rich ore. A tunnel examined by the writers and reported to be on the Konigsburg lode shows a fairly strong vertical vein with a northwesterly trend, somewhat oblique to the trend of the more important veins of the northwest system.

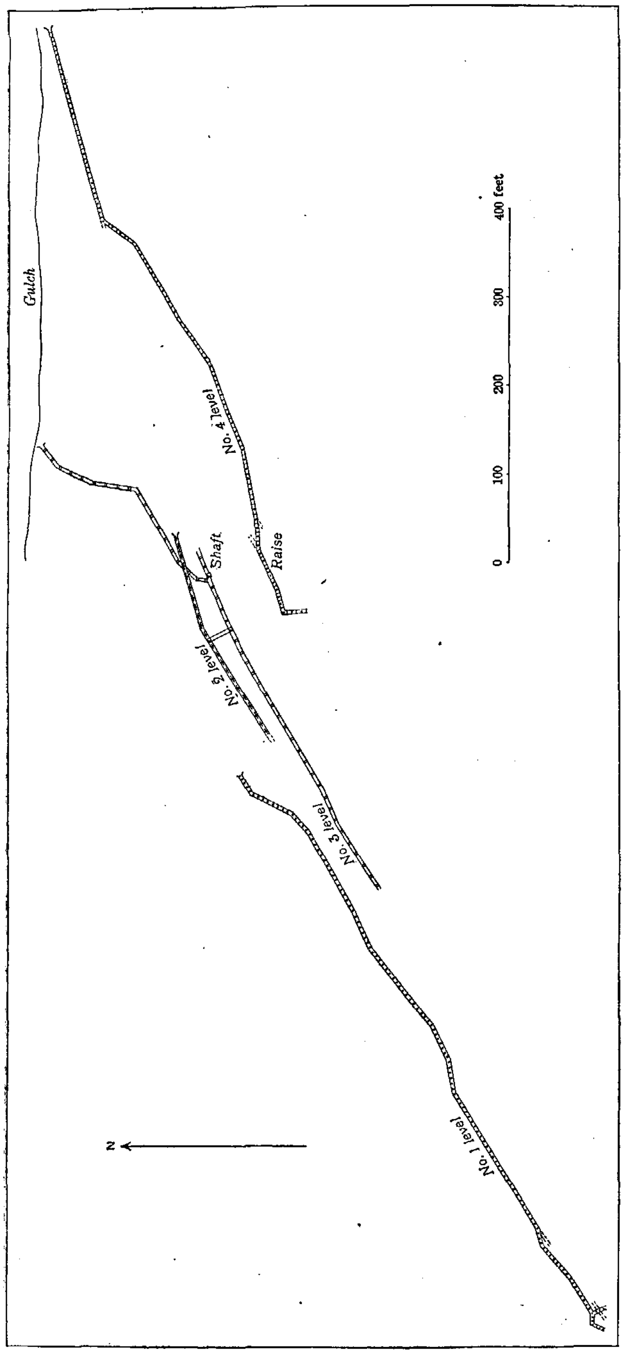


FIG. 116.—Plan of workings of Cliff mine.

The northeast system of lodes is represented principally by the Rogers and Cliff veins, which are parallel and nearly 1,000 feet apart. Both are strong lodes, the Rogers having been traced by underground workings for about 2,500 feet and the Cliff for about 1,500 feet. Minor veins of the same system include the White Metal, Premium, La Plata, and the northeastward-striking vein zone in the Edgar tunnel workings.

The Rogers vein, perhaps the strongest and most mineralized lode of the district, probably crosses the Polar Star-Junction and Emma-Galie veins, its continuation beyond the intersection being known as the Polar Star Extension. At the time of examination the Rogers vein was visible in only three places—in the Edgar, Bonanza, and White Pine tunnels. In these localities it appears as a broad crushed zone in granite and gneiss, more or less silicified and containing sulphides.

The White Pine lode is intersected in the Bonanza tunnel and also in the White Pine tunnel. Like the Rogers, it is nearly vertical and has a northeast trend. Its relations to the Rogers indicate that it is very likely a branch of this lode, although the connection is not known to the writers. This vein contains, in a silicified gangue, galena and blende; the best ores are reported to carry chalcopyrite and gray copper. It has not been well developed.

The Cliff mine (fig. 116) was actively worked as early as 1857. Up to the end of 1883 the production, as estimated by Burchard,[a] was about $60,000. Kimball[b] gives the yield of the mine for 1887 as $1,939.13 and for 1888 as $2,762.80, of which $2,586 represented the silver and $176.80 the gold content. The vein is developed by four tunnels, aggregating about 2,500 feet in

[a] Burchard, H. C., Precious metals in the United States in 1883.
[b] Kimball, J. P., Production of gold and silver in the United States, 1887, p. 159; idem, 1888, p. 100.

length, of which all except the lowest, or fourth level, were caved shut at the time of visit. The vein is a strong, soft gouge in gneiss and pegmatite, with some granite. A number of small branches which leave the main vein appear to have influenced ore deposition favorably, as the vein is somewhat better mineralized immediately beyond the junctions of the more prominent branches than elsewhere (fig. 117). The ore is made up of galena and dark-colored blende, the gangue of quartz and brown carbonates; pyrite and chalcopyrite are lacking.

The Premium lode, which is developed in the White Pine tunnel, is a minor vein parallel to the Rogers and lying in an intermediate position between the White Metal and the La Plata veins, which are also parallel. Of these minor northeast veins some are probably continuous with the Nyanza or with the minor northeast leads that are encountered in the outer portion of the Nyanza tunnel, lying between the Nyanza and the Rogers lodes. As a rule they are soft lodes, containing only a little ore.

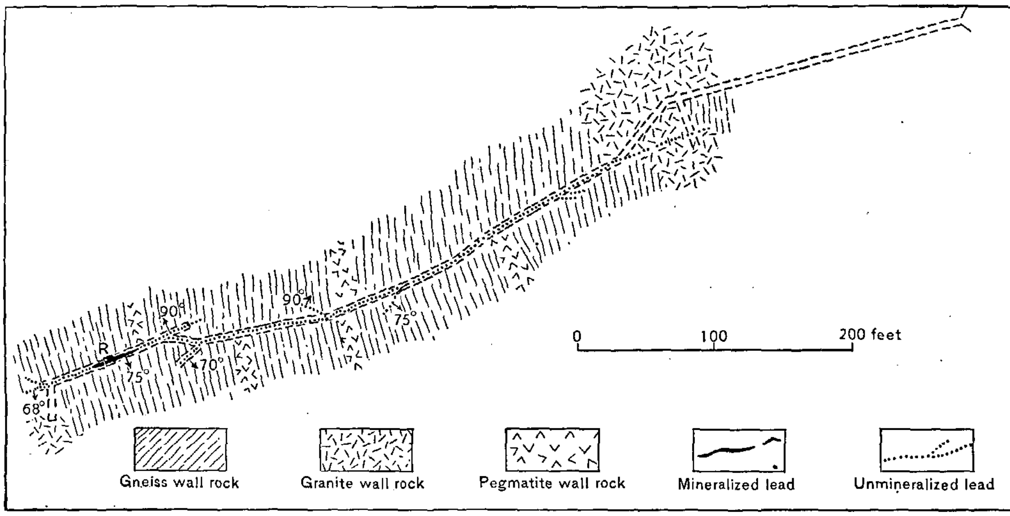


FIG. 117.—Geological plan of fourth level, Cliff mine.

MINES OF LINCOLN MOUNTAIN WITHIN THE GEORGETOWN QUADRANGLE.[a]

RAMSDALE TUNNEL.

LOCATION.

The Ramsdale tunnel is located at an elevation of a little over 9,400 feet on the south slope of Lincoln Mountain, about a mile west and a little north of the summit of the pass on the road between Georgetown and Empire. The tunnel, which runs a little west of north for about 400 feet, cuts the Ramsdale vein at a point about 340 feet from its mouth.

NATURE OF WALL ROCKS.

The wall rocks consist of granite and porphyries. The porphyries are probably of different kinds, which, though highly decomposed, may be described as alaskite porphyry and quartz monzonite porphyry. The alaskite porphyry was found in a 15-foot dike which crosses the tunnel about 65 feet from its mouth, with a strike of N. 60° E. and a dip of 65° NW. At a distance of about 230 feet from the mouth of the tunnel a dike of very much altered porphyry 30 feet wide, probably belonging to the quartz monzonite class, crosses the tunnel in a N. 88° E. direction. This dike had a quartz streak carrying some pyrite and traces of sphalerite along the north side, at the contact with the granite. The dip of the vein and the porphyry dike is 70° N. There had not been sufficient development work at the time of visit to show the relations between the two dikes, although they appeared to be converging toward the east.

[a] For description of the mines of Lincoln Mountain north of the Georgetown quadrangle see pp. 408–410.

NATURE OF VEIN.

The Ramsdale vein was encountered in the tunnel about 40 feet north of the 30-foot porphyry dike, at which point both walls consisted of granite. (See fig. 118.) The vein, which has a general strike of S. 80° E. and a dip of about 70° N., varies considerably in width. Where cut by the tunnel it consists of a quartz streak 2 feet wide, carrying some pyrite and a little zinc blende, but a short distance farther east it is 5 to 10 feet wide and is composed (*a*) of a breccia of light-gray quartz and granite, cemented by a dark-gray to black quartz carrying specks of pyrite and small masses of galena and cupriferous pyrite ore, or (*b*) of a fractured zone of granite almost entirely replaced by quartz and containing disseminated specks of pyrite. Some of the vein filling shows movement subsequent to the ore deposition, by which the ore was brecciated and mixed with crushed and pulverized country rock. This crushed mass, however, was subsequently recemented by silica carrying pyrite. Slickensides were noticed along the north wall of the lead, which showed movement striæ dipping 40° E.

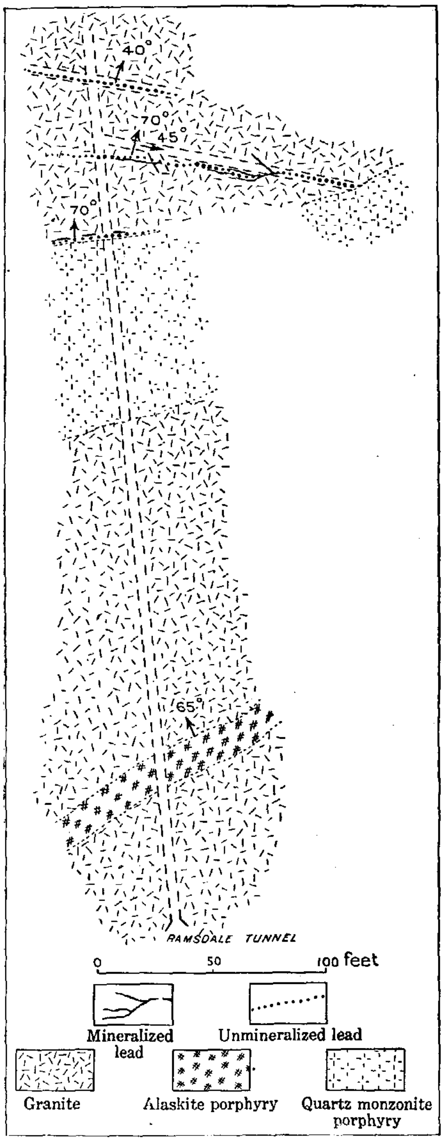


FIG. 118.—Geological plan of tunnel of Ramsdale mine.

The best ore consists of a banded mixture of galena and copper-bearing pyrite associated with a little zinc blende. The blende is usually black in color, but some resin blende is found. Quartz is practically the only gangue mineral, although a little siderite is locally present. Black, sooty sulphides are here and there associated with the galena. The miners hold that the higher the copper content in the ore the greater the value. Assays as high as 15 to 25 ounces in gold to the ton are reported by some of the leasers, and some of the ore is said to carry 8 to 11 per cent of lead and 10 per cent of copper, with a maximum of 10 to 15 per cent of zinc. An assay of a sample of ore from this mine made for the writers by R. H. Officer & Co., of Salt Lake City, Utah, showed 3.53 ounces of gold and 12 ounces of silver to the ton.

From 25 to 30 feet north of the Ramsdale vein and running parallel to it is a vein of crushed granite, clay, and quartz carrying a little pyrite and dipping 45° N.

VIRGINIA CITY MINE.

LOCATION AND DEVELOPMENT.

The shaft on the Virginia City lode is located just south of the crest of the ridge running east from Lincoln Mountain, at an elevation of about 10,300 feet. No work had been done on the vein for some time previous to the visit and the shaft was filled with water up to a point about 80 feet below the collar.

A short tunnel about 50 feet below the collar connects with a drift which extends for a short distance on either side of the shaft. At the time of visit a long tunnel had just been started for the purpose of connecting with the lode at a point in the shaft below the lowest level.

PRODUCTION.

The exact production of this mine could not be learned, but according to Mr. Frank A. Maxwell, of Georgetown,[a] there are still in existence mill-run sheets which aggregate $20,000.

COUNTRY ROCK.

The wall rocks are chiefly granitic gneiss and pegmatite. The gneiss is somewhat decomposed, and some of the biotite gneiss at a considerable distance from the vein shows small, irregular, isolated bunches of pyrite, carrying no values so far as known.

DESCRIPTION OF VEIN.

Above the sulphide zone, which on this hill came in at a depth of about 25 feet below the surface, the vein filling was chiefly a gold-bearing honeycombed quartz which had evidently resulted from the dissolving of the sulphide constituents from the quartzose vein filling. On the 50-foot level the vein material consists of a breccia of quartz and ore (galena, sphalerite, and pyrite) embedded in a matrix of crushed pegmatite, gneiss, and granite; this matrix, with the inclosed fragments, has also been crushed and fractured and again recemented by silica. A few very small stringers of still younger galena and sphalerite ore were observed running through the whole vein mass. Small stringers of pyrite, up to three-eighths of an inch wide, enter the gneiss of the hanging wall here and there. These carry very low values.

The vein and stope on the 50-foot level strike about S. 45° W. and dip from 70° to 80° SE. On the surface, however, the trend of the vein outcrop appears to be approximately S. 31° W.

CHARACTER OF ORE.

On the surface and in many places to a depth of 25 feet the values were mainly in free gold, which occurred either in fractures in the honeycombed quartz of the oxidized zone or within the quartz itself. The sulphide ores were chiefly silver bearing, some of the ores running as high as 300 ounces in silver and 0.2 to 0.5 ounce of gold. Some mill runs contained as high as 66 per cent of lead, but others showed practically no lead whatever, probably as a result of sorting the ores into a lead class and a siliceous class. Zinc and copper were not present in sufficient quantity to receive mention in the mill-run sheets.

MINES NEAR IDAHO SPRINGS.

PLACER DEPOSITS.

HISTORY.

The first discovery of pay gold in Clear Creek County, and one of the first in Colorado, was made by George Jackson, about April 1, 1859,[b] on Chicago Creek, just above its junction with Clear Creek. This is considered by many to have also been the first discovery of gold in Colorado, but, according to Hollister,[b] B. F. Langley had about the end of the preceding January found placer deposits in a gulch on South Boulder Creek. These deposits, which were known as "Deadwood diggings," had by the end of March produced considerable gold and were affording employment to a number of men. Small amounts of gold had also previously been encountered near Golden and on Ralston Creek, a small tributary of Clear Creek. On South Clear Creek placer mining was prosecuted from Grass Valley Bar, 3 miles below the mouth of Chicago Creek, to the forks of the south branch, about 9 miles above this same point. By the end of May, 1859, there were nearly 300 men employed at "Jackson's diggings" and on the various claims for several miles up and down Clear Creek. (See Pl. LXI.)

[a] Oral communication.

[b] The mines of Colorado, 1867, p. 60.

Shortly after Jackson's discovery complications began to arise over the question of ownership, owing to the nonexistence of mining laws. Finally, on May 9, 1859, the following laws were adopted at a miners' meeting at Jackson's diggings:

1. Each claim shall be 50 feet front by 200 feet deep.[a]
2. Every claim shall be marked and staked with at least two stakes, and shall be improved within ten days after taking.
3. The discoverers of new diggings shall be entitled to one extra claim each.

Owing to the small extent of the claims located under this law, extensive mining operations were impossible and as a result many of the deposits which if worked on a large scale would have paid proved unprofitable. Some of the deposits, moreover, such as those on Spanish Bar, offered serious difficulties, owing to the large size of the bowlders and the depth and roughness of the beds of the narrow streams. Accordingly, many of the unsuccessful miners were diverted to the new fields resulting from the discovery of the gold-bearing "Gregory lode" on May 6, 1859, by John H. Gregory. Here, in the vicinity of what is now Central City, the rich surface ores of the veins were sluiced for a year or two, with comparative ease, as contrasted with the obstacles encountered at Spanish Bar and some of the other placer deposits along Clear Creek.

The Empire mines, which were located in 1860 and were the scenes of great excitement for three or four years, while the surface ores were being sluiced, also attracted many of the Clear Creek miners.

In spite of the fact that some forsook the Clear Creek placer diggings, these deposits yielded good returns to a number of the workers for a great many years. In fact, the yield of the precious metals in Colorado from 1859 to 1864 was almost entirely from gold derived from these placers and from the sluicing of the decomposed surface ores of the veins, for the silver mines were not operated until 1865 and the unaltered gold-bearing sulphides could not be treated with profit. The placers were most profitably worked between the years 1859 and 1863. In 1883 the most extensive placer-mining operations in the county were being carried on in the vicinity of Alice, which is located on Silver Creek, a branch of Fall River.

Placer mining remained an important industry in Clear Creek County and added materially to the gold production up to the early eighties. Since then, however, although considerable work has been carried on at various times, it has met with variable success and as a rule has not been highly profitable, though it has yielded good wages to a few miners and has added slightly to the gold output of the county.

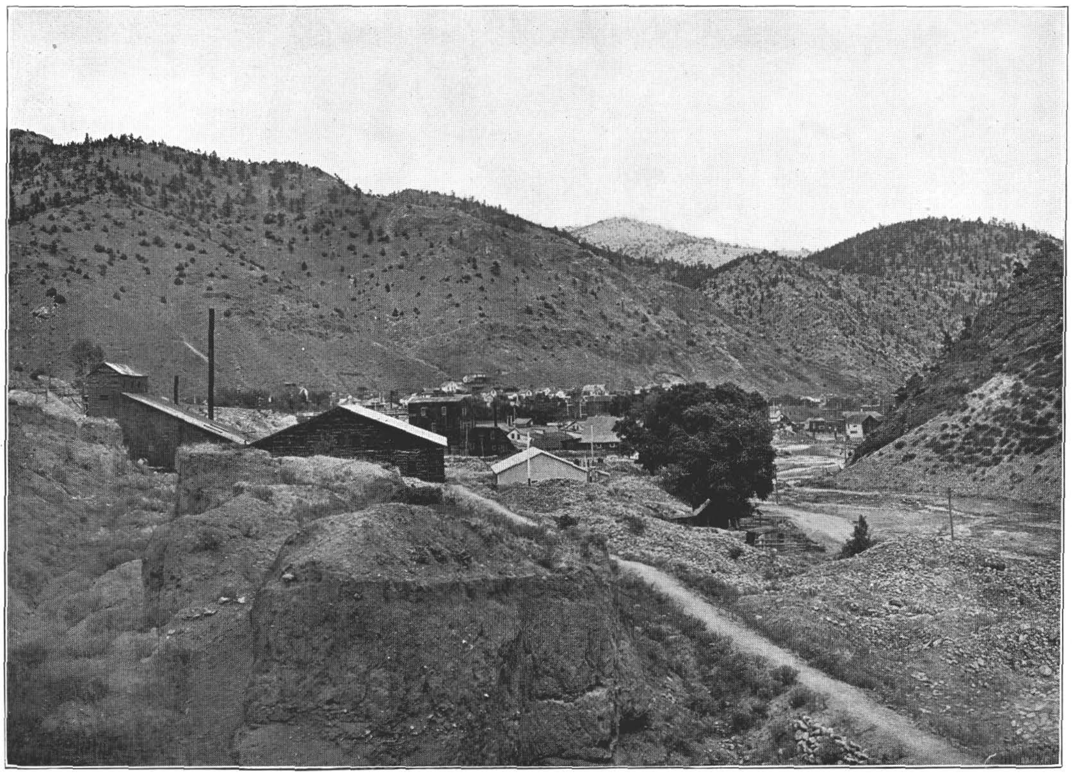
OCCURRENCE AND NATURE OF THE DEPOSITS.

The placer-gold deposits of Clear Creek County may be classed as (1) river-bar placers, (2) stream placers, and (3) bench placers. The river-bar deposits are those on gravel flats in or adjacent to the beds of the streams. The stream deposits consist of bowlders, gravel, and sand filling the channels and forming the beds of the streams. The bench placers are ancient stream deposits, which are now represented by remnants of old stream terraces located at a considerable elevation above the level of the present watercourses (Pl. LXII, *B*). There are three conspicuous lines of terraces. The lowest one of these lines occurs about 25 feet above the present stream beds. Though not of glacial origin, the deposit consists largely of glacial material which has been worked over and transported to its present position by streams which were developed subsequent to the period of glaciation. The second gravel terrace, which according to Mr. Ball is possibly preglacial in origin, lies 55 feet above the creek beds. The terraces of the third set are 180 feet above the channels of the present streams and are covered with indurated river gravels of late Tertiary or early Pleistocene age.

The principal deposits along Clear Creek occur in the vicinity of Idaho Springs and extend from the junction of Fall River and Clear Creek to the Forks, a point several miles below the town, where North Clear Creek, which flows through Blackhawk, joins the main stream.

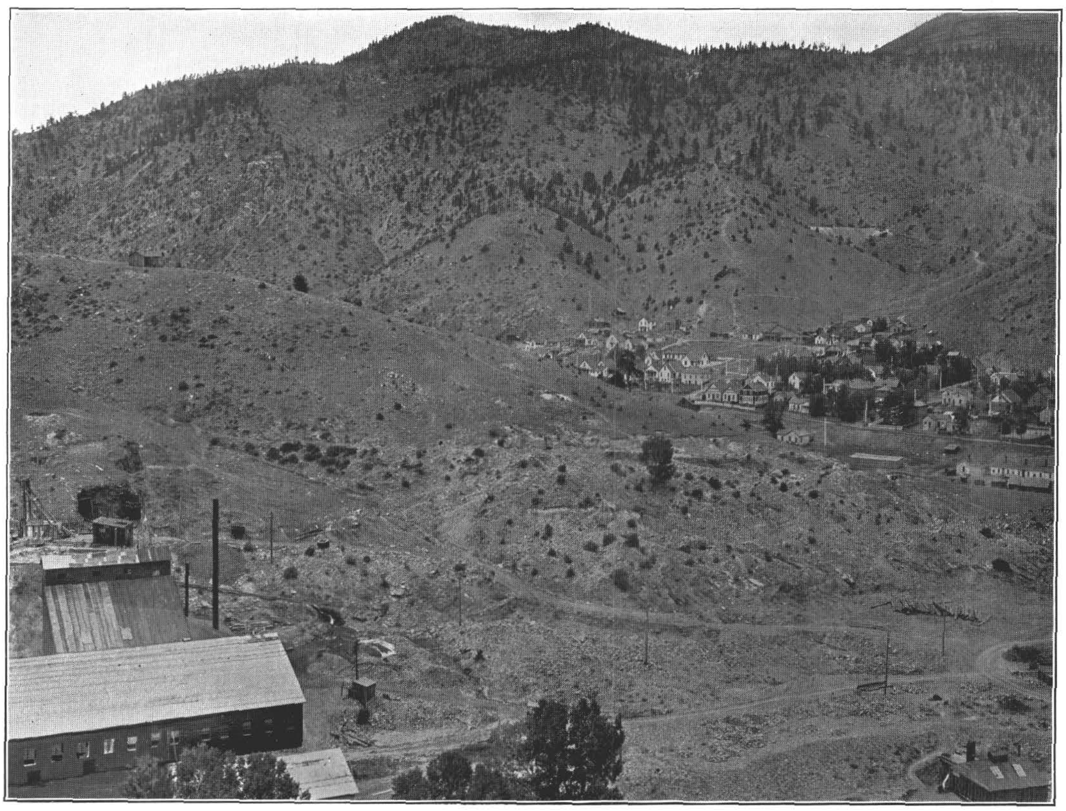
The exact site where Jackson first found gold is said to be beneath one of the large willow trees along the road on the north side of Chicago Creek, about halfway between the Jackson

[a] The size of a placer claim at present is limited to 20 acres for each individual.



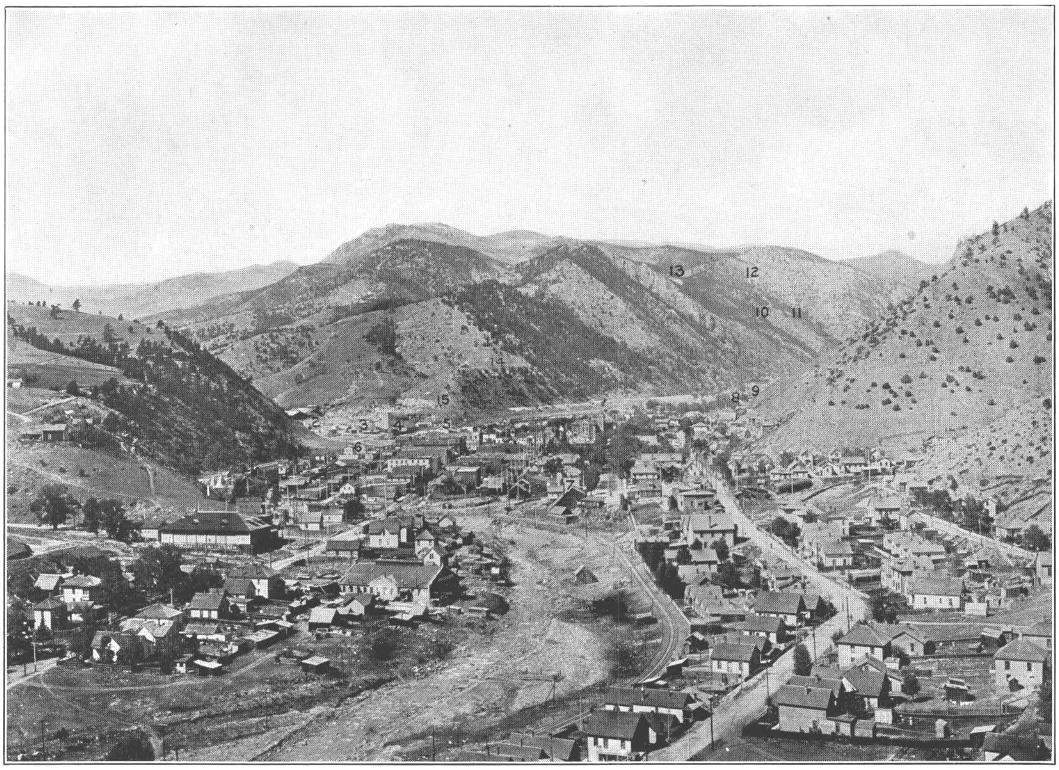
A. OLD PLACER DIGGINGS ON CHICAGO CREEK NEAR JUNCTION WITH CLEAR CREEK; ALSO WALTHAM MINE AND MILL.

Looking northwest from slope of Flirtation Peak.



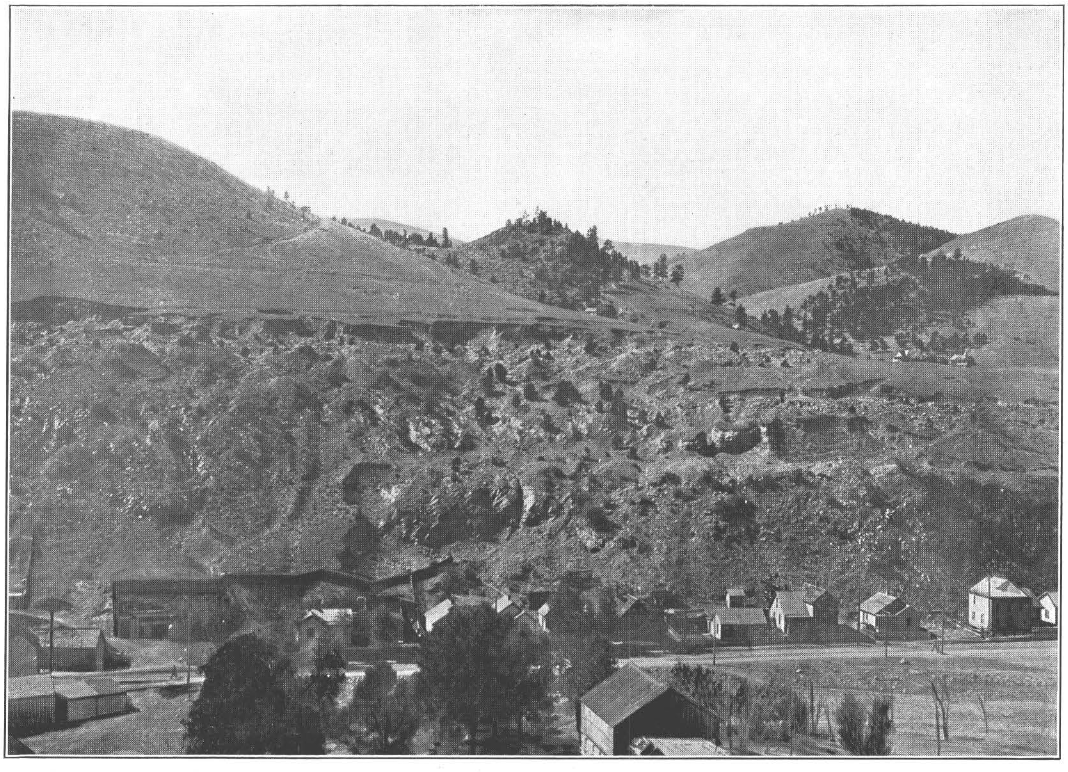
B. OLD PLACER DIGGINGS NEAR POINT WHERE JACKSON DISCOVERED GOLD IN 1859 (IN FOREGROUND), AND MILLS NEAR JUNCTION OF CHICAGO AND CLEAR CREEKS.

Looking down valley of Chicago Creek.



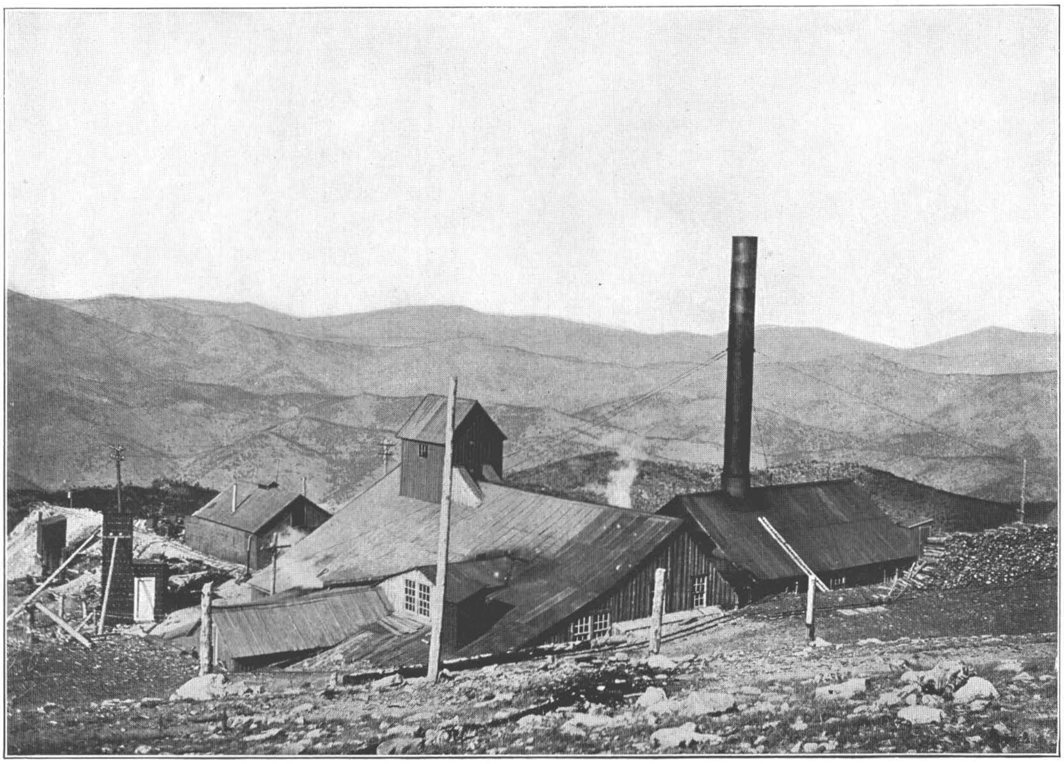
A. IDAHO SPRINGS AND SOME OF THE MINES AND MILLS IN THE IMMEDIATE VICINITY.

Looking west toward junction of Clear and Chicago creeks. 1, Blue Ribbon Spring tunnel; 2, Waltham mine and mill; 3, Jackson mill; 4, Hudson mill; 5, Newton mills; 7, Bertha mill; 8, Alpine mill; 9, Big Five power house; 10, Golden Link shaft, Stanley mine; 11, Cardigan mine; 12, England mine; 13, Bullion King mine; 14, 15, bench gravels.

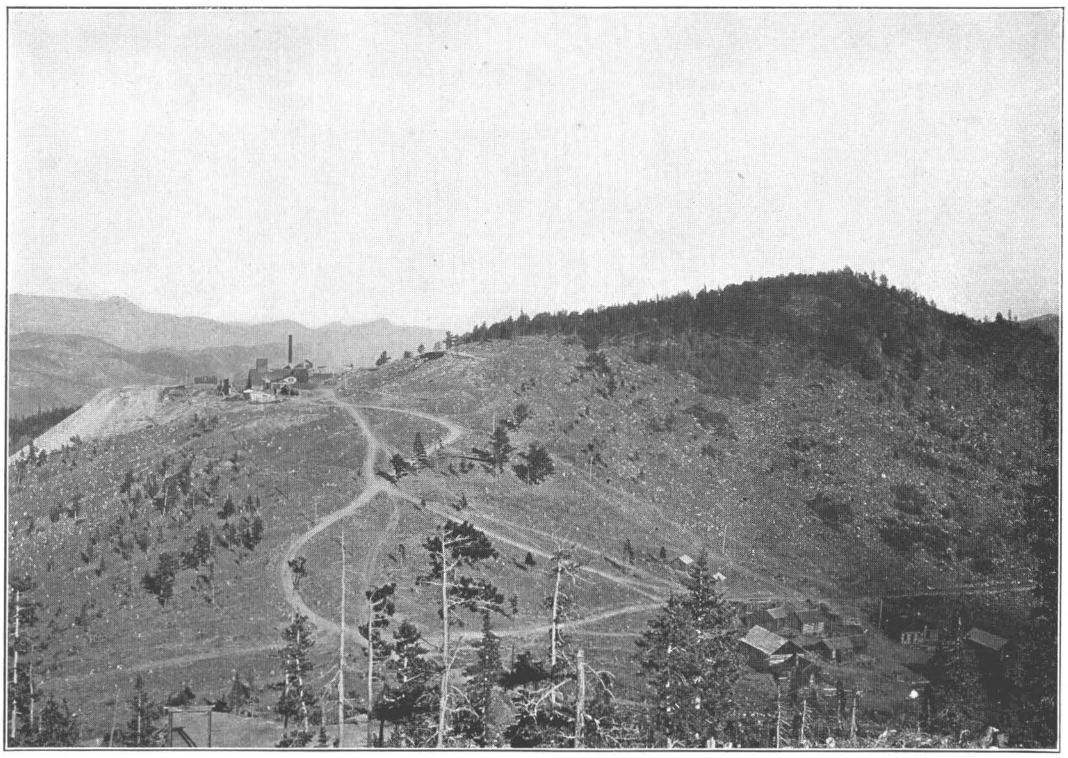


B. OLD PLACER DIGGINGS IN BENCH GRAVELS SOUTHEAST OF THE JUNCTION OF SODA AND CLEAR CREEKS, IDAHO SPRINGS.

Looking south-southwest from mountain slope above Newhouse tunnel.



A. LAMARTINE MINE SHAFT, LOOKING NORTH-NORTHEAST.



B. VILLAGE OF LAMARTINE AND LAMARTINE MINE WORKINGS, LOOKING EAST.

and Waltham concentrating mills. This site is now included in what is known as the Edwards placer. (See Pl. LXI, *A*.) The "Jackson diggings" consisted of coarse gravel and sand, occurring as bars or flats in or adjacent to the streams, and of deposits forming the stream bed itself. The low benches which occur along the sides and in places on the top of the low ridge or spur of land that separates Chicago Creek from Clear Creek just above their union were also worked extensively. Much of this material was sluiced at a very high profit in the early days. The deposits of Spanish Bar, which was the name given to the portion of Clear Creek extending from the junction of Fall River and Clear Creek to a point below the Stanley mine, consisted mainly of a mass of bowlders of all sizes, gravel, and sand filling the channel of the stream which here runs in a comparatively narrow valley. According to Hollister,[a] the creek at this point "was very rapid, the valley narrow and rough, the bars were masses of bowlders of all sizes, the gold very deep and below the bed of the creek, and the pits were constantly flooded with water." On account of the difficulty in handling the large bowlders, the depth, and the troublesome waters, but little of the bed rock was ever uncovered along Spanish Bar, and for this reason also these deposits were less remunerative.

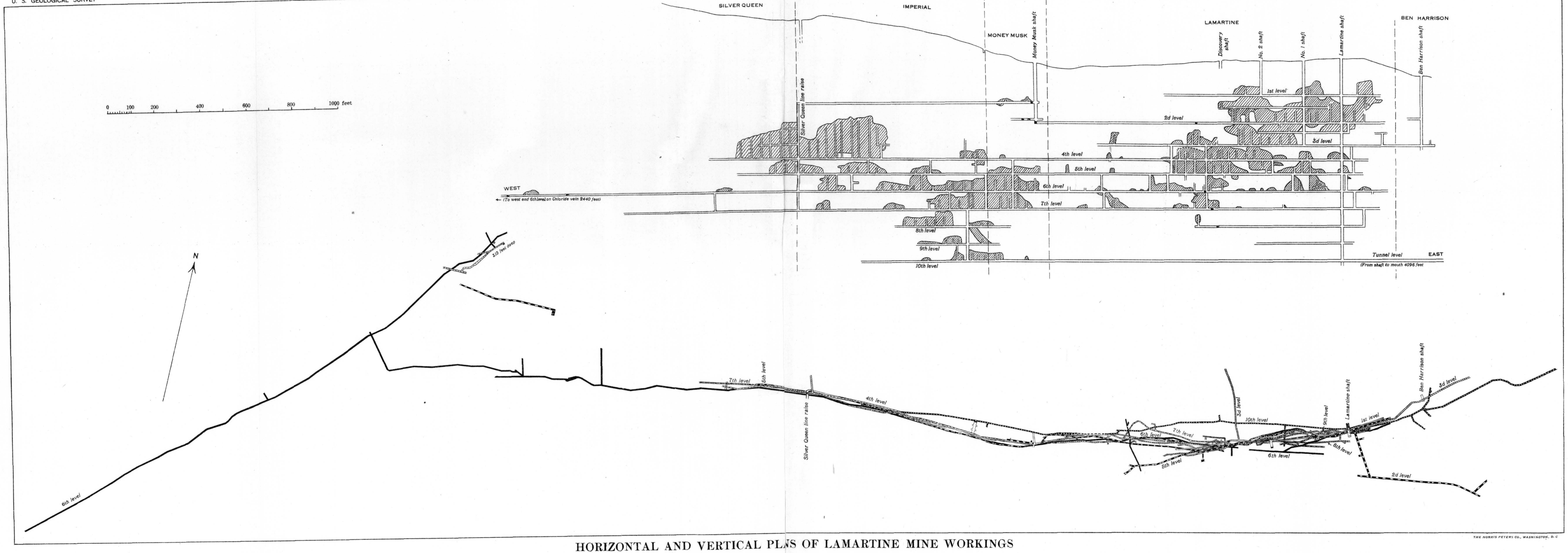
The uppermost old river terrace is to be seen on the south side of Clear Creek and extends from the eastern edge of the area included in the Georgetown quadrangle along the creek to the western edge of the town of Idaho Springs. This terrace is cut through by both Soda and Chicago creeks and is beveled by Clear Creek. The upper part of the scarp, due to the action of the present stream, is about 100 feet above the present valley, and the upper part of the terrace, which has a slope toward the present stream, has an elevation of about 180 feet above Clear Creek. The gravels on this terrace, which are now covered by the Arthur and Doherty placer claims, were formerly extensively worked with very profitable results. In the southeast angle formed by the union of Soda Creek with Clear Creek this terrace is underlain by a bench of bed rock which in few places reaches the surface, being usually covered with a river deposit averaging 40 feet in thickness. The lower 20 feet of this deposit consists of large rounded bowlders, gravel, and sand; the upper portion is composed of finer gravels and silts capped by aerial talus or silt having an average thickness of 6 feet.

Good gold values were found in these deposits, the best values usually occurring either in the deeper gravel-filled channels or immediately on bed rock. Where the gravel above bed rock was very thick, tunnels were run, shafts were sunk, and the deposit was worked by drift mining. Many hundreds of feet of tunneling and drifting on bed rock were run during the period of active development, and according to Fossett[b] there was one tunnel over 900 feet long. That the deposits are fairly well consolidated is shown by the fact that untimbered drifts and tunnels run forty or fifty years ago can still be explored to a considerable extent.

The high bench just described as lying at the junction of Soda and Clear creeks is not visible below this point on the south side of Clear Creek, but reappears on the north side about one-fourth of a mile downstream. At this place there is a horizontal or slightly sloping shelf or ledge of coarse conglomerate and soft sandstone or granitic arkose, similar in character to the placer deposits on the other side of the valley. This fairly well indurated conglomerate, which is composed chiefly of rounded masses of gneiss and granite but also contains some rounded pebbles of porphyry, is of moderate extent and is plastered unconformably upon the rather steep gneiss walls of the valley at this point. Through this conglomerate and to a less extent in the underlying gneiss are veins (fissure fillings) of calcite.

The placer deposits in the Alice district, which were extensively worked in the eighties, were located mainly on Silver Creek or at the junction of Silver Creek with Fall River, 7 miles above the point where the latter stream empties into Clear Creek. The principal deposits occurred on the south slope of the high spur lying between Silver Creek and Fall River and between 1 and 2 miles north of their junction. These deposits were not examined by the writers, but according to Burchard[c] "the débris removed consisted of from 3 to 6 feet of coarse gravel and soil, 2 feet of fine yellow dirt, and about 3 feet of shattered bed rock." Burchard

[a] The mines of Colorado, 1867, p. 70. [b] Fossett, Frank, Colorado, 1880, p. 381.
[c] Burchard, H. C., Precious metals in the United States, 1883, p. 280.



THE NORRIS PETERS CO., WASHINGTON, D. C.

HORIZONTAL AND VERTICAL PLANS OF LAMARTINE MINE WORKINGS also states that of these materials the yellow dirt seemed to carry the highest values and also that considerable native silver was found in the sluice boxes. The scarcity of large bowlders and the favorable location on the hill slope allowed the deposits to be easily removed by the processes of hydraulicking then employed.

PRODUCTION.

It is difficult to make even a rough estimate of the yield of the placers, owing to the fact that in compiling early statistics the production of gold from this source was not kept separate from that derived from the hydraulicking of the decomposed surface outcroppings of the gold-bearing veins. However, although the separate production of the placers and surface lode materials is unknown, the yield of the precious metals in Clear Creek County between 1859 and 1864 was almost wholly from these two sources.

According to Fossett[a] South Clear Creek and its branches, including Chicago Creek, from 1859 to 1880 probably yielded $750,000 in gold dust.

The following miscellaneous items on the production of the placers of Clear Creek County have been collected from various reports of the Director of the Mint:

Production of gold placers in Clear Creek County.

Year.	Amount.	Source.	Reference.
1872	$24,000	Bars and placers	Raymond, 1872, p. 276.
1875	42,500	Placer and stamp gold	Raymond, 1875, p. 365.
1876	80,000	Gulch gold on and below Spanish Bar	Raymond, 1876, p. 297.
1880	5,000	Placers	Burchard, 1880, p. 145.
1881	5,000	.....do	Burchard, 1881, p. 374.
1882	6,000	.....do	Burchard, 1882, p. 425.
1884	12,000	Alice placers	Burchard, 1884, p. 202.
1889	25,000	Pauline placer	Leech, 1889, p. 146.
1890	20,000	.....do	Leech, 1890, p. 131.
1890	1,160	Big Bar	Leech, 1890, p. 130.
1890	2,616	Trout Park placer	Leech, 1890, p. 132.
1890	560	W. Blatchford placer	Leech, 1890, p. 132.
1891	1,875	Trout Park placer	Leech, 1891, p. 177.
1891	1,000	Gold Dirt (surface lode)	Leech, 1891, p. 177.
1892	2,220	.....do	Leech, 1892, p. 122.
1897	50,000	Placers (approximately)	Roberts, 1897, p. 118.

MINES.

LAMARTINE-TRAIL CREEK GROUP.

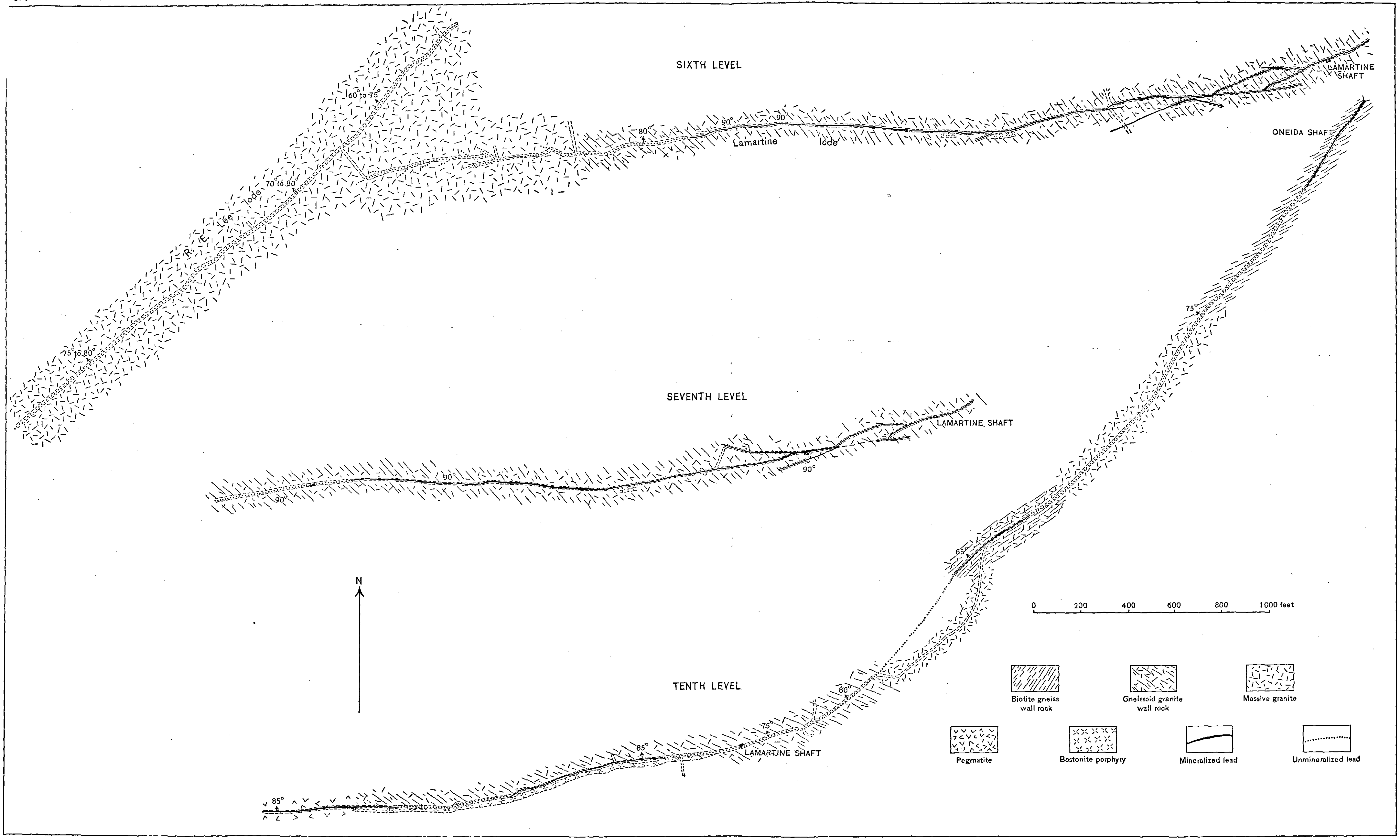
LAMARTINE AND CONNECTING VEINS

HISTORY AND PRODUCTION.

The Lamartine mine (Pl. LXIII) was located in 1867. The original discovery was made by Peter Cooper, John J. Bougher, and Peter Chavanne, who were searching for a gold mine. As the surface indications of this lode were not favorable, one of these men sold a fourth interest for $25, another for $250, and Chavanne sold out for $5. The property was acquired by Peter Himrod, of New York City, who in 1887 let a contract for sinking a shaft in the vein. This shaft encountered the Lamartine ore body at a depth of about 100 feet, in May, 1888, one month after the death of Mr. Himrod. Fred E. Himrod, his son, gave a lease on a small block of ground to Messrs. Armstrong, Burns, Williams, and Hanchett, who produced $616,000 from it in sixteen months. At the expiration of this lease, vigorous development work was carried on by the owner, under the direction of Silas Hanchett.

The following statement of the production of the mine was taken from the record books by the courtesy of the present owners: Total production to August, 1905, ore, net weight, dried, 67,946,019 pounds, yielding 39,291.81 ounces of gold, 2,677,470.79 ounces of silver, and 3,232,020 pounds of lead, having a total actual value of $2,361,039.15. No copper appears in the returns.

[a] Fossett, Frank, Colorado, 1880, p. 380.



GEOLOGICAL PLANS OF SEPARATE LEVELS, LAMARTINE MINE.

The underground workings of the mine have a total extent of 12 miles, included in which is a drainage tunnel 8,000 feet long (Pl. LXIV). From 1894 to 1904 the mine was under the management of Lafayette Hanchett.

At present not much work is going on at the mine, and many of the old workings are inaccessible.

COMPOSITION OF VEIN.

The vein material contains abundant galena and blende, with some pyrite. The product has been chiefly galena ore which has been selected from ore containing blende. The zinc-bearing ore as a rule is poor in gold and silver. The best ore appears to be a fine galena, much of the coarse galena being of lower grade as regards gold and silver, as in many other mines of the region. The gold content ranges from little more than nothing up to several ounces per ton; the silver in a good grade of ore amounts to about 150 ounces. A few years ago the total value of the ore per ton was about $100, but it has grown less in recent years.

NATURE OF WALL ROCK.

The vein walls comprise different rock formations, which are usually present in relatively large masses. They include porphyritic granite like that around Georgetown (Silver Plume granite), gneissoid granite, biotite gneiss, and pegmatite. The principal wall rock is the gneissoid granite, which in some places contains biotite and in others is free from it. This granite is locally porphyritic, but becomes also pegmatitic and aplitic.

A dike of porphyry lies on the south side of the vein where it is most productive. As the mine workings are now partly caved this porphyry was not noted, at the time of the writers' examination, above the sixth level. On this level (Pl. LXV) the porphyry was found in two places, about 200 feet apart, forming the south wall of the vein. Apparently the dike is not continuous between these two points, as a drift on a branch vein which runs into the south wall of the main lode between these points shows no porphyry.

On the seventh level west of the Lamartine shaft the same dike was found in one place only, along the south wall of the vein. On the tenth level, however, the south wall of the vein for a distance of 1,600 feet is chiefly formed by this porphyry dike. Where it does not form the exact wall, it usually lies only a few feet south of the wall, as is proved by several crosscuts. On the surface this dike has been recognized by Mr. Ball, where it has been found to outcrop at intervals for nearly half a mile. The relation of these outcrops to one another indicates that the dike is not continuous, but intermittent, a conclusion which probably applies underground as well. As determined by Mr. Ball this porphyry is to be classed as bostonite.

NATURE OF VEINS.

A general view of the veins connected with the Lamartine mine is shown in fig. 119. There are two parallel northeastward striking and nearly or quite vertical veins—the Oneida and the R. E. Lee. The Oneida vein is opened up in the Lamartine workings chiefly by the long Lamartine tunnel, which serves principally as a drainage tunnel, but follows this vein nearly all the way from the Lamartine shaft to the surface and shows that it is continuous with the Lamartine vein. The Oneida vein is also opened up by the Oneida tunnel about 100 feet below the Lamartine tunnel. A shaft about 200 feet from the mouth of the Lamartine tunnel connects the two tunnels. The Oneida vein contained considerable ore at the surface, but is for the most part, as shown in the Lamartine tunnel, very little mineralized, though some low-grade ore was encountered about 2,500 feet in.

This vein has been cut at a depth of (roughly) 150 feet below the Lamartine tunnel, at a point approximately below the mouth of this tunnel (following down on the dip of the vein), by the Old Stag tunnel (fig. 120), which runs in from Trail Creek valley due south, the distance from the mouth to the vein being 820 feet. The vein on this tunnel has produced some ore. A shipment of 120 tons without sorting yielded $15 per ton, the contents being 0.6 ounce of gold, 5 ounces of silver, and 0.5 per cent of copper. It is reported that from one of the two shoots worked out in the Oneida workings above $600,000 worth of ore was produced. The following returns from 1,000 tons of ore are reported: Gold, 1.26 ounces; silver, 16 ounces; copper, 2+per cent.

The R. E. Lee lode has been drifted on for a distance of 2,500 feet on the sixth level of the Lamartine. It is a smooth, straight fault zone marked by soft crushed and decomposed material in granite walls. Its dip ranges from steeply northwest to nearly vertical. On this level it contains no ore and no quartz. Locally there is a little iron pyrite.

The Oneida vein encountered the zone of an earlier porphyry dike which strikes east and west. The vein zone, which was a zone of fracture and probably slight faulting, was largely deflected from its normal course along this dike. Thus this portion of the vein now possesses an east-west strike and the dike is in most places its south wall. This is the Lamartine vein proper. At the place where the fault has been deflected from its northeast course by the porphyry the angle is occupied by a number of minor intersecting veins representing the directions in which the main vein trends on either side of the point of deflection, some striking east and west and others

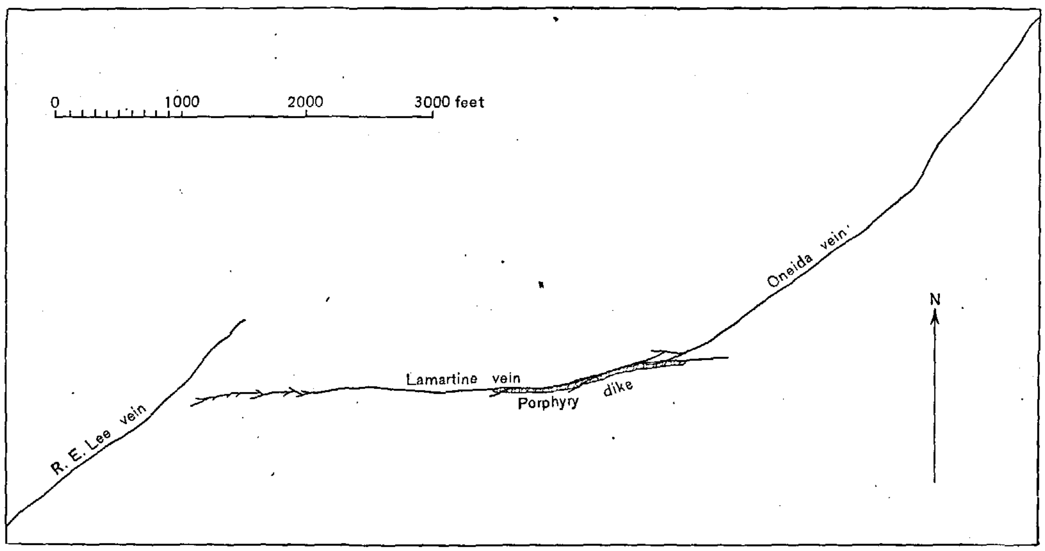


FIG. 119.—Generalized horizontal plan of veins exposed in Lamartine workings, compiled chiefly from the plans of the sixth and tenth levels.

northeast and southwest. The Oneida vein as developed in the Lamartine tunnel has an horizontal extent of about 4,000 feet from the Lamartine shaft to the mouth of the tunnel.

The Lamartine vein has a horizontal length of about 4,000 feet measured from the Lamartine shaft westward to the last point where it has been identified. On the sixth level west the vein weakens at a point 3,000 feet west of the shaft; also at about this place it passes westward from hard gneiss into granite, in which it assumes the character of a chain of branching and splintering minor fractures, continually weakening. As the R. E. Lee lode is approached this character becomes more pronounced, so that the junction of the two has not been observed, and it is doubtful if it exists. This weakening of a strong fault lode when entering the field of immediate proximity of another transverse or oblique lode is a common occurrence in this general region. It seems to indicate that a general internal stress experienced by the rock was taken up along a zone of movement and crushing, which was strong and well marked in proportion as it was obliged to assume the entire work of readjustment while the process of discharging the strains was going on. Where, however, such a zone entered the field of a stronger zone the internal rock stress was taken up by the latter, and the weaker zone, on nearing it, found progressively less and less cause for existence.

It is probable that the northeastward striking vertical line of faulting represented by the Oneida vein is continued to some degree also southwest of the Lamartine shaft, past the point where a large part of the movement has been deflected along the preexisting porphyry dike, to form the Lamartine vein. The plan of the sixth and seventh levels (Pl. LXV) shows branches which diverge to the southwest from the south side of the main Lamartine vein, leaving the region of minor intersecting veins (which occupies the bend between the Oneida and the Lamartine veins) on the southwest, much as the main Oneida vein does on the northeast side. These branches have not been followed far in the underground workings, so their extent is unknown. From the surface, however, a vertical shaft goes down on the Financier lode, which appears to strike northeast, approximately parallel to the Oneida vein, and an extension of which northeastward from its observed position at the surface would bring it into the Lamartine lode near the west end of the field of intersecting minor veins above mentioned.

From some of the underground workings shown on the map (Pl. LXIV), but now inaccessible, especially those on the second level, it is probable that the east-west Lamartine fracture zone continues for a short distance at least beyond and to the east of the incoming of the Oneida.

The character of the Lamartine vein proper as a zone of sheeting and faulting is shown in many places. Striæ indicating the direction of movement were observed here and there. At one place, near the breast of the third level west, they dip 75° W. Although the vein, especially on the tenth level, borders the north wall of a porphyry dike, that it follows a zone of faulting is clearly shown by the fact that it does not keep close to the porphyry, but at many points deviates more or less from the contact. Moreover, it was noted that in one place the fault lead cuts through a projecting curve of the porphyry dike. The porphyry contact, then, simply afforded a zone of weakness or of minimum resistance, which was followed by the later movement. In some places the vein is accompanied by a band of soft clay or gouge; in others, the vein zone, which has normally been simply sheeted by the movement, has been partly brecciated. The vein cementation was subsequent to this brecciation.

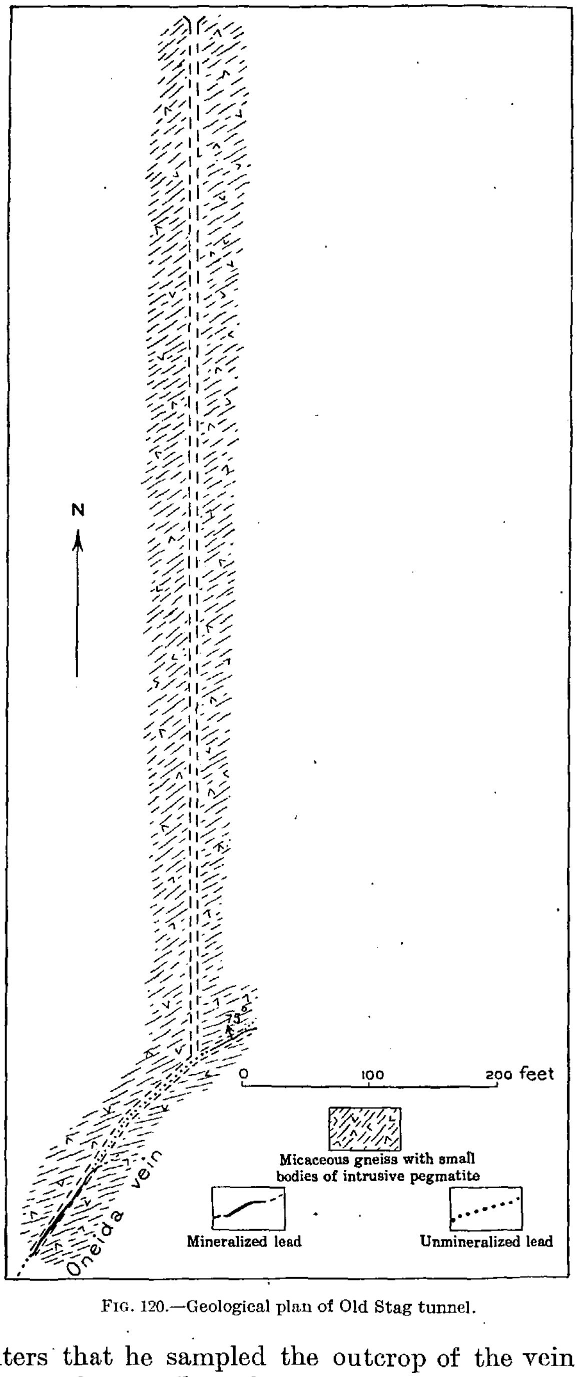


FIG. 120.—Geological plan of Old Stag tunnel.

LOCATION OF ORES.

The Lamartine ore shoot is rather the exception among the ore shoots of the region in that it does not come to the surface. Mr. W. H. Wiley, of Idaho Springs, informs the writers that he sampled the outcrop of the vein thoroughly and that it did not go over $4 anywhere. The relation of the ore body to the surface is best shown in the stope plan (Pl. LXIV), where it is seen that in the neighborhood of the Lamartine shaft the ore approaches within 100 feet of the surface, but that at most other points the stopes have kept at a vertical distance of 400 feet or more on the vein from the outcrop. The general form of the ore body as seen in this stope plan is roughly horizontal, or, more correctly, the form of the highly mineralized portion is like the cross section of a thick saucer, having a length of nearly 3,000 feet and a vertical thickness of 400 feet, more or less. Below as well as above this great ore body, the vein channel is relatively little mineralized.

The richest portion of this ore body occupies the field of intersecting minor veins which have formed in the angle between the Oneida vein and the Lamartine, near the point where the fracture has been deflected on encountering the porphyry dike. These minor veins are well exposed on all the accessible levels in the region just west of the Lamartine shaft, and are shown on the plans of the different mine levels. Some of the veins are parallel to the Oneida, striking northeast; others are parallel to the Lamartine, striking east and west. The intersection of these veins is characteristically mineralized to a high degree and large stopes have been made at these points. The ore, which at many places extends a long distance away from the intersections, becomes richer and more abundant as the junctions are approached. Inasmuch as these minor veins are all nearly or quite perpendicular, conforming with the attitude of the master veins to which they are auxiliary, a given vein can be recognized on different levels, and the relation of these veins and their intersections as observed on these levels shows that the whole field of cross faulting extends downward almost vertically. Therefore this principal portion of an ore shoot, which appears when entirely mapped out to have a greater horizontal than vertical extent, was actually formed along a vertical chimney. Plainly the field of intersecting veins has furnished a chimney of maximum water circulation. On the tenth level, however, the intersecting veins characterizing this chimney, if present, have not been opened up or were not observed, the Lamartine on this level having the form of a plain straight vein, very slightly mineralized as compared with the portion of the vein immediately above, on the upper levels.

The best portion of the nearly horizontal ore shoot, according to this conclusion, has been formed by the intersection of perpendicular veins forming a perpendicular channel of water circulation. The mineralization extends for a considerable distance west of the principal field of intersection, to a point about 3,000 feet west of the Lamartine shaft, which is practically at the east end of the ore shoot and also of the field of vein intersection. It is probable that much of the western portion of the shoot is also marked by minor fractures intersecting the main lode. For example, on the sixth level there is a northeastward striking mineralized branch which runs into the main east-west lode, in the center of a vertical ore shoot. This locality is about 1,500 feet west of the shaft.

The most important feature about this ore body from a theoretical standpoint is that nowhere does it reach the surface. In fact, if we may credit the commonly accepted account, its discovery was accidental and was the consequence of a hoax. Under ordinary conditions it may very well have entirely escaped discovery down to the present day. The significance of this fact becomes immediately apparent. An explanation which naturally arises to fit the case is that the upper portion of the vein zone has been leached out and the minerals carried to the lower portion—an explanation which is apparently favored by the general parallelism of the ore shoot to the surface. In this general region, however, most of the known ore bodies outcrop at the surface, are similar in composition to this vein, and are exposed to the same climatic conditions as affect it.

The definite rule observed in these bodies is that the ores are not leached out from the superficial portions to be concentrated below, but on the contrary the richest zone lies immediately at the surface, and the ores, if any change is noticeable, decrease in value and abundance with increasing depth. It seems probable, therefore, that the Lamartine ore body was formed in its present position and that the plane of the surface, which is being continually carried lower by the process of erosion, has not yet reached it. In this connection attention should be called to the fact that the situation of the mine is high, the collar of the Lamartine shaft being 10,500 feet or more above sea level. If the location were somewhat different topographically—for example, if it were 500 feet farther down the side of the mountain instead of being at the actual top—the plane of erosion would have reached the ore body and we should have precisely the same phenomenon as is observed in most of the other veins—an outcropping ore body enriched near the outcrop by atmospheric waters.

BRAZIL MINE.

The Brazil mine is located near the head of Trail Creek and develops a vein which has been opened at an elevation of 9,800 feet in Trail Gulch and is traced on the surface beyond the point where it crosses a ridge half a mile farther N. 80° W., at an elevation of 10,500 feet. The wall rocks consist entirely of micaceous gneiss and pegmatite.

The Brazil vein is said to be joined just west of the main shaft near the crest of the ridge by the Poor Boy vein, which dips 75° N. and runs a little south of west.

The vein is developed by three tunnels and two shafts. The upper two tunnels, however, are caved shut. The lower tunnel (fig. 121) is open for a distance of more than 800 feet and follows a lead all the way. For the first 450 feet the tunnel follows a N. 70° W. vein which

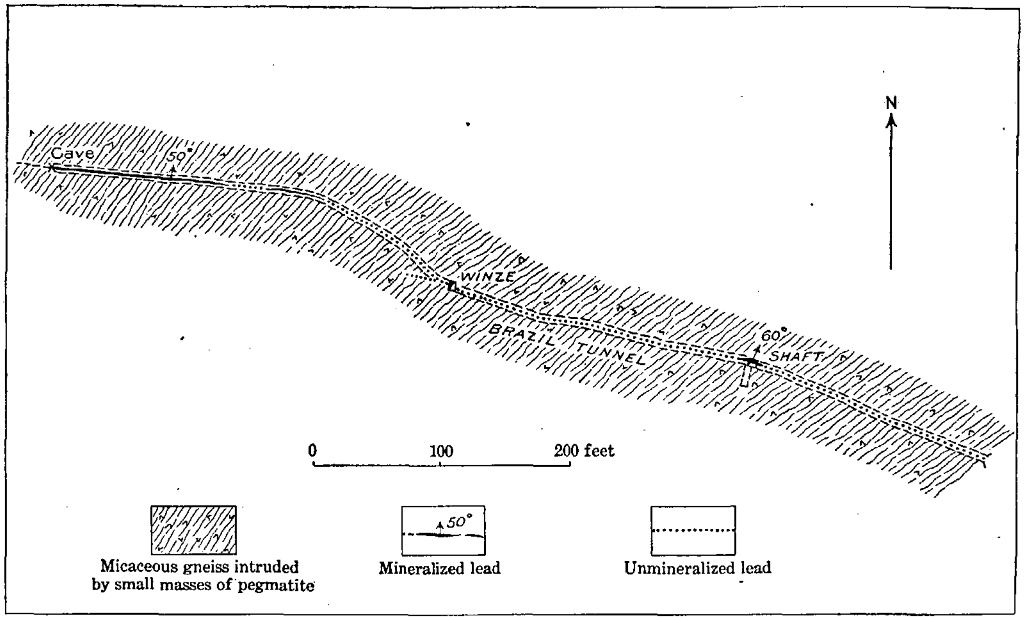


FIG. 121.—Geological plan of lower Brazil tunnel.

dips 60° NE. At that point, however, there is a split in the lead; the south branch enters the wall and the north branch trends N. 55° W. for 125 feet and then bends to N. 85° W., with a dip of 50° N. The vein is a crushed gneiss and clay lead 1 to 6 inches in width, showing little if any mineralization for the first 600 feet. Where the vein assumes a N. 85° W., direction, however, a stope 150 feet or more in length and 20 to 40 feet high has been made. This stope yielded a yellowish-brown oxidized ore, containing abundant iron oxides. Black sooty copper sulphides were also observed associated with some of the oxidized ores, as were also fibrous white crystals of cerusite ($PbCO_3$). Solid sulphide ores, however, occur along the vein at greater depth and consist of black sphalerite, pyrite, and some galena. The ores obtained from this mine have been chiefly silver bearing. No ore has been extracted in the last few years.

POOR MAN MINE.

The Poor Man mine is located near the head of Trail Creek, several hundred feet north-northwest of the lower Brazil tunnel. The development consists of a crosscut tunnel about 250 feet in length trending N. 20° W., and a drift on a vein which runs a little south of west. The rocks in the vicinity consist of gneiss, pegmatite, and granite. The pegmatite and granite were observed to contain small scattered masses of magnetite. The vein dips 75° N. and is said to intersect the Brazil vein just west of the Brazil shaft, near the crest of the ridge. It consists of a hard quartz streak adhering rather tightly to the walls and containing a little mineral.

NEW ERA MINE.

GENERAL DESCRIPTION OF VEINS.

The New Era mine is located in the valley of Trail Creek, at an elevation of about 9,150 feet, a short distance west of the town of Freeland. The mine workings for the main part were driven for the purpose of developing the New Era and Great Western veins, which run approximately parallel to one another and only 40 to 90 feet apart.

The New Era vein on the surface runs about S. 27° W. and is probably a continuation of the Lone Tree vein, which runs up the hill slope to the south-southwest and has been opened up to a point 100 feet or so west of the Teller shaft. Formerly the vein was extensively developed by the workings of the Lone Tree mine, most of which have long since been inaccessible, due to caving resulting from the mines having lain idle for a considerable number of years. Northeast of the New Era mine, on the surface, the New Era vein runs up the hill with a trend of about N. 45° E., but the Great Western vein straightens somewhat, runs N. 30° E., and is probably continued as the Rough and Ready vein.

UNDERGROUND DEVELOPMENT.

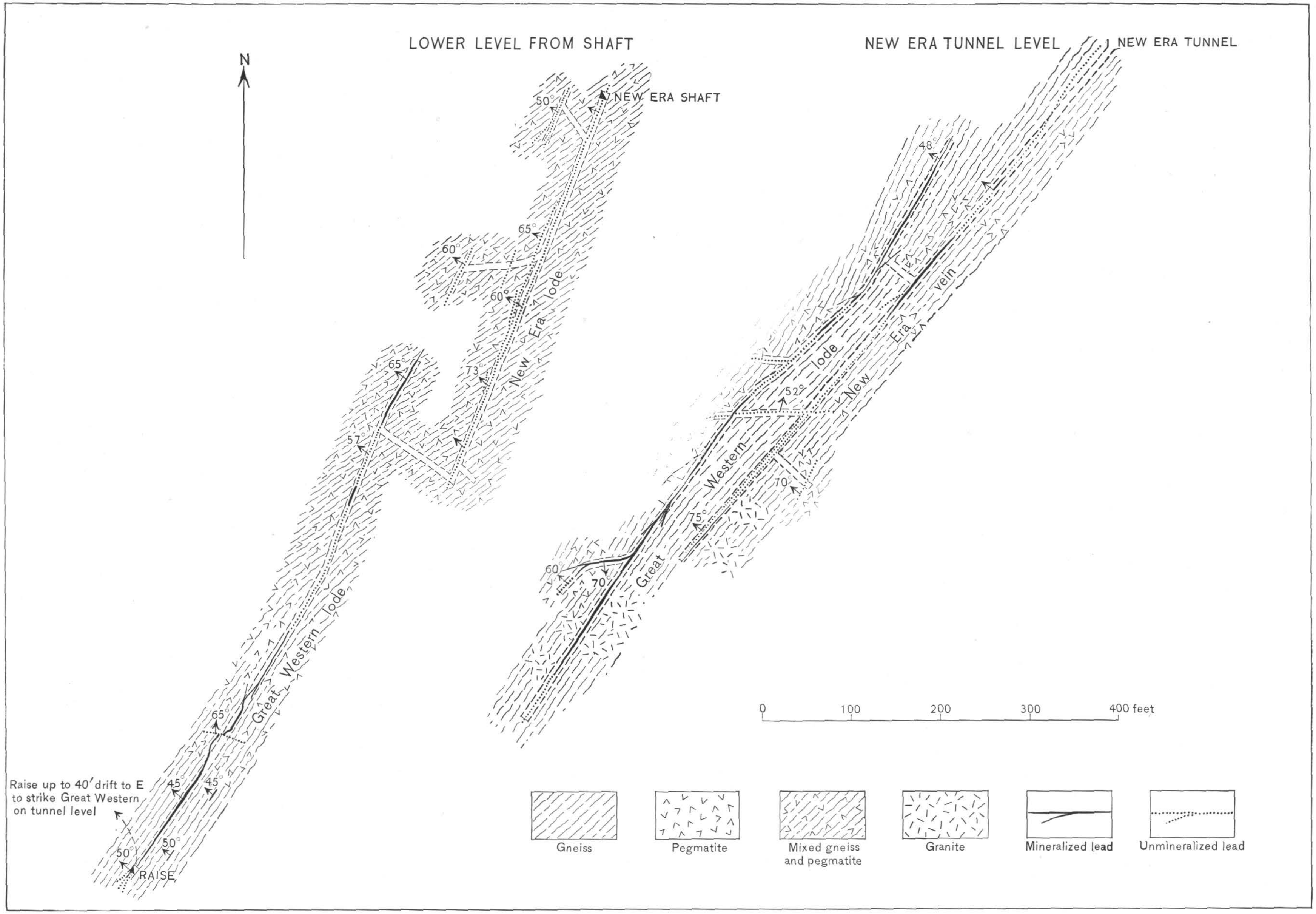
Underground the New Era and Great Western veins are developed by workings connecting with two tunnels and a shaft (Pl. LXVI). On the south side of the creek is the main tunnel, driven on the New Era vein for 700 or 800 feet. This tunnel is connected by two crosscuts with a drift 800 or 900 feet in length on the Great Western vein, and by raises and winzes with other minor drifts. On the north side of the creek is the shaft, which is connected with drifts on both the New Era and Great Western veins, and also a tunnel level with about 350 feet of drifting, which shows the New Era and Great Western veins approximately 75 feet apart. The main level connecting with the shaft shows 1,500 feet of drifting, all but about 500 feet of this being on the Great Western vein.

NATURE OF WALL ROCK.

All the workings on both veins are chiefly in gneiss, which is both of the micaceous and granitic varieties. Some pegmatite is also present in places, especially near the shaft, where the mixture of gneiss and pegmatite has locally a crushed or gnarled appearance.

NEW ERA VEIN.

The New Era vein, which has a general trend of S. 40° W. and a dip of 60° to 75° NW., consists for the most part of foot and hanging wall leads separated by 1 foot to several feet of altered pegmatite or granite heavily impregnated with pyrite. On the main shaft level the two leads, which run about 15 feet apart for some distance, consist mainly of small clay or gouge selvage streaks, many of them stained black, which are here and there associated with narrow seams of low-grade galena and pyrite ore. However, little "pay ore" has ever been taken from the New Era vein itself. The only good body of ore so far opened up on this vein was located on the south tunnel level, near the first crosscut to the Great Western vein. This ore body, which was stoped out years ago, had a length of 100 feet along the drift and extended up to a blind level about 75 feet above the tunnel. Near this ore body the walls of the vein approached within about 2 to 3 feet of each other, and the intervening gneiss and pegmatite was almost completely replaced by quartz and pyrite or by quartz and a galena-pyrite ore containing traces of sphalerite. In places the vein filling was heavily stained by iron oxides.



GEOLOGICAL PLANS OF SEPARATE LEVELS, NEW ERA MINE.

GREAT WESTERN VEIN.

The Great Western vein, which lies 40 to 90 feet west of the New Era vein, is flatter, ranging in dip from 45° to 60° and striking S. 25° to 40° W. Where lacking in ore this vein consists of a crushed and silicified rock lead, containing some quartz and pyrite and ranging from a few inches to 2 feet in width. In the main shaft level the vein is mineralized to some extent, for near the southwest breast there was a drift stope 150 to 200 feet in length on a 6-inch streak of quartz and ore. At the time of examination some good-looking galena-chalcopyrite ore was also being obtained from a drift stope near the northeast breast of the long drift on the Great Western on this same level, at a point about 400 feet southwest of the shaft. On the tunnel level the Great Western vein was comparatively heavily mineralized for most of its length. Near the northeast end of the drift on it the vein zone was about 2 feet wide and consisted of small galena and pyrite seams running parallel to the schistosity of the gneiss, the strike of which at this point corresponded with the trend of the vein. The low stope at this northeast end was between 150 and 200 feet long. The main ore body, however, was one extending continuously from a point near the southwest breast of the drift on the Great Western vein to a point more than 400 feet to the northeast. For much of this distance stopes had been made on the vein for only 20 to 40 feet above the tunnel level. Most of the best and largest bodies of ore along the vein appeared to be located at or near the junctions of minor, slightly mineralized leads with the main vein. At one point where several small veinlets joined the main vein there was an ore body about 10 feet in width, on which stopes were made for a vertical distance of about 60 feet.

CROSS LEADS.

A little more than 500 feet southwest of the mouth of the main tunnel, on the south side of the creek, is an east-west vein consisting of 1 inch of clay or gouge and about 5 inches of crushed gneiss. This vein, which dips 52° N. and is practically unmineralized, crosses both the New Era and Great Western veins. Its course is altered very little where it crosses the New Era vein, but it is faulted about 3¼ feet by the Great Western vein, the west portion of the cross vein being offset to the south. At the point of crossing the Great Western vein itself also seems to have been somewhat disturbed and the segments displaced about 1 foot. The junction of the two veins does not appear to have had any effect on the ore deposition.

On the main shaft level, about 800 feet south-southwest of the shaft, the Great Western vein splits in going southwest, the east branch entering the wall as a lead of quartz, pyrite, and silicified gneiss, and the west branch swerving slightly more to the southwest and continuing about 90 feet farther, to a point where it appears to be intersected and faulted by a N. 75° W. gouge vein dipping 65°. At this point the southwest portion of the Great Western vein, which here consists of a 6-inch streak of quartz and ore trending N. 32° E., is offset 5 or 6 feet to the west of the northeast portion, which a few feet from the fault contains a streak of low-grade galena and pyrite ore over 1 foot wide trending N. 60° E. This fault lead on the lower level is possibly the same one that crosses both the New Era and Great Western veins on the south tunnel level, although the effect on the crossing veins is somewhat different. However, the definite correlation of the two was made impossible by the lack of accurate mine maps showing the relation of the tunnel level to the shaft workings.

NATURE OF ORE.

Most of the ore from the New Era mine consists of a mixture of coarse galena, chalcopyrite, and pyrite, associated with a gangue composed mainly of quartz but carrying locally a little siderite or ferruginous rhodochrosite. A dark-gray, shiny, metallic mineral resembling tetrahedrite (gray copper) or tennantite is also rather abundant, but does not seem to carry any larger values of gold and silver than the other ore minerals.

The ore is notable for the abundance of its chalcopyrite and for the lack of zinc blende, although a little of the latter mineral is occasionally found. The vein filling in places consists of a thin layer of comb quartz and slightly cupriferous pyrite next the two walls, with a mixture of approximately contemporaneous galena and chalcoypyrite in the center. Some of this galena is fibrous in structure; but where it has been crushed by movement subsequent to deposition it is finely granular. In somewhat porous vuglike portions of the massive galena and chalcopyrite ore, a mixture of crystalline pyrite and the dark-gray shiny mineral resembling "gray copper" occurs in association with a little siderite. That the gray copper and pyrite are of later origin than the galena and chalcoypyrite is shown by the fact that seams of the first-named minerals up to 2 inches in width cut the latter or include angular fragments of them.

In many places the vein consists, instead of a single fracture, of a number of parallel seams somewhat similar in structure to the vein described above. In places, however, much of the ore seems to have resulted from a replacement of the altered wall rocks included between a series of fractures.

The first-class ore of the mine averages about $60 to the ton and carries from 1¼ to 2 ounces of gold, 5 to 20 ounces of silver, and 45 to 50 per cent of lead. Copper up to 5 per cent and zinc up to 3 per cent have at times also been obtained, although in quantities so small that even the copper has not been paid for by the smelters. The second-class ores give mill concentrates that consist of ore carrying about 1.4 ounces of gold, 5 ounces of silver, 17 or 18 per cent of lead, and a little copper. The richest ore found in the mine came from a small seam of galena and gray copper only one-half inch to 3 inches in width, said by the superintendent to have given assays of 1,100 ounces in silver, 33 ounces in gold, and 51 per cent of lead. However, this small seam was only a few feet in length, and so yielded but a small quantity of ore. This rich ore was not located along the main vein, but was 30 or 40 feet west of the Great Western vein, at the junction of two small veins, one of which joined the Great Western vein and caused another body of good ore there.

The total production of the New Era mine is not known, but besides the first-class ore being shipped the mine was supplying 18 to 20 tons of low-grade ore to the 10-stamp concentrating mill of the New Era Mining Company. The output of concentrates from this mill at the time of visit was about one carload a week.

FALU MINE.

GENERAL DESCRIPTION.

The Falu mine is located at an elevation of 9,250 feet a little north of the town of Freeland. The vein is developed through a shaft and a series of drifts connecting with it. The mine had been idle for some time when visited, and as the shaft was caving no attempt was made to examine the underground workings.

NATURE OF VEIN.

The vein near the shaft has a general strike of S. 70° W. and a dip of about 50° NW. A little southwest of the shaft, however, the vein swerves a little more to the west and runs toward the New Era vein. The material in the ore bins consisted of gray jaspery quartz and pyrite, no galena or zinc blende being observed.

The vein developed in this mine, or at least a branch of it, is possibly a continuation of one observed in the open cuts and caved shafts of the Turner mine, which is located about 1,000 feet distant in a N. 78° E. direction.

TELLER MINE.

The Teller mine consists of workings connected with a shaft located approximately 3,000 feet southwest of Freeland at an elevation of about 9,750 feet, and of a tunnel about 1,800 feet N. 42° E. of the shaft at an elevation 400 feet lower. The shaft develops a northeast-southwest vein, which has produced some coarse galena, chalcopyrite, and sphalerite ore carrying from one-half to 1 ounce of gold and occasionally as high as 25 to 50 ounces in silver.

The tunnel at the time of visit was being run with the purpose of intersecting the vein at a lower depth. (See fig. 122.) It follows a minor lead which dips 60° to 65° NW. and is marked by poorly mineralized crushed gneiss and pegmatite, carrying a little pyrite and traces of galena and sphalerite. The tunnel is driven on this lead for 300 feet to the southwest and then for 200 feet S. 80° W., to a point where the lead intersects a slightly mineralized vein striking N. 38° E. and dipping 65° to 80° NW. The last-mentioned lead is marked by a seam of clay, quartz, and crushed rock 2 to 6 inches wide, which in places carries a little pyrite and siderite or ferruginous rhodochrosite ore, with local galena and sphalerite. High assays in gold are said to have been obtained from this vein, from small streaks of light-colored pyrite and milky quartz.

The N. 80° E. tunnel vein faults the northeast-southwest vein about 1 foot, but at the same time has its own course changed slightly.

No pay ore had been mined from the tunnel level at the time of visit. The relation of the veins on the tunnel level to the vein developed by the shaft workings was not determined.

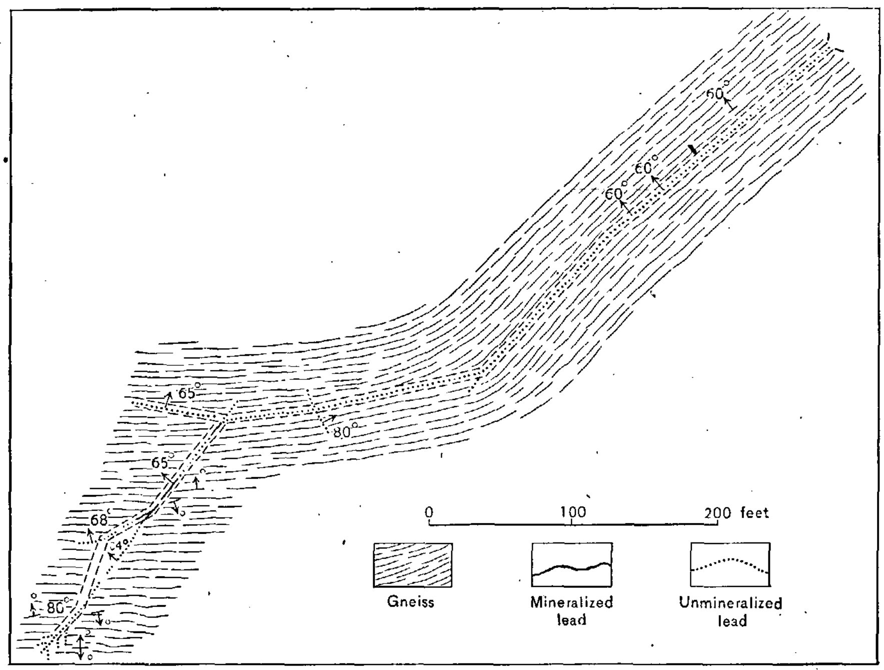


FIG. 122.—Geological plan of lower Teller tunnel.

FREELAND VEIN AND CONNECTED VEINS.

GENERAL DESCRIPTION OF VEINS.

Freeland vein.—The Freeland vein is a strong trunk vein having a northeast strike and a comparatively flat northwest dip which is said to average about 36°. This trunk vein is about 2,200 feet long. On the southwest end there are two strong branches, each of which is ore bearing; the general direction of the trunk vein bisects the angle between the two. In the Freeland mine (Pl. LXVII) these two branches are known as the Freeland Extension vein and the Split vein. The Freeland Extension vein, which is the more southern of the two, has a southwest strike, more southerly than that of the main vein, and a northwest dip. On the Freeland tunnel level this dip was noted in one place to be 60°. The average angle, however, in the interval between this level and the surface at the top of the Freeland Extension shaft is 41° or 42°. Nearer the surface the dip of this branch flattens markedly, and for the first 200 or 300 feet of vertical depth it is only about 30° or a little more. The more northern branch, the Split vein, has a northwest strike, which approaches very nearly due east and west, and a northerly dip, the angle of which on the Freeland tunnel level was observed in one place to be 42°. Each of these branches is drifted on in the Freeland tunnel level for about 600 feet from the junction. The end of the drift on the Split vein was inaccessible at the time of visit, but the maps indicate that another branch diverges from the Split vein at this point and runs off to the southwest, parallel to the general direction of the Freeland vein and the Freeland Extension. However, there appears to have been very little drifting on either of the veins past this junction.

Toledo, Gum Tree, and Anchor veins.—At its northwest end the Freeland trunk vein has been followed nearly to Trail Creek, beneath which there are no workings. On the opposite (north) side of the creek there are two ore-bearing veins whose trends converge to the southeast. The junction of these two veins is not visible at the surface on account of the overburden and has not yet been developed underground, but their trends make it probable that the junction or intersection takes place not far north of the mouth of the Freeland tunnel, near the bottom of Trail Creek. (See fig. 123.)

The main northeasterly trend of the Freeland vein is continued by the Toledo vein, with a similar relatively flat northwesterly dip. The angle of dip is about 45° in the western part of the Toledo tunnel, but becomes flatter near the east end of the tunnel, being noted in different places as 22° and 24°. At the east end of the tunnel, also, the Toledo vein becomes very weak.

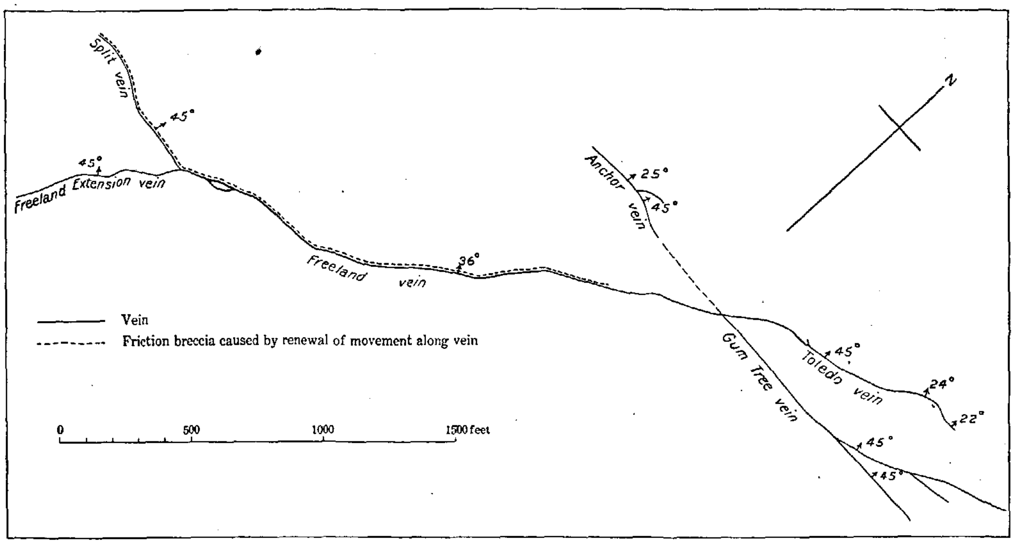


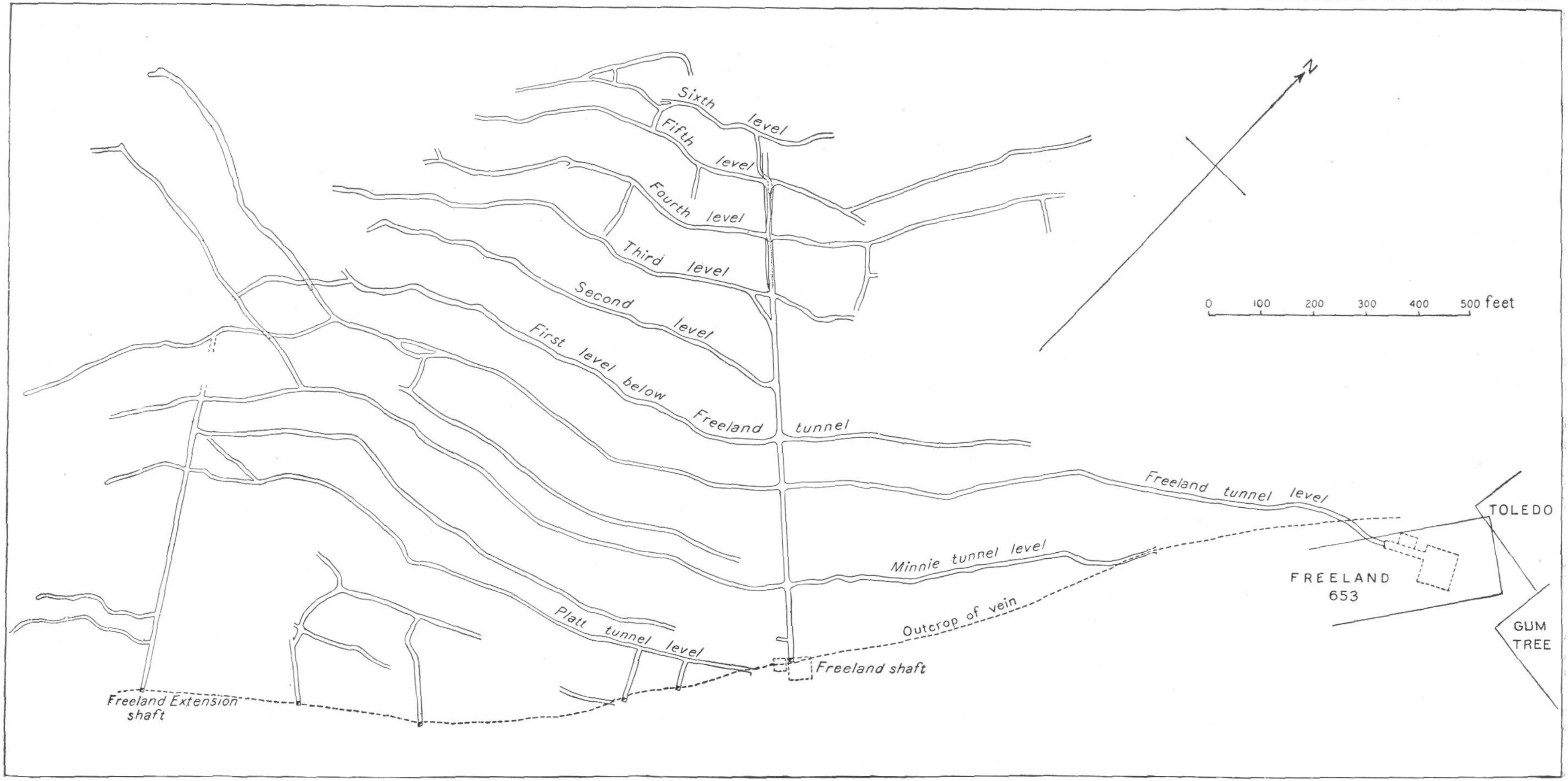
FIG. 123.—General plan of Freeland vein and some of its branches.

The Gum Tree vein diverges from the Freeland trunk vein with a general east-west strike. About 600 feet away from the probable junction or intersection with the Freeland, the Gum Tree splits, the weaker branch continuing the normal east-west strike of the vein from its junction with the Freeland, and the stronger branch having a northeast trend, divergent from that of the Gum Tree and parallel in general with that of the Toledo and Freeland. Both of these branches are mineral bearing to a greater or less extent. They dip 45° N. Farther east on the Gum Tree workings the stronger branch again divides and becomes weak.

The Toledo vein has been opened up underground to a point about 1,000 feet from the junction (see fig. 124); the Gum Tree to about 1,300 feet.

A few hundred feet northeast of the mouth of the Freeland tunnel is the Shakespeare tunnel, which runs 200 or 300 feet southwest until it cuts a fairly strong vein called the Anchor, which has been drifted on for more than 400 feet. This vein (Pl. LXVIII) has an east-west strike similar to the normal strike of the Gum Tree as stated above and a flat northerly dip of 25° to 45°, typical of the Freeland group of veins. Its strike is such that it probably joins or intersects the Freeland beneath Trail Creek.

It will be seen that the somewhat obscure relations of the Freeland trunk vein to the Toledo, Gum Tree, and Anchor veins are concealed beneath the drift of Trail Creek. What appears to be the most likely solution is shown in fig. 123. According to this hypothesis the



HORIZONTAL PLAN OF FREELAND MINE WORKINGS.

Toledo is the extension of the Freeland, and the Anchor and the Gum Tree are the same vein, which crosses the Freeland-Toledo obliquely and without great displacement.

Brighton and Harrisburg veins.—Veins representing an extension of some of the veins of the Freeland group are seen in the Brighton and Harrisburg workings, which lie west of the Freeland Extension workings. The workings of these mines, however, are separated from those of the Freeland and the Freeland Extension. The Brighton shaft is approximately 1,000 feet S. 60° W. of the Freeland Extension shaft, on the outcrop of a vein which strikes northeast, parallel to the Freeland, and has also the flat northwest dip of the Freeland vein and its different branches. The average angle of dip, calculated from the collar of the Brighton

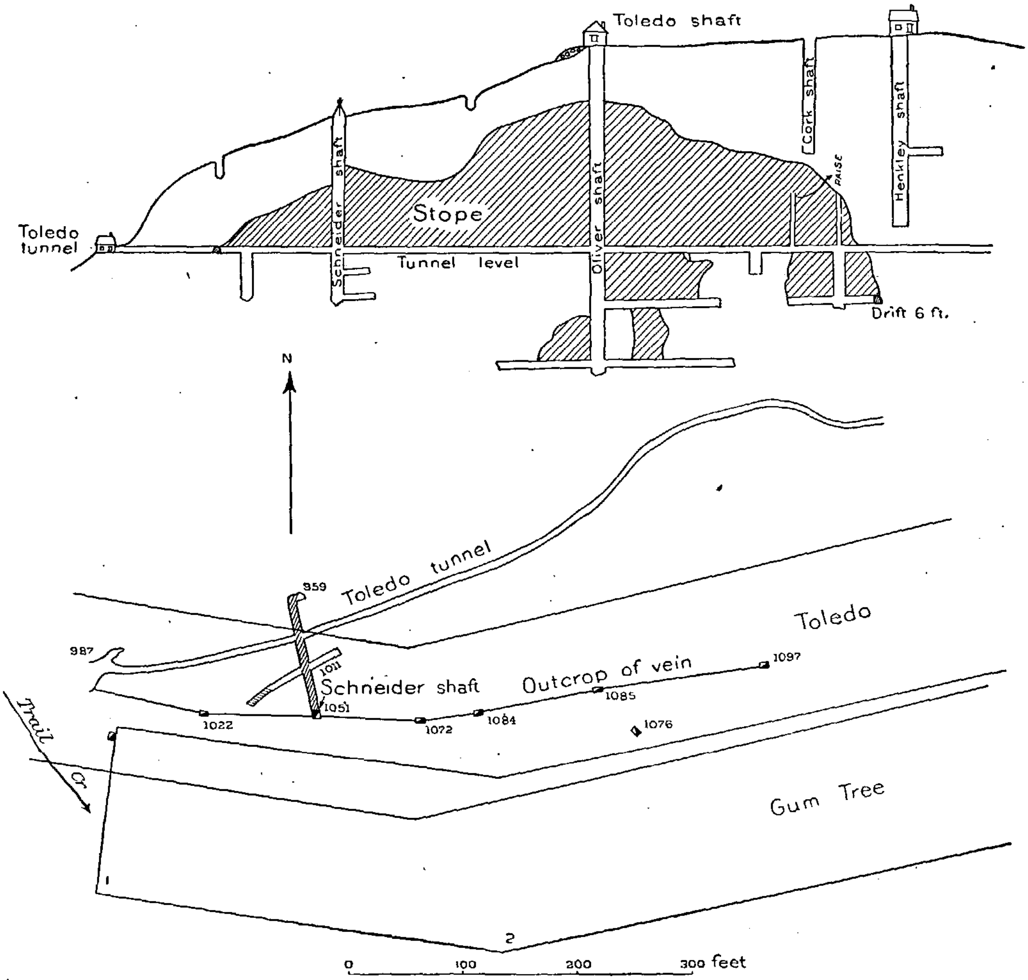


FIG. 124.—Vertical and horizontal plans of Toledo mine. Figures represent elevations in feet with reference to the arbitrary datum plane (1,000 feet) shown west of Trail Creek.

shaft to the fourth level, an actual difference of elevation of 215 feet, is $31\frac{1}{2}°$. This dip corresponds with the dip of the Freeland Extension vein as measured in the Freeland Extension inclined shaft. The average angle of dip from the surface of the Freeland Extension vein to the Platt level (nearly 300 feet difference of elevation) is 30°.

The Brighton vein is opened up underground by five levels, of which the most extensive is the fourth (fig. 125). The Brighton outcrop is in the same rough general line as the outcrops of the Freeland, as traced from the mouth of the Freeland tunnel to the top of the Freeland Extension shaft. It is probable that the Brighton is a vein of the Freeland system, distinct from the Freeland Extension vein, which it probably joins on the northeast.

The Harrisburg shaft is situated N. 20° W. of the Brighton shaft, at a distance of 300 or 400 feet. It is located on the Harrisburg vein, which has a general northwest or nearly east-west strike, about the same as that of the Split vein of the Freeland workings. Like all the veins of this group, the Harrisburg has a flat northerly dip, noted as approximately 40° in the upper parts of the workings. The exact position of the Harrisburg on the level of the Freeland tunnel is conjectural.

It is reported that the junction of the Harrisburg and Brighton veins has been encountered in the workings from both mines, and that the nature of this junction shows that the Brighton is the main vein, for it continues northeastward past the junction, whereas the Harrisburg does not cross the Brighton.

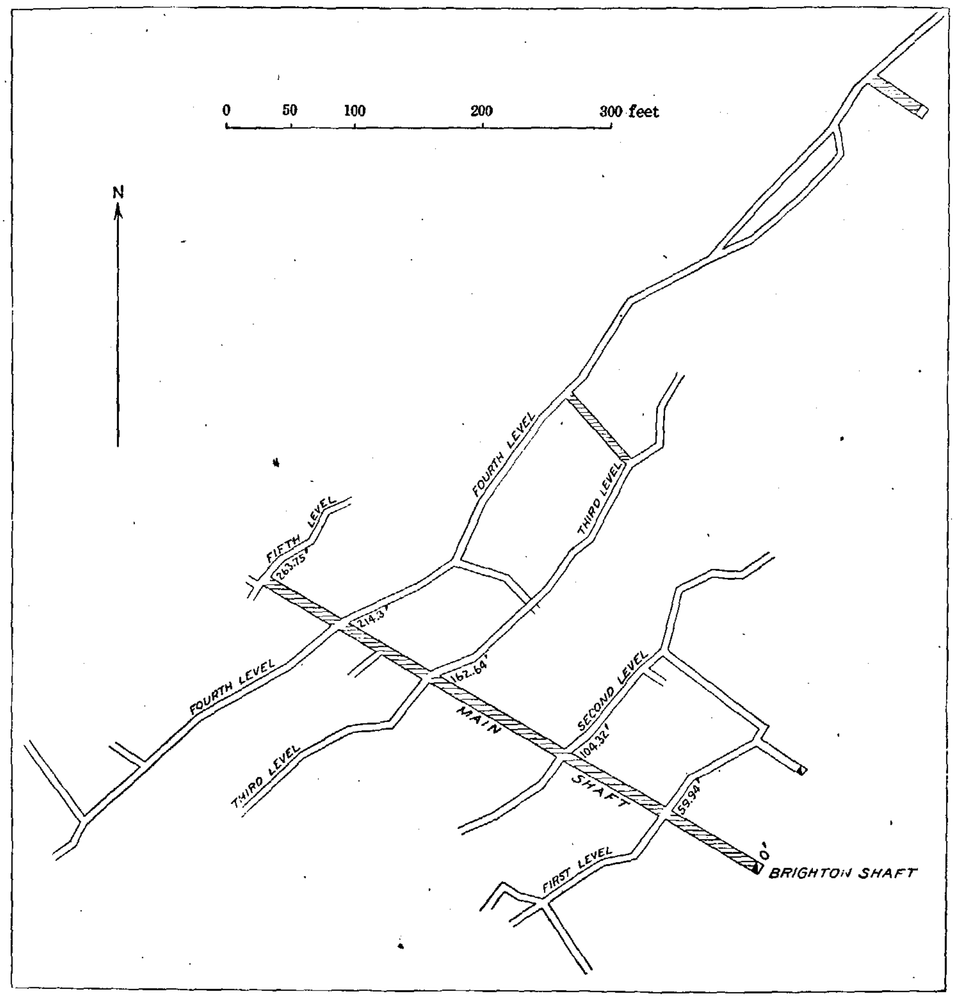


FIG. 125.—Map of Brighton mine workings.

St. Patrick lode.—On the Freeland tunnel level of the Freeland mine, about 600 feet from the mouth, a crosscut runs northwestward in the hanging wall, exposing first a porphyry dike and beyond that a minor vein parallel to the Freeland. This vein lies on the north side of the dike, about 20 feet from the contact, with gneiss for both hanging and foot walls. It has a northeast strike and a dip of 35° NW. The portion opened up in a short drift at this point shows a streak of pyritic ore 3 or 4 inches thick. This is called the St. Patrick lode.

PRODUCTION.

The Freeland vein was discovered in 1861. In 1879 the mine was bought by California mining men. From 1880 to 1888 it was owned by the California millionaire John W. Mackey.

The mine is claimed to have produced during Mackey's ownership over $3,000,000 worth of ore. The following are the estimated figures of the total production of the Freeland, furnished by the present management of the mine:

Production of Freeland mine.

Estimated production from 1861 to 1879, of which no records have been kept	$1,000,000
Production from 1879 to 1888	3,299,000
Estimated increase of this amount to account for four months' production when the records were improperly kept	200,000
Record of production since 1888 by lessees	156,000
Total	4,655,000

The production of the Gum Tree is stated by the owner at $300,000; that of the Toledo at $130,000.

The Harrisburg mine was worked some time ago, but no figures as to the production have been obtained. The Brighton mine was only two years old at the time of the writers' examination in 1905. At that time no ore had been produced, although considerable development work had been done and ore had been accumulated on the dump awaiting the completion of a mill on Fall River.

EXTENT OF MINE WORKINGS.

The Freeland vein is opened up by several tunnel drifts, of which the lowest starts in on the outcrop of the vein near the bottom of Trail Creek. It is also opened up by an inclined shaft running from the surface down through the various tunnel drifts and thence down to the lowest workings. There are six levels beneath the lowest tunnel drift (the Freeland tunnel), the actual difference in elevation between the Freeland tunnel and the bottom of the Freeland shaft being about 630 feet. A few years ago the McClelland tunnel was begun, to cut the Freeland and other veins of this region at a considerable depth and to drain this portion of the country. This tunnel starts in from Clear Creek, below Dumont, and will cut the Freeland vein at a point very roughly estimated as about 400 feet beneath the bottom of the Freeland shaft. In July, 1906, this tunnel was in more than 5,100 feet. The map of the Freeland mine (Pl. LXXX) shows about 4 miles of underground workings.

The Gum Tree mine, which is under a separate ownership from the Freeland and Toledo, is opened up by an inclined shaft running from the outcrop of the vein down on its dip and by four drift levels on the vein, aggregating in all several thousand feet of workings. Only the upper two levels are shown on the accompanying map (fig. 126).

The Toledo vein also is chiefly opened up by an inclined shaft, connecting with the tunnel drift running northeastward for about 700 feet from the outcrop of a vein at the surface near Trail Creek.

The Anchor vein is opened up by the crosscut Shakespeare tunnel and by a drift several hundred feet in length.

The Brighton vein is opened up by an inclined shaft from the outcrop. Drifts extend both ways from this shaft at five levels, of which the fourth is the most extensive. The total difference of elevation between the collar of the shaft and the drift level is 264 feet.

The Harrisburg vein is developed by an inclined shaft and various levels. Not much information is at hand concerning it.

NATURE OF VEINS.

These veins lie along lines or zones of fracturing and minor faulting. It is probable that the displacement has been relatively slight. On the second level of the Gum Tree mine (fig. 127) the main branch of the vein shows on its walls slickensides dipping 70° E. On the third level striæ dipping 45° W. were found.

Some indication of faulting along the Harrisburg vein is seen in the Harrisburg mine, where on the first level a transverse porphyry dike was observed in the foot wall and not in the hanging wall. Inasmuch as the line of surface exposures of this dike is practically straight, showing that it trends in general across the strike of the vein, it is probable that it has been offset at this point by movement along the vein, but that the displacement has not been great.

NATURE OF WALL ROCKS.

The wall rocks of the Freeland trunk vein and of all its different branches or connected veins above mentioned consist chiefly of black gneiss with some pegmatite. (See Pl. LXVIII.) The schistosity in the gneiss has in general an oblique trend as compared to the strike of the veins.

Porphyry dikes are present here and there in the walls of the veins or close by. On the Freeland tunnel level of the Freeland mine, about 600 feet in from the mouth, a crosscut to the northwest in the hanging wall of the vein, which at this point is as usual of gneiss, cuts at a distance of 10 feet a porphyry dike which is about 60 feet thick, as measured by a horizontal section. This dike has a strike oblique to that of the vein, or nearly due east and west, and a northerly dip of 55°. It consists of an entirely altered rock showing numerous large

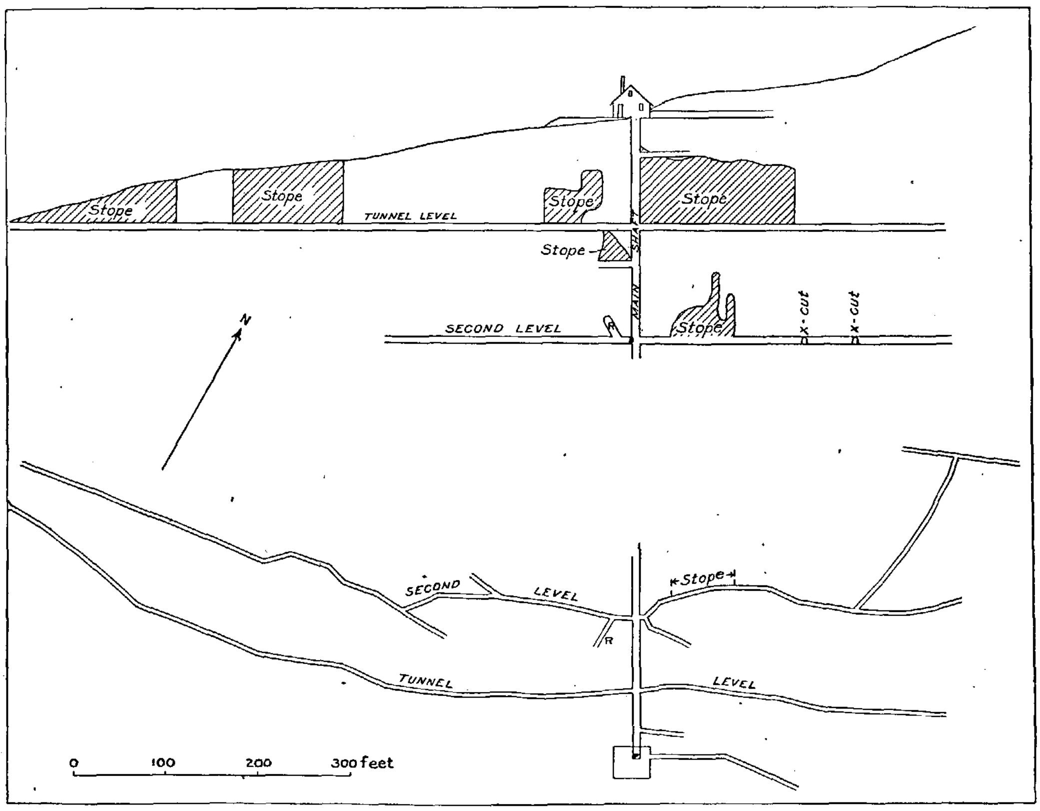
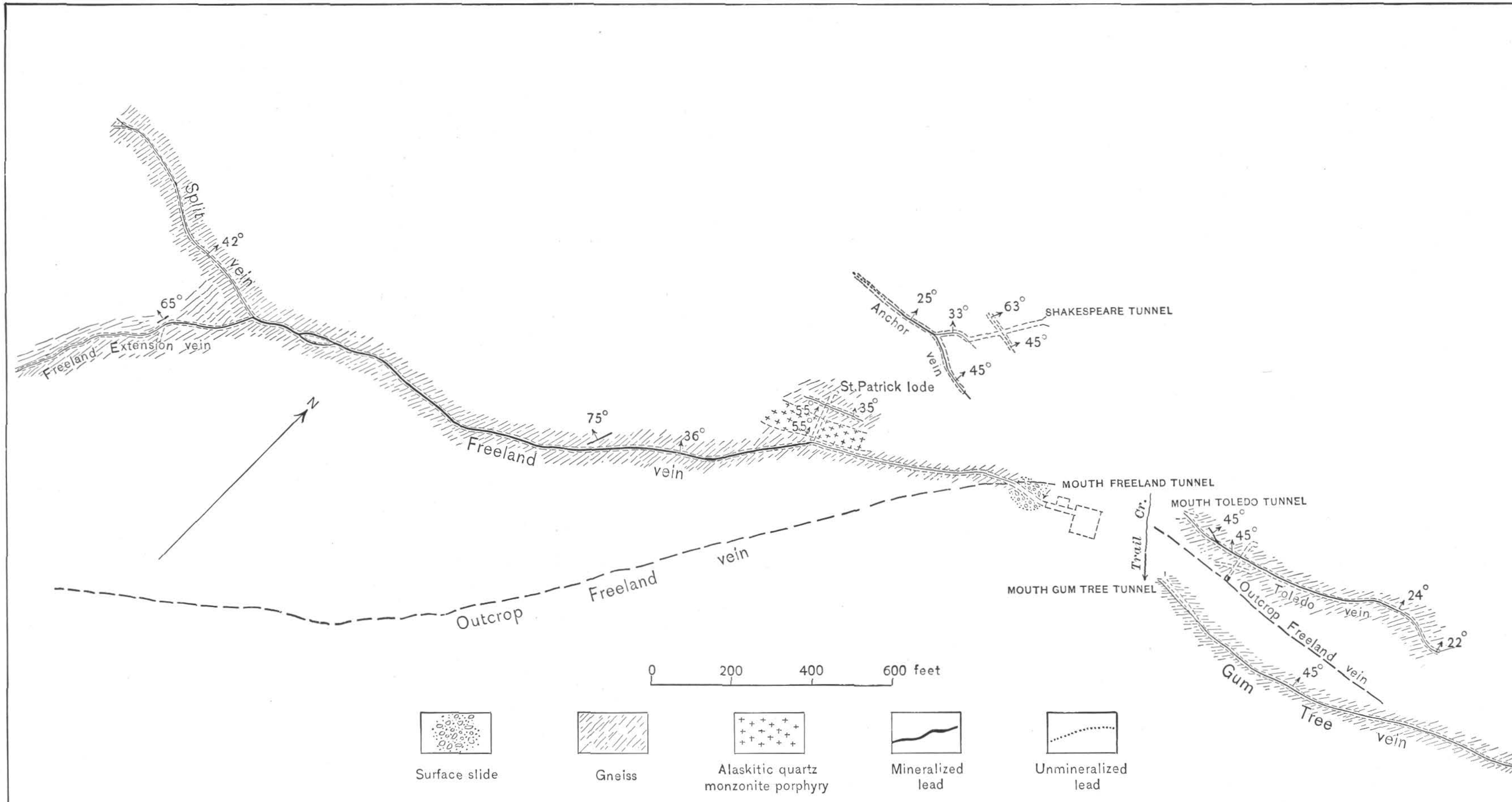


FIG. 126.—Vertical section and plan of two upper levels of the Gum Tree mine.

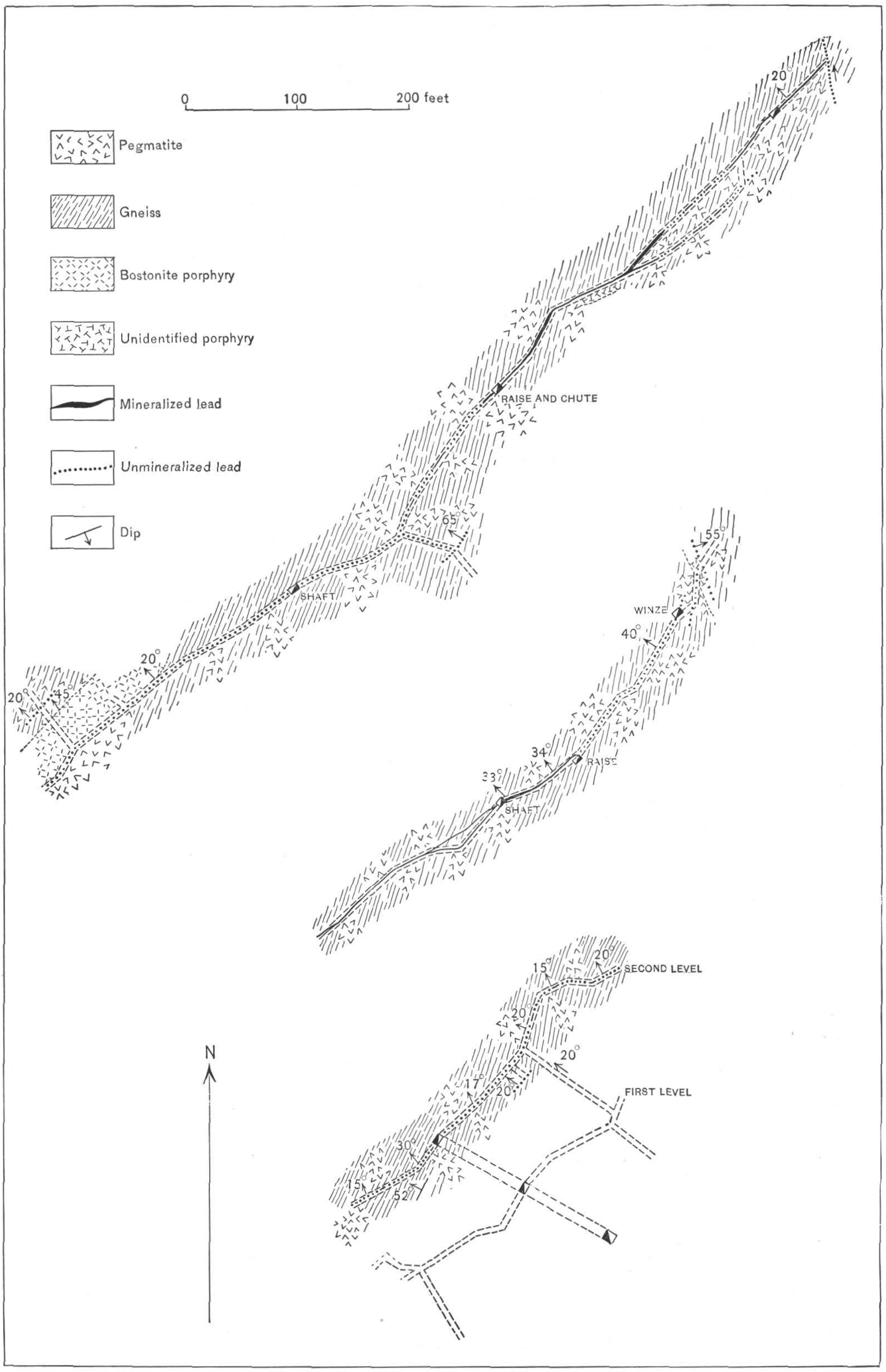
altered feldspar phenocrysts and, under the microscope, pseudomorphs of alteration products after biotite phenocrysts. Near the mouth of the Freeland tunnel level an outcrop of the same porphyry was noted by Mr. Ball near the hanging wall of the vein. This rock was determined by him to be probably alaskitic quartz monzonite porphyry. It was reported by the foreman that porphyry is encountered in a number of other places in the Freeland mine in the hanging wall of the vein. It does not occur on the Freeland tunnel level, however, so far as known, at any other place than that described. It is reported that porphyry occurs on the Minnie level, forming both walls of the vein.

No porphyry was observed in the Gum Tree or Toledo workings.

In the Brighton mine, on the fourth level (see Pl. LXIX), porphyry comes into the hanging wall of the vein at the southeast end of the drift, in the form of a dike having a width as measured in horizontal section of about 40 feet, which represents an actual thickness of about 20 feet, as the dike has a northwest dip of 45°. The strike of this dike diverges from that of the Brighton vein, opening out from it to the north when followed in a northeasterly direction.



GEOLOGICAL PLAN OF FREELAND, TOLEDO, GUM TREE, AND SHAKESPEARE TUNNELS, ALL ON NEARLY THE SAME LEVEL.



GEOLOGICAL PLANS OF SEPARATE LEVELS, BRIGHTON MINE.

It has not been observed elsewhere in the mine. In the Harrisburg mine, on the first level near the shaft, porphyry forms the foot wall, the hanging wall consisting of pegmatite and gneiss. Farther east on the first level porphyry also occurs as a layer in the hanging wall.

Specimens of the porphyry from the Harrisburg and the Brighton mines prove to be of the same kind of rock. Both of these occurrences are evidently a part of the strong dike of bostonite which has been followed on the surface from Trail Creek, where its outcrop occurs about 1,000 feet northwest of the outcrop of the Freeland vein at the opening of the Freeland tunnel, southwestward up the hill. This outcrop is nearly parallel to that of the main Freeland vein, but the two outcrops converge to the southwest. This dike evidently crosses the Harrisburg vein near the shaft and runs transversely across to the hanging wall of the Brighton vein.

COMPOSITION OF VEINS.

The nature of the vein materials is similar in the main Freeland vein and its different branches. The deeper workings of the Freeland mine show ore composed mainly of pyrite and

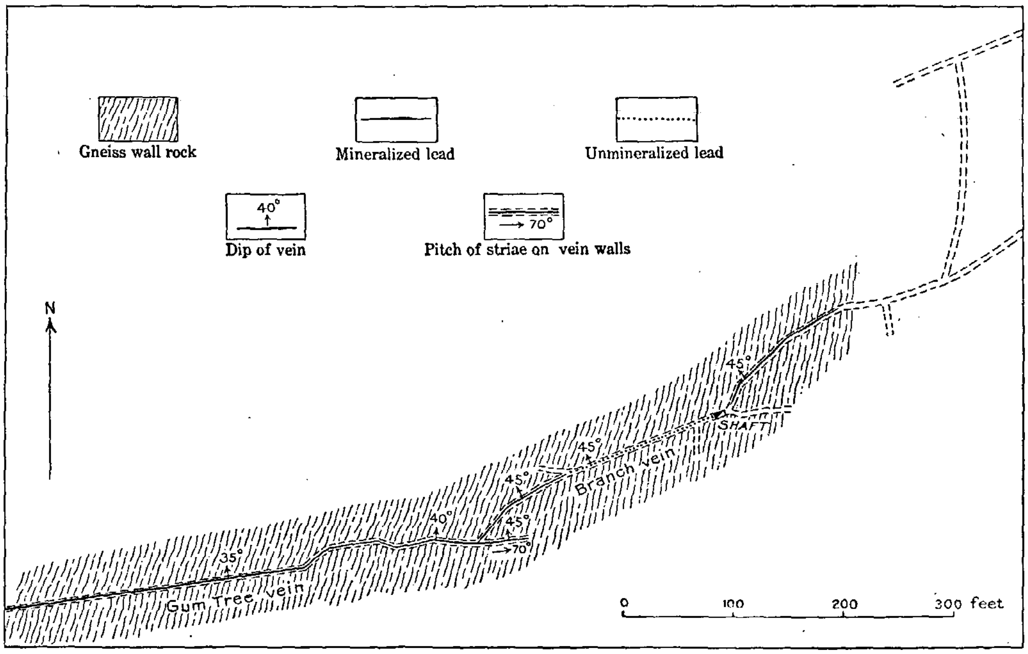


FIG. 127.—Geological plan of second level, Gum Tree mine.

chalcopyrite, with a little tetrahedrite. Only a small amount of blende is present—not enough to make the zinc enter into the smelter returns. Galena occurs chiefly in bunches near the surface; in the deeper workings there is hardly any. The average ore is roughly stated to be worth about $30, containing 1 ounce or more of gold, 4 to 20 ounces of silver, and 3 to 4 per cent of copper. Statements of returns from different lots of smelting ore taken from the Minnie level of the mine showed total values ranging from $15 to $40. A typical return sheet, picked out by the writers, is as follows:

Total value	$30.87
Gold .... ounces..	1.35
Silver .... do....	9
Copper .... per cent..	2.8
Lead	0
Zinc	0

It is reported that the gold and silver in the ore are very closely associated, the relative amount of one rising with that of the other, but that there is no close connection between the gold and the copper. Some of the iron pyrite carries very high values in gold.

The ore of the Toledo mine is of similar character, consisting of pyrite, much of it cupriferous, and some tetrahedrite. The ore showed very little galena except some near the surface associated with quartz.

The ore of the Gum Tree mine consists largely also of pyrite and chalcopyrite. Tetrahedrite occurs in small quantities, in many places following cracks in the chalcopyrite and evidently secondary to this sulphide. The ore of this mine, however, contains considerable galena down to the fourth level, which was the deepest level at the time of examination; and at a depth vertically beneath the surface of, roughly, 400 feet the lead still forms an important part of the ore from a commercial standpoint. The massive pyritic ore is said to contain 2 to 3 per cent of lead and 3 to 4 per cent of copper. A shipment of galena ore carefully sorted out yielded the following returns: Gold, 0.42 ounce; silver, 13 ounces; lead, 56.5 per cent; copper, 2.2 per cent; value, $39.

The material of the Anchor vein is mostly quartz and pyrite, but chalcopyrite and a little blende also occur.

The Brighton vein shows, like the Gum Tree vein, considerable galena associated with pyrite. There is also some chalcopyrite, though much of this mineral is considerably altered to tetrahedrite. Sphalerite occurs in much of the ore. The gangue consists of quartz (some of it being comb quartz), rhodochrosite, siderite,[a] and barite. The walls of many open druses have a coating of soft black or dark-gray pulverulent secondary sulphides.

Ore from the Harrisburg vein shows galena and pyrite, with barite, quartz, and siderite.

LOCATION OF ORES.

The main Freeland trunk vein splits up on the southwest into two branches. The ore continues along the more southern of the branches, the Freeland Extension, although not in such large amounts as on the trunk vein. On the Split vein, the more northern of the two branches, no stopes were observed on the Freeland tunnel level for the first 225 feet from the junction, but on the remainder of the vein ore has been stoped. The largest and most persistent body of ore on the Freeland vein appears to extend from the junction back along the trunk vein for a distance of approximately 1,800 feet. This ore body appears to be thickest and strongest at the junction, and on the whole to decrease gradually toward the northeast. It has been followed from the surface down to the lowest workings of the mine. (See fig. 128.) These lowest workings are vertically 1,040 feet below the collar of the Freeland shaft and about 1,340 feet below the collar of the Freeland Extension shaft. Thus the actual length of the shoot, measured downward along the dip, is about 2,000 feet.

The Toledo vein shows a similar ore body about 600 feet in length along the vein. The southeast end of this body is located about 80 feet east of the mouth of the Toledo tunnel. Here a small mineralized branch vein, striking N. 75° W., joins the main vein in the manner of a reversed branch, opening out on it to the southwest, instead of to the northeast, as is normal in this portion of the Freeland vein group. The ore begins at the junction of the branch with the main Toledo vein and extends eastward. It has been followed down along the dip of the vein by a shaft, the bottom of which is 28 feet below the tunnel level.

In the Anchor vein ore has formed at the junction of a branch striking northeast and dipping flatly northwest.

RENEWAL OF MOVEMENT ALONG VEINS.

On the Freeland tunnel level of the Freeland mine, on the south side of the horse of country rock which occurs in the trunk vein near the point of branching, hard consolidated breccia was observed. This material contained broken and rounder fragments of gneiss, pegmatite, and ore in a hard fragmental matrix. The included fragments in general have the appearance of pebbles, being subangular and rounded like pebbles that have been rolled in a stream bed. The general relations of this material, however, indicate that it is probably a breccia due to friction. The vein has been reopened subsequent to the chief period of mineralization, and the new differential movement along the vein walls has produced a zone of crushed material,

[a] Yellow-brown carbonate from this mine, analyzed by W. T. Schaller, was found to be mixed carbonate of iron and manganese.

the harder and larger fragments of which have been rounded by rubbing against one another. Evidently the pressure on this zone of fragmental material has not been great, otherwise it would have been ground to a soft paste rather more typical of a fault zone than the material in question. Given, however, differential movement along the walls of this crushed zone and relatively slight pressure, the origin of the rounded forms, which are characteristic of this friction breccia and of other similar breccias, which are commonly found along other veins in this region, is easily understood, and the resemblance to stream pebbles is due to the fact that both have a somewhat similar origin. Stream pebbles are not, strictly speaking, waterworn, but are worn by rubbing against one another when they are set in motion by the current of stream water. Similarly, these pebbles have been rounded by friction, though the movement which has agitated them has originated in stresses in the rocks of the crust, not in the action of atmospheric waters due to gravity.

At the point above described this friction breccia or conglomerate is about 3 feet thick. It was reported that this formation was seen at intervals all along the Freeland vein, generally on the hanging wall. It also continues along the Split vein. The Freeland Extension branch, however, has no gouge or breccia, and therefore was not disturbed by reopening of the fissure subsequent to the principal period of cementation.

Where observed in the Freeland level, most of the ore in this breccia lies in broken fragments and is evidently older than the period of brecciation. Some of it, however, lies in regular seams in the breccia, suggesting that it was formed later than the breccia, at a period altogether distinct from that of the main vein filling.

Gouge, probably due to movement along the vein since the main period of mineralization, has been noted along the Gum Tree vein. The Harrisburg vein also shows signs of post-mineral reopening. In places near the Harrisburg shaft open fissures were observed along the vein.

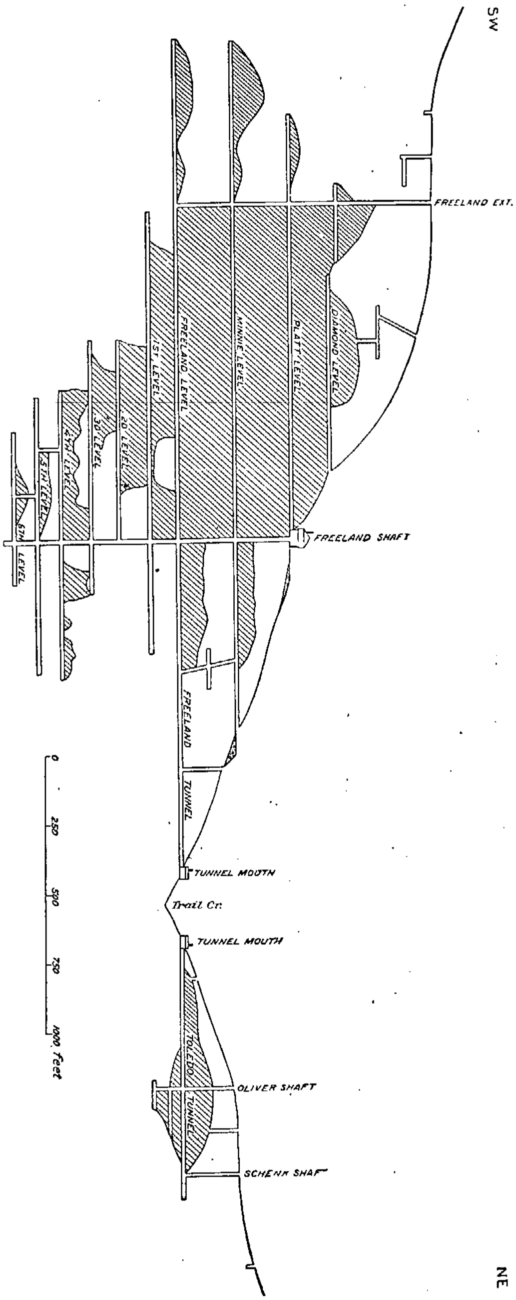


FIG. 128.—Vertical longitudinal projection of workings on Freeland-Toledo vein. Stopes shown by shaded areas.

CHANGES OF ORE IN DEPTH.

It is reported that the ore of these veins shows no marked changes in depth, but the examination has not been complete enough to give many data on this point. The only feature noted was that the galena appears, so far as reported, to be more characteristic of the uppermost 200 or 300 feet of the veins rather than of those portions more remote from the surface. In the Freeland trunk vein galena is practically absent from the lower workings, although it occurred near the surface in bunches. The same observation applies to the Toledo. In the

Gum Tree vein galena is present, but the lower stopes at the time of examination were only about 400 feet vertically below the surface. In the Brighton mine, where ore has been developed to a vertical depth of only 215 feet below the surface, there is considerable galena associated with pyrite, rhodochrosite, siderite, and barite. Some of the pyrite is distinctly contemporaneous with the siderite. In several places it was shown that siderite, barite, and clear cerusite crystals[a] were younger than the galena.

It appears possible that the carbonates of iron and manganese, with the associated pyrite and barite, found in these upper workings may be characteristic of the more superficial portions of the ore and may be due to atmospheric waters. It is also possible that the greater abundance of galena near the surface is due to the same cause.

PARAGENESIS OF MINERALS.

The principal ore which occurs in the lower portions of the veins consists of pyrite and chalcopyrite or cupriferous pyrite, with a very little galena and blende. The relatively more abundant galena observed in many places near the surface is, as above noted, very probably of later origin than the scanty galena found at greater depths.

Tetrahedrite, observed in a number of places, has characteristically the appearance of being due to the alteration of chalcopyrite along the cracks in which it is usually formed. This is probably the result of descending surface waters.

Ore from the Brighton mine shows galena brecciated and cemented by brown carbonates, probably siderite. Vugs in this material are lined with crystals of siderite and cerusite. In many other specimens this siderite is uncrystallized and contemporaneous with pyrite, which is therefore in general later than the galena above mentioned. Some quartz and galena, however, occur as crystals contemporaneous with this latest iron mineralization. A specimen from the Harrisburg mine shows the reopening of a fissure along an original vein of galena. Although the bulk of the new fissure was filled by crystalline barite, the side of the fissure which joined the wall rock of the vein was coated with crystalline siderite contemporaneous with the barite. The gneiss wall rock of this vein was, at the time of the earlier mineralization and before the opening of the new fissure, highly impregnated with pyrite, and the occurrence of the siderite fringing a fissure in this pyritic rock suggests that the iron for the carbonate was derived from the older sulphide, while the carbonic acid was supplied by the waters which circulated through the subsequent opening.

Some of the specimens of ore from the Brighton and Harrisburg workings show on the walls of geodes a sooty black or gray coating, determined by W. T. Schaller to contain sulphide of lead, in many places associated with and contemporaneous with small crystals of quartz and beautiful crystals of cerusite. All these minerals have formed in druses which exist in ore made up of quartz, pyrite, and galena and which have the appearance of having been dissolved out subsequent to the entire cementation of the original vein opening. Both the sooty black material and the cerusite are formed on the surface of galena, which is part of the walls of the geodes and is apparently older than the opening, in such a way as to suggest that both have originated from the galena. In another specimen similar sooty black material (secondary sulphide material) is associated with probable tetrahedrite, and both are plainly derived from the alteration of older chalcopyrite along cracks and in geodes.

PRESENT ACTION OF UNDERGROUND WATERS.

The mine waters of the Freeland mine contain the sulphates of copper and iron and carbonate of lime. This is shown by the deposition, on the walls, of copper and iron sulphates and calcite. It is said that nails have been changed to native copper by the mine waters, through the well-known action of metallic iron upon copper in solution.

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[a] Determined by W. T. Schaller.

INVINCIBLE MINE.

LOCATION.

The Invincible mine is located on the Lamartine road about 3,000 feet N. 60° W. of Alps Mountain. The mine has long been unworked and most of the openings have caved so that they are inaccessible. One tunnel and the shaft, however, show a S. 53° W. vein which dips about 70° NW. As the Invincible mine is located in a line between the Brighton and Cecil mines and develops a vein which heads in the direction of each, it is probable that the vein belongs at least to the same general vein system as these mines.

CHARACTER OF ROCKS AND VEIN.

The rocks in the vicinity consist chiefly of micaceous gneiss associated with a little pegmatite. Fragments of porphyry were found on the mine dump, showing that a dike was probably encountered in the mine workings. The dump contained vein material which consisted of galena and quartz, finely crushed and recemented by silica.

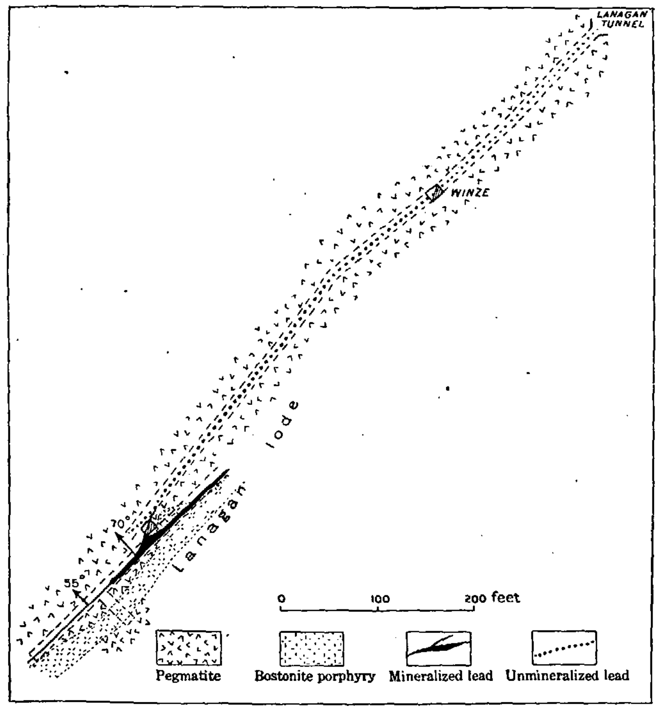


FIG. 129.—Geological plan of Lanagan tunnel.

ALPINE MINE.

DESCRIPTION.

The Alpine mine lies about 1,000 feet south-southwest of Alps Mountain, at an elevation of 10,300 feet. A fire has destroyed the shaft house and the mine workings were inaccessible. The vein, which has a general northeast-southwest trend, dips slightly to the northwest and cuts through an area of micaceous gneiss associated with a little intrusive quartz monzonite, pegmatite, and granite.

CHARACTER OF ORE.

The ore from the ore bins showed narrow seams of galena and grayish-brown sphalerite, associated with a little tetrahedrite and argentite. Much of the tetrahedrite occurs in minute but well-formed crystals. Pyrite, although rare, is present in some of the ore. In a few specimens thin seams of ore were noted between the laminæ of the gneiss and conforming with its schistosity. The Alpine mine has produced considerable ore and was worked up to the time when the fire destroyed the mine buildings.

LANAGAN MINE.

LOCATION AND DEVELOPMENT.

The Lanagan mine is located at an elevation of about 10,200 feet on the slope of Alps Mountain, 700 feet north of the summit. The developments consist of a tunnel about 350 feet in length, which runs through pegmatite, gneiss, and granite and follows a slightly mineralized clay lead (fig. 129).

DESCRIPTION OF VEINS.

This tunnel vein connects with a short drift and stope on a N. 42° E. vein, which dips from 55° to 70° NW. and runs somewhat parallel to and only a short distance from the tunnel vein all the way from the mouth of the tunnel. In places this second vein consists of a broad clay, quartz, and crushed rock lead several feet wide; in others it comprises a network of small stringers of quartz or ore cementing fractured wall rock. It is approximately parallel to a 10-foot dike of bostonite porphyry. Locally it runs along the northwest or hanging-wall contact of the porphyry dike, but elsewhere it is separated from the dike by several feet of pegmatite or other country rock. In some places the vein evidently cuts through portions of the dike, for a few small patches of porphyry occur also on the hanging-wall side of the vein. Specimens found on the mine dump showed small stringers of ore running all through and cementing fractured porphyry.

CHARACTER OF ORE.

The ore which has been mined, to judge from specimens found on the dump, consisted of galena, zinc blende, both resin blende and "black jack," and some pyrite in a quartz gangue. Minute blotches and fibrils of probable tetrahedrite were also noted in some of the specimens. According to the owner, the average of all the ore shipped from the mine gave values of 2.21 ounces in gold, 150 ounces in silver, and 5 per cent of lead.

LOCATION AND PRODUCTION OF ORE.

The only stope in the mine is near the junction of the S. 42° E. vein and the tunnel vein, and is a good illustration of ore deposition at the point of union of two veins.

The production of the mine has consisted of four shipments of ore, aggregating 14 tons in all.

MILLER MINE.

LOCATION AND DEVELOPMENT.

The Miller mine is located at an elevation of about 9,950 feet, just below the Lamartine road, about 1,500 feet north-northeast of the summit of Alps Mountain. The development consists of a crosscut tunnel about 80 feet in length to a vein which is drifted on to the southwest for about 850 feet (fig. 130).

WALL ROCKS.

Except for small amounts of gneiss, pegmatite, and bostonite porphyry near the point where the tunnel cuts the vein, the mine workings are all in dark-gray biotite granite. This granite immediately in contact with the vein shows striking examples of the development of secondary adularia. The rhombic colorless crystals of this mineral occur as aggregates of grains associated with secondary quartz and also as border fringes surrounding altered orthoclase crystals which have been clouded by kaolin.

DESCRIPTION OF VEIN.

The vein, which dips 75° NW. and strikes about N. 60° E., consists of a clay, quartz, and friable granite lead several inches wide. Here and there, however, quartz and low-grade ore appear along the vein in small streaks. Near the inner or southwest breast of the drift, which was being driven ahead at the time of visit, the vein split into three small branches, striking S. 50° W., S. 60° W., and S. 70° W. and dipping from 78° to 82° NW. The southern two of these leads were mineralized to a small extent, but the most ore occurred at the very junction of these two leads a short distance to the northeast, where the vein formed a small trough pitching to the southwest and containing from 1 to 4 inches of galena-sphalerite ore. The granite between stringers of ore and the wall rocks near the vein were pretty well impregnated with pyrite.

CHARACTER OF ORE.

The little ore produced by the mine has consisted of galena, dull-black sphalerite, and some pyrite in the quartz gangue. Specks of probable tetrahedrite were observed, associated with the galena and sphalerite, but possibly of slightly later origin. The first-class ore averages about $30 to $40 to the ton, the main values being in silver, although the owners are paid about $2 a ton for the gold. The sphalerite, which is of a peculiar dull-black variety, occurs at many places in considerable abundance, to the detriment of the ore. Black, sooty sulphides, resembling the "black sulphurets" of the miners of the district, are also here and there associated with the lead and zinc ore, but as they carry no higher values than the rest of the ore they probably represent simply pulverized zinc blende and galena. Recognizable dull-gray crushed galena is found at some places.

Besides the galena-sphalerite ore, which occurred with quartz as a fissure-vein filling and as small stringers in fractured granite, stringers of solid pyrite also cut the wall rocks. Good examples of pyrite gradually replacing the granite wall rock were also seen. So far as known, the pyrite carries but slight values in this mine.

RELATION OF VEIN TO PORPHYRY DIKE.

A noteworthy feature in this mine is the fact that the vein cuts through and faults for a distance of several feet a dike of bostonite porphyry.

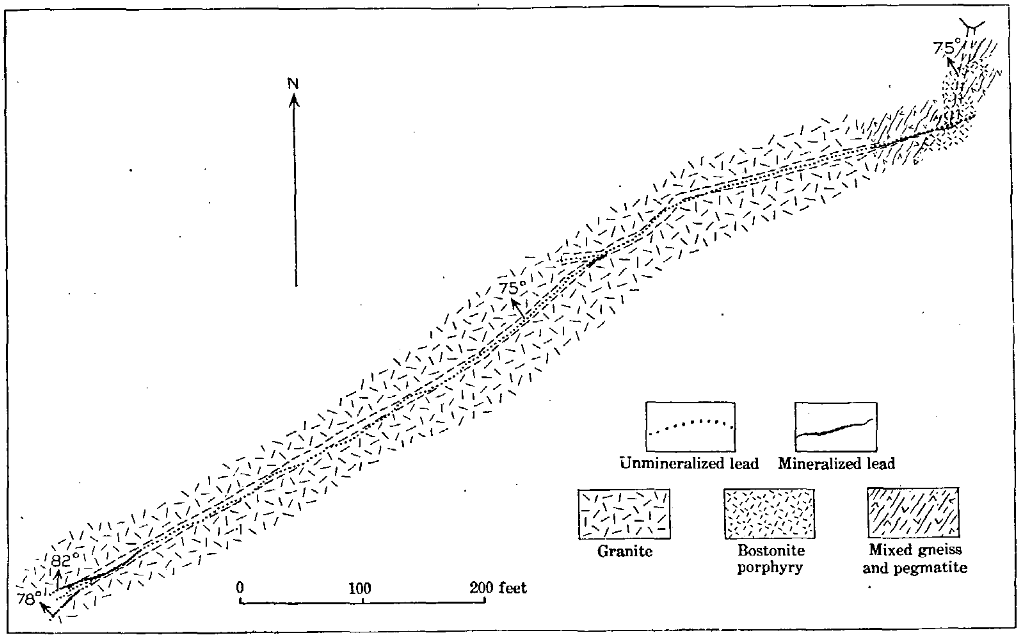


FIG. 130.—Geological plan of Miller tunnel.

CRAZY GIRL MINE.

LOCATION.

The Crazy Girl mine is located about 3,000 feet north-northeast of Alps Mountain. As the workings were not accessible at the time of visit, the underground development was not observed.

CHARACTER OF VEIN MATERIAL.

The mine is situated in a granite area, and, to judge from material found on the dump, the vein consists of a series of quartz stringers running through fractured granite. The mine is reported to have produced a small amount of ore, and some ore that was found on the dump consisted of galena, cupriferous pyrite, zinc blende, and quartz. A little specularite and tetrahedrite was also observed associated with the sulphides, and clusters of white to brownish fibrous crystals of cerusite or pyromorphite were noted in vugs in the oxidized ore.

In some places the ore appears to have been brecciated and recemented by quartz crystals; in others it fills the space between the comb-quartz coatings on the granite walls.

DONALDSON-CHAMPION DIRT GROUP.

DESCRIPTION OF VEINS.

The Donaldson-Champion Dirt group consists mainly of a single well-defined vein with several minor branches, which outcrops first on one side of Trail Creek and then on the other from a point near the junction of that stream with Clear Creek to a point within half a mile of the village of Freeland, the circuitous outcrop being 10,000 feet in length. The vein has been extensively developed by the Wheatland, Donaldson, Kelly, Little Albert, Champion Dirt, Harrison (and Union), and Morgan mines. (See Pl. LXX.)

The vein, although strong and well defined, has a flat northward dip, usually not over 35°. In consequence of this dip, the rugged topography of the surrounding region, and the slight variations in strike, the surface outcrops have an exceptionally tortuous course.

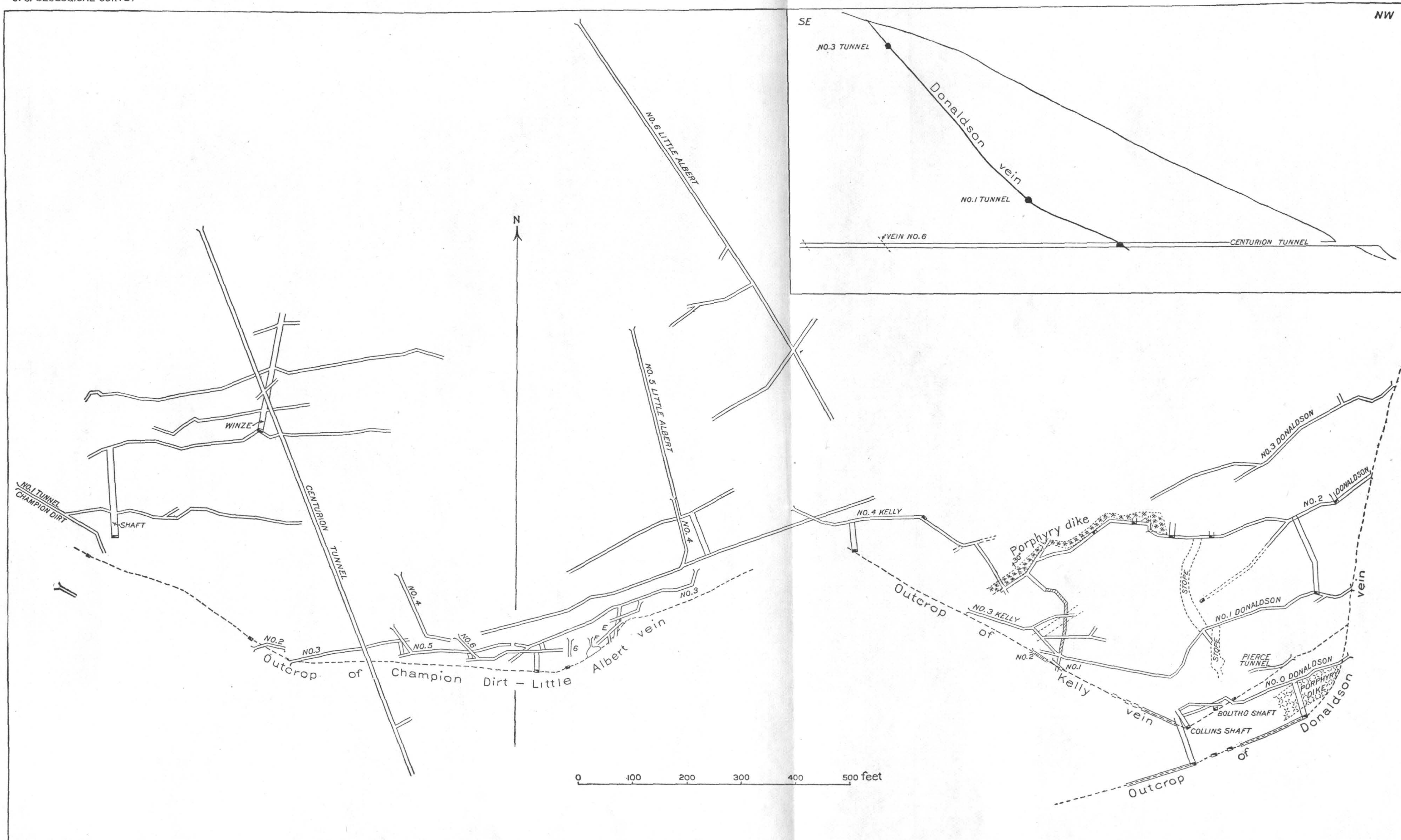
On the surface the vein was recognized trending about east and west along the south slope of the mountain spur separating Trail and Clear creeks, a short distance above their junction; it then crosses Trail Creek gulch at an elevation of 7,900 feet near the ore house of the Wheatland mine, turns abruptly to the south, and runs up the steep mountain slope on the Golden Link claim to the point where it is developed by the workings of the Donaldson mine. At an elevation of about 8,850 feet there is apparently a split in the vein, so that on the crest of the ridge, at an elevation of about 8,925 feet, two veins appear. The southern of these two, where last exposed by workings, had a trend of S. 73° W. The northern vein, which may possibly coincide with the so-called "Mount Vesuvius lode," connects with the main workings of the Kelly mine, and after running at the very crest of the ridge somewhat parallel to the southern vein, swerves to a N. 60° W. course as it proceeds down the steep northwest hill slope, although the actual strike is to the southwest. At an elevation of about 8,700 feet, where the vein crosses a small gulch 150 or 200 feet south of the mouth of the Little Albert tunnel No. 4, the effect of topography is again shown and the surface outcrop of the vein makes an abrupt turn to a S. 42° W. direction until it crosses the crest of another small mountain spur. Beyond this point, where it is developed by the Champion Dirt workings, it trends irregularly N. 75° W. The vein then crosses the valley of Trail Creek and is probably the one which strikes about S. 72° W. and is developed in the Harrison and Union and the Morgan mines.

MINE DEVELOPMENT.

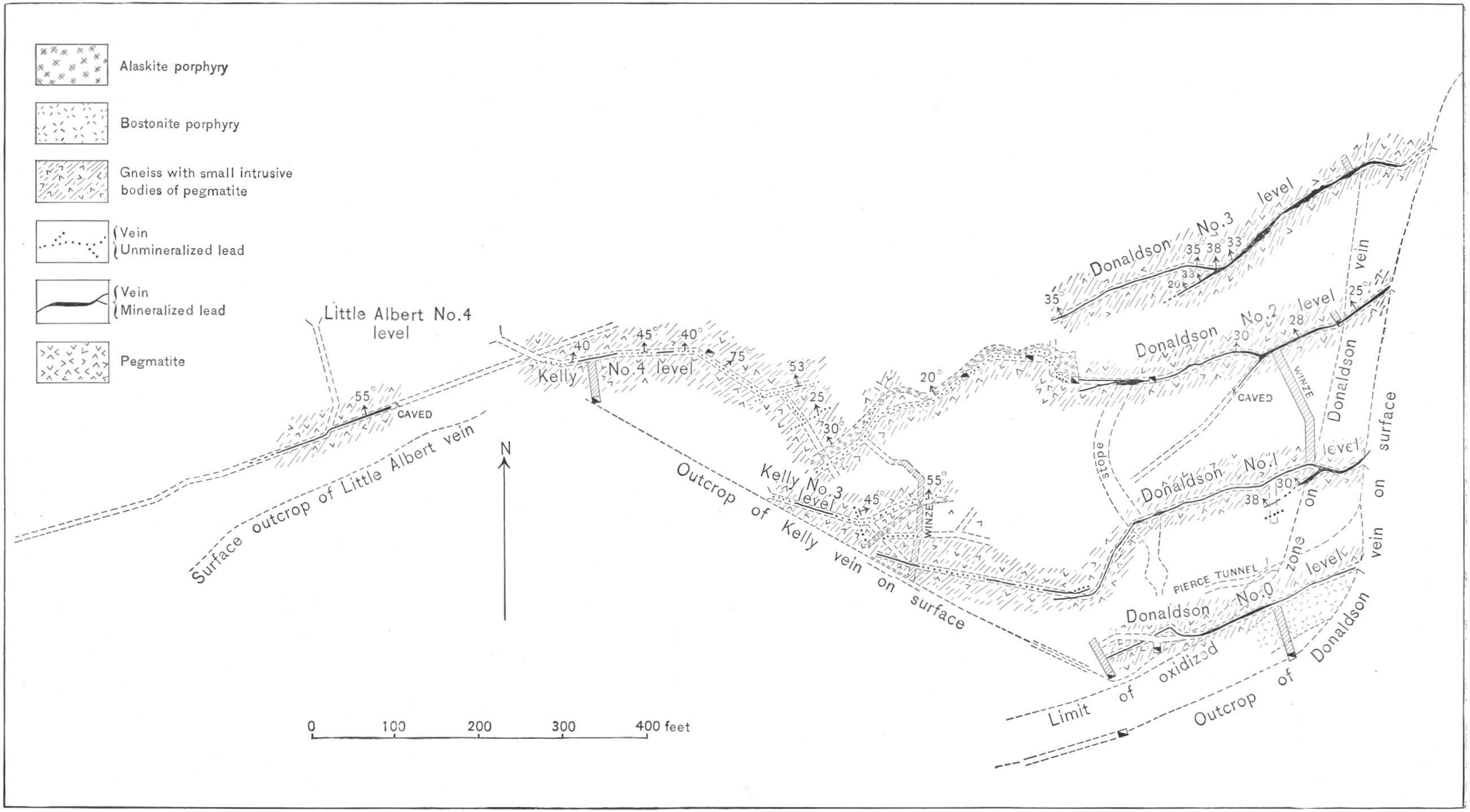
All the way from the lowest Wheatland tunnel to the top of the hill above the Donaldson mine the vein is almost continuously opened by tunnels at short intervals, from which there are numerous stopes and raises. On the Donaldson there are four tunnels, all driven on the vein and aggregating more than 2,000 feet in length. Both the Donaldson No. 1 and No. 2 tunnels connect with drifts running into the Kelly tunnels Nos. 3 and 4, respectively, which open to the surface on the opposite or west side of the mountain-spur. The Kelly mine comprises about 1,700 feet of crosscuts, drifts, and tunnels. The Little Albert mine has about 1,400 feet of crosscut tunnels, which connect with 2,100 or 2,200 feet of drifting. The Champion Dirt is developed by the Centurion tunnel, which is about 1,100 feet in length and connects with a shaft and drifts on four levels aggregating about 2,100 feet in length; and also by six tunnels which connect with a total of nearly 1,500 feet of drifts. The Harrison and Union mine develops the vein by means of a shaft from which drifts run, and by a tunnel 60 feet in length connecting with a drift on the vein. In the Morgan mine the workings on the vein all connect with the shaft.

NATURE OF WALL ROCKS.

The veins lie in an area of gneiss intruded by dikes of pegmatite. As a rule the gneiss strikes northeast and southwest and dips toward the west. In the Donaldson mine workings the gneiss is chiefly of the compact granitic variety, but farther west, in the Kelly mine, considerable micaceous gneiss is present. Near the Morgan mine both walls are composed of granite, and a small amount of granite also appears in the southwest end of the Centurion tunnel level on the Champion Dirt vein.



HORIZONTAL PLAN OF DONALDSON-CHAMPION DIRT MINE WORKINGS.



GEOLOGICAL PLAN OF DONALDSON-KELLY MINE WORKINGS.

Porphyry dikes are encountered in some of the workings of the different mines. Most of the porphyry, however, is altered almost beyond recognition. Bostonite porphyry was found in the west end of the second level below the Centurion tunnel. In the Kelly mine a much altered white, shelly, banded porphyry, possibly of the alaskitic variety, forms a dike from 2 to 8 feet wide. This same porphyry body was also encountered near the breast of No. 2 tunnel on the Donaldson. A 40-foot dike of altered bostonite porphyry which occurs on the surface just southeast of No. 0 tunnel on the Donaldson vein forms the foot wall of the vein for a distance of more than 100 feet from the mouth of the tunnel, and then disappears to the southeast, behind the pegmatite and gneiss which come in on the foot wall.

COMPOSITION OF VEINS.

The ore found throughout this whole group of veins consists chiefly of pyrite and quartz, which, according to the miners, carry gold values almost exclusively. According to the reports of the Director of the Mint for the years 1890 to 1892, however, which give figures representing the production of the different metals, the silver output seems to have averaged about one-fourth the value of the gold output. A little siderite or ferruginous rhodochrosite is also associated with the quartz. The pyrite, which is as a rule only slightly cupriferous, occurs both in the massive and in the crystalline forms, associated with either massive or crystalline vein quartz. Cubes of pyrite fully 2 inches in diameter were seen in ore from the Centurion tunnel, but the crystals had evidently been severely strained subsequent to deposition, and crumbled readily.

Some of the ore obtained along different parts of the vein is pegmatite or gneiss heavily impregnated with pyrite; elsewhere these rocks have been completely replaced by the pyrite.

On the 50-foot level below the Centurion tunnel a small pocket yielded about 700 pounds of ore, which consisted of massive galena and chalcopyrite, associated with smaller amounts of pyrite, "gray copper," and siderite or ferruginous rhodochrosite.

The best ore taken from the Donaldson mine is reported to have been oxidized ore averaging 6 ounces to the ton in mill-run lots. At the time of the visit to this mine a little desultory work was being done by lessees, who were obtaining a small quantity of oxidized ore, consisting of quartz, limonite, and yellow clay, which is said to have averaged from 2.25 to 2.36 ounces of gold to the ton. According to some of the miners, the last shipment of ore taken near the west breast of the Centurion tunnel level yielded 4.74 ounces in gold and 4 ounces in silver to the ton.

The Mount Vesuvius vein, although it has produced little ore, is said to have yielded some fine specimens of free gold.

PRODUCTION.

The output from the group at the time of the examination was not large, as the portion of the main vein developed through the Centurion tunnel was the only section of the vein which was being actively developed, and was yielding much ore. However, in times past the production from this group has been large, and the total has been estimated to be nearly $500,000.

DONALDSON MINE.

The main vein, after being extensively developed in the Wheatland mine, some of the workings of which extend along the part of the vein crossing the northern boundary of the Georgetown quadrangle, is opened up by the different levels of the Donaldson mine. (See Pl. LXXI.) In the Donaldson workings the main vein strikes N. 60° to 65° E. and dips 25° to 30° NW. To the west this vein splits into two parts; the southern branch continues with approximately the trend of the main vein and the northern branch swerves slightly northward and then continues S. 75° to 85° W. to the Kelly mine workings.

Toward the west end of the No. 2 Donaldson tunnel there is a dike of white highly altered porphyry (probably alaskite porphyry), which shows in places banded and glassy contact phases. This porphyry extends along the drift for only about 40 feet; on the east its contact turns into the vein wall and on the west it narrows and wedges out. It is probably the same dike that runs along the inner drift on the Kelly No. 4 mine and forms the hanging wall of the small stope near the breast of that drift. On the surface what is probably the same dike was found about 250 feet north of the mouth of the No. 2 tunnel.

The line of the junction of the two branch veins with the main vein pitches slightly in a west-of-north direction, owing to the fact that the south branch has in general a slightly flatter dip than the north one. The north branch is inclined from 30° to 35° N., whereas the dip of the south branch ranges from 20° to 35° at various points. Although not yet located, the junction of the two branches probably reaches the surface somewhere between the No. 0 and No. 1 tunnels, as the fork in the vein, which occurs on all the levels below No. 1 Donaldson, is not found on No. 0 level.

Most of the ore in the Donaldson mine occurred on the main vein at and immediately east of the junction of the two branch veins, and the part of the vein to the east of this union is almost entirely stoped out between the different levels up to the surface. On No. 3 level the length of this ore body was 275 feet, on No. 2 level it was 175 feet, and on No. 1 level the junction occurs at a distance of only about 60 feet from the mouth of the tunnel.

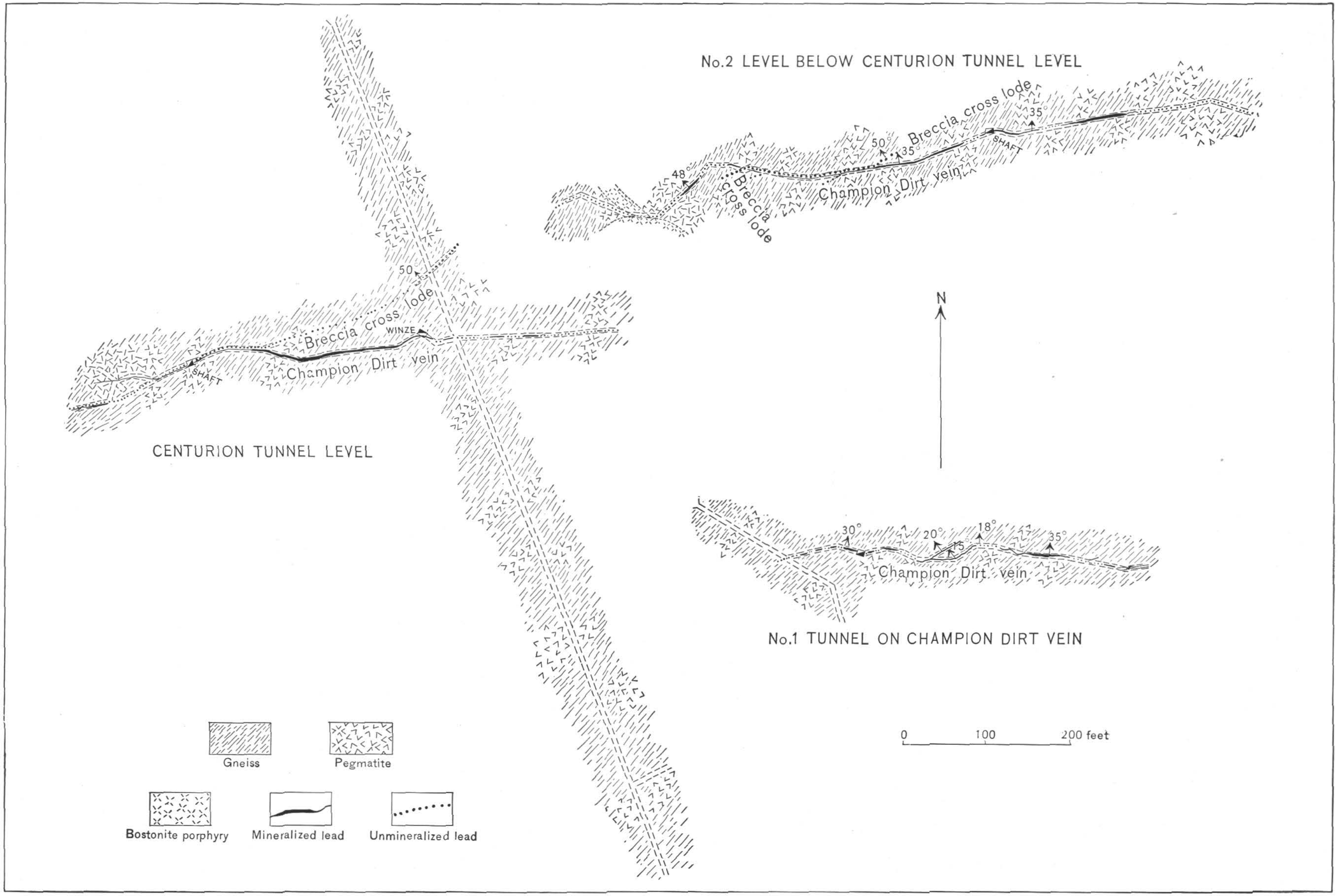
Both of the branch veins also carry considerable ore near the junction, but the south vein, although heavily mineralized near the point of union, diminishes in strength rapidly toward the west and gradually becomes inconspicuous through branching. The north vein, however, carries considerable low-grade ore to the point where it leaves the Donaldson workings, and stopes from 20 to 40 feet in height are common on most of the levels. A little more than 200 feet west of the main fork in the vein a minor branch vein enters the north vein, and at this junction also there was a rich ore shoot, about 20 feet wide, which was followed from a point below No. 2 level to a point halfway between No. 1 and No. 0 levels. On No. 0 level a 40-foot dike of porphyry with conspicuous large feldspar phenocrysts (probably altered bostonite) forms the foot wall of the vein for a distance of more than 100 feet from the mouth of the tunnel. For most of this distance there was no stoping, as little ore was encountered. From the point where the porphyry dike disappears behind pegmatite and gneiss, however, the vein is stoped for a distance of nearly 100 feet along the drift.

An interesting feature well shown by the Donaldson mine workings is the relation of the sulphide-ore zone to the oxidized portion of the vein. The original vein filling consists of streaks of slightly cupriferous pyrite, tightly adhering to the wall rocks. The oxidized zone is 40 to 70 feet deep and follows approximately the configuration of the present topography for the whole length of the northeast hill slope. The oxidized material is a porous, skeletal mass of quartz from which the sulphides have been disolved, or of quartz and limonite. Soft light-yellow to brown clay is also present in many places.

KELLY MINE.

In the Kelly mine the workings are very tortuous. The vein developed on the No. 1 level of the Donaldson mine was followed up an inclined passageway until it connected with a drift on No. 3 level of the Kelly mine, and along this drift for 40 or 50 feet to the point where the vein, which dips 35° N. and trends a little south of west, enters the south wall of the drift. The drift just mentioned continues N. 78° W. along another and steeper lead dipping 65° N., which emerges from the north wall of the drift near the same point. This last vein, where developed, shows but little mineralization. It is very likely that exploratory work will show another vein (the continuation of the lead which entered the wall) south of the west end of the drift, though whether it will be well mineralized can only be determined by actual development work.

Although a connection also exists between the Donaldson No. 2 and the Kelly No. 4 levels, this connection was not open at the time of visit. However, in the portions of the two levels adjacent to one another the vein in each level has white shelly porphyry either immediately at or a short distance from the north wall, showing the probable identity of the veins. Some ore was obtained from a narrow stope extending a little way above and below the drift at the east end of the fourth level on the Kelly, but the vein followed westward from this point shows but little evidence of mineralization.



GEOLOGICAL PLANS OF SEPARATE LEVELS, CHAMPION DIRT VEIN.

For the whole distance exposed this vein has a 2- to 8-foot dike of white porphyry of very irregular trend as its northwest wall or is separated from the porphyry either by a breccia zone 2 feet wide or (where the porphyry loops away from the contact to the north) by from 1 to 25 feet of pegmatite and gneiss. In places the porphyry dike dips to the north only 10° to 30° from the horizontal. The same porphyry dike, with a width of 3 to 6 feet, is encountered on No. 3 level, where, although close to the vein near its southwesternmost exposure, it is about 100 feet distant where exposed farthest northeast. Near the latter portion of the dike a minor clay and crushed-rock lead follows the northwest contact of the dike, lopping off protuberances of porphyry here and there, and as it approaches the breast of the drift this lead enters the porphyry and crosses nearly to the foot-wall side of the dike, which is here only 3 feet wide. It then splits into two light-colored clay leads, each one-half inch in thickness, one of which swerves back to the hanging-wall side of the dike and the other one follows the foot-wall side. In the breast of the drift this porphyry is marked by a series of curved concentric varicolored lamellæ, which have probably resulted from contraction attendant on the loss of a part of the bulk by alteration. The banding is probably due to the concentration of iron and other colored oxides along the planes of weakness between the lamellæ thus formed. Similiar occurrences of banded porphyry have been described from the Mercur mining district in Utah.[a]

LITTLE ALBERT MINE.

Practically all of the ore obtained in the Little Albert mine is reported to have come from the upper workings located near the surface. However, all these upper four levels were caved shut, and the lower and more recently run tunnels Nos. 5 and 6 were not visited. The general trend of the vein where still exposed on No. 4 level is N. 70° E., and the dip at the point where a winze to No. 5 level is situated is 55° NW.

CHAMPION DIRT OR CENTURION MINE.

Champion Dirt vein.—In the Champion Dirt mine the vein has a general strike of N. 80° to 85° E. On the levels connecting with the shaft leading down from the Centurion tunnel level it dips from 35° to 48° N., and on the upper tunnel levels the vein ranges in inclination from 15° to 60° from the horizontal. The flattest dip was noted on the Champion Dirt tunnel No. 1, at a point where the vein splits and loops around a large horse of rock. (See Pl. LXXII.) In the upper levels, near the surface, the vein zone is 2 inches to 1½ feet wide, and usually comprises a series of quartz stringers (many of which show comb structure), in gneiss and pegmatite. Although some of this quartz carries a little sulphide ore, the ore is usually a soft brown oxidized material which either runs in a streak beside the quartz or occurs in cavities in it. On the lower levels connected with the Centurion tunnel, however, the vein consists either of solid streaks of massive pyrite and quartz ore, separated from the wall rocks on each side by gouge selvage, or of pyrite and quartz stringers in gneiss and pegmatite. In places, however, pyrite ore seems to have been formed by a replacement of the gneiss or pegmatite adjacent to the fractures.

Near the west end of the drift on the second level below the tunnel level the Champion Dirt vein cuts through a dike of bostonite porphyry and appears to have offset the north portion of the dike 25 to 35 feet to the west of the south portion.

Postmineral movement.—An interesting fault zone having its origin subsequent to the period of deposition of the ore was noted crossing the Centurion tunnel about 220 feet from its mouth. At this point there is a band of soft breccia from 2½ to 4 feet wide, containing crushed and angular fragments of gneiss, pegmatite, quartz, and pyrite ore, embedded in a gouge matrix. A few fragments of porphyry were also noted in the vein at this point, though no porphyry was observed in place within several hundred feet.

Although low assay values have been obtained from this material, no pay ore has been struck and all the values are probably from ore "drag" from the older mineralized vein. This

[a] Spurr, J. E., Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1895, p. 413.

fault zone enters the wall, trending S. 47° W., and was encountered again on this same level, at the point where it emerges from the north wall of the drift on the Champion Dirt vein, 200 feet west of the Centurion tunnel. The breccia zone, after joining the main vein, runs along in contact with it to the west breast of the tunnel-level drift, a distance of 225 feet or more. On the second level below the tunnel level, however, the same soft zone joins the Champion Dirt vein at a point about 125 feet west of the shaft, and then, after following the hanging-wall side of the main vein for a distance of 150 feet, cuts through the vein and disappears in the rocks on the foot-wall side. (See Pl. LXXII.) At the point where it cuts through it faults the main vein, causing an offset and gap between the two faulted ends equal to its own width—about 3 feet. Where the vein and the breccia zone were in contact, the continuous streak of hard pyrite and quartz ore which usually exists in other portions of the Champion Dirt vein was badly broken up by movement and in places mixed with so much crushed and triturated wall rock that what would normally have been good ore was rendered valueless.

Occurrence of ore bodies.—Considerable stoping was done years ago in the upper tunnel levels on the Champion Dirt vein, and a good deal of ore was taken out. A series of small stopes separated by low-grade pyrite and quartz streaks several inches wide were also made in tunnel level No. 1. There are large stopes in the workings connecting with the Centurion tunnel, the largest of these being immediately east of the point where the broad, soft breccia zone joins the main vein, but they do not extend far east of the shaft on any of the levels. In the upper levels minor branches enter the main vein and here and there the points of junction seem to have been the seats of somewhat more extensive ore deposition, but on levels connecting with the Centurion tunnel branches to the main vein are rare.

HARRISON AND UNION MINE AND MORGAN MINE.

The Harrison and Union mine and the Morgan mine were both inactive at the time of visit, and as no one in authority could be found the underground workings were not examined. Each of these mines is said to have yielded a little ore, although the development in them is slight in comparison with that done at other points along the main vein. The vein, where intersected by a 60-foot crosscut tunnel 100 feet west of the Harrison and Union shaft, has a trend of N. 85° W. and a dip of 45° to 50° N. Farther west on the surface, however, the vein ranges in trend from N. 85° E. to N. 70° E.

In the vicinity of the Morgan mine a vein which is supposed by the miners to be a continuation of the Harrison-Champion Dirt vein is entirely in granite and has a dip of only about 20° NW.

OLD SETTLER MINE.

HISTORY.

The Old Settler mine, which is situated at the summit of the divide separating Turkey Gulch from the valley of Trail Creek, was discovered in 1860, and in the following few years yielded large quantities of rich oxidized quartz ore from points near the surface. With depth, however, sulphide ore carrying less values came in and the mine became less remunerative, and consequently little work was done for years. In 1884 work was resumed for a short period, but at the time of visit the mine had again long been idle, although some work was contemplated.

DESCRIPTION OF VEIN.

The vein consists of a very irregular lead, striking approximately east and west and dipping to the north. The vein is developed by a series of levels running from an inclined shaft following the dip of the vein, which near the surface is 50° NW. but flattens below to 30°, so that the dip nearly corresponds with the north slope of the hill. The workings are mainly in micaceous gneiss, the schistosity of which has a strike parallel to the vein but a somewhat flatter dip.

The vein on the first and second levels consists of a soft crushed-rock lead heavily stained by iron oxides, of a granulated mixture of crystalline and massive pyrite with quartz, or of a series of small pyrite stringers in gneiss. The pyrite, especially on the lower level examined, carries considerable copper and the walls in many places show traces of copper sulphate and also of the carbonates azurite and malachite. Near the surface the soft oxidized ore has practically all been stoped out for some distance on either side of the shaft.

CHARACTER OF ORE.

It is reported that the best ore recorded from this mine, as shown by the old Freeland smelter-return sheets, gave values of 3 to 4 ounces in gold to the ton and 22 per cent of copper. Assays of 3 ounces in gold and 5 per cent of copper have also been obtained, but most of the cupriferous pyrite ore ran less than 1 ounce in gold to the ton. Some pyrite ore associated with a black sooty copper sulphide, probably chalcocite (Cu_2S), is said to have averaged 0.85 ounce in gold per ton. The production from this mine has been considerable, but as most of the records have been lost its total production is unknown; probably, however, it is at least to be valued in the tens of thousands of dollars.

STANLEY-LITTLE MATTIE GROUP.

STANLEY MINE.

HISTORY AND PRODUCTION.

According to Hollister,[a] the Whale Mining Company was organized in 1864 to develop the Whale lode and other lodes of the vicinity. This is the lode which is at present known as the Stanley. In 1871[b] development of the Hukill lode was begun by John M. Dumont. The lode known by this name is the portion of the Stanley vein which lies on the northern side of Clear Creek. The identity of the Hukill and Whale lodes was afterward established by drifts along the vein beneath the creek. In June, 1878, the Hukill and Whale mines were consolidated. At present the property is known as the Stanley and is owned by the Stanley Mines Company, of which A. G. Brownlee is president and general manager.

The Hukill lode, or that portion of the Stanley vein which lies on the northeast side of Clear Creek, is reported to have paid well from the start. Development was begun in 1871, and at the end of five years the mine was sold for $200,000. The excavation of 1,600 feet of adits, drifts, and shafts had returned, besides a large amount of low-grade ore, 1,700 tons which sold for $195,200. The cost was $167,140 and the profit $20,060. The average yield was $114.82 per ton. From 1871 to the summer of 1879 the Hukill mine yielded $55,000, of which $25,000 came out in the last two years. In 1879 the mine was bought by the same Californians who had bought the Freeland, and passed under the management of F. F. Osbiston, an experienced Comstock miner.

The total production of the Stanley mine to date is rather uncertain, but is estimated to be $3,600,000 by Colonel Brownlee, the present manager.

From $25,000 to $75,000 worth of ore is roughly estimated to have been shipped from the Crockett vein, which is a branch of the Stanley and is situated on the southwest side of Clear Creek.

GENERAL DESCRIPTION OF VEIN.

The Stanley vein extends from a point beyond the northern boundary of the Georgetown quadrangle southwestward across Clear Creek and up the slope of the ridge between Clear Creek and Spring Gulch. Midway of this slope is the Golden Link shaft, which has been sunk on the vein. Farther southwest the vein splits and the branches as they cross the summit of the ridge and descend into Spring Gulch diverge to the southwest, the western branch probably uniting farther southwest with the Niagara-Lord Byron vein. The mines situated along Spring Gulch, including the Niagara, Lord Byron, Fraction, Kitty Clyde, and Gomer, are situated on veins that either run together in such a way as to prove their identity or overlap one upon

[a] Mines of Colorado, 1867, p. 234. [b] Fossett, Frank, Colorado, 1880, p. 368.

the other with relatively little distance between and form a zone of veins which taken together may be considered as a general trunk lode, of which the Stanley, Phoenix, and Cardigan veins are probably extensions.

On leaving Spring Gulch the trend of the Stanley deviates to the east of the general northeast strike of the trunk vein, but recovers this typical northeast direction near the Golden Link shaft and preserves it from this point on. Near Clear Creek the Stanley splits into two branches, slightly divergent from one another to the northeast. The exact point at which this bifurcation takes place is reported to be about 200 feet west of the Stanley shaft house, which would be near the mouth of the Road level. Of these two branches the more northern is the principal one and retains the name of the Stanley vein; the other is called the Crockett. At the Crockett shaft, situated on the northeast side of Clear Creek, the south branch, which strikes N. 57° E. and dips 80° NW., is located a few hundred feet southeast of the Stanley vein.

The underground workings of the Stanley show the same change in the strike of the lode as was observed at the surface. Near the Golden Link shaft there is a sharp curve to the northeast, beyond which the vein has almost a due northeast strike, whereas to the southwest the strike is more nearly east and west.

MINE WORKINGS.

The Stanley mine is developed by tunnel drifts which follow the vein from the surface into the mountain which lies on the southwest side of Clear Creek. Of these tunnels the chief is the Road level, which starts in near the bottom of the creek. Above this one to the southwest come the Whale, York, Golden Link, and smaller tunnel drifts. On the opposite or northeast side of the creek is the Hukill tunnel. The vein has also been developed by inclined shafts following down the dip of the vein. Of these the most important is the main or Gehrman shaft, which starts in Clear Creek valley on the level of the Road tunnel and follows the vein downward. Eight levels start from this shaft below the Road level. Another important shaft is the Golden Link, which starts at the outcrop of the vein about halfway up the mountain ridge to the southwest and follows it down to the Road level. The general dip of the vein as shown in these workings is about 60° NW.

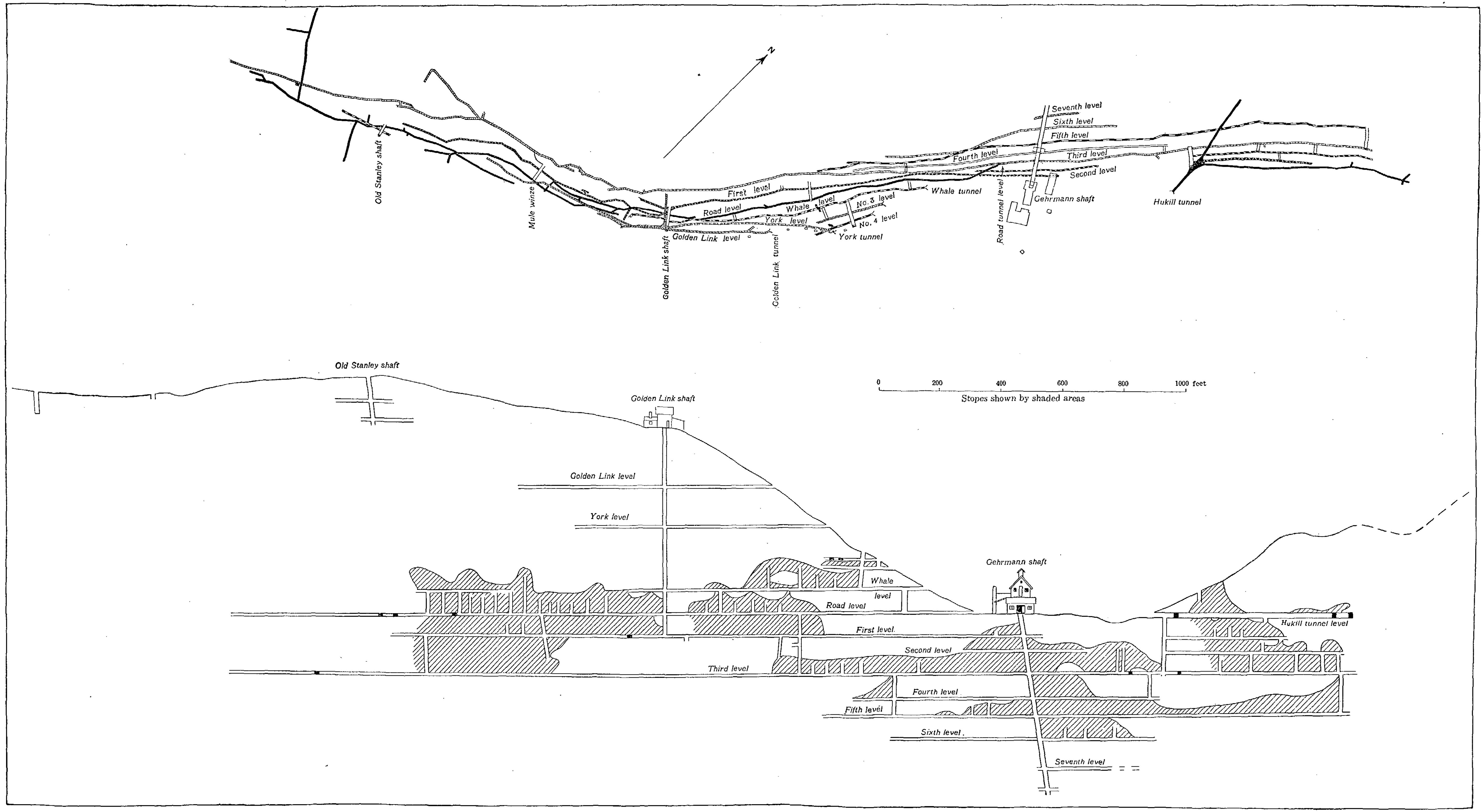
The underground workings of the Stanley (Pl. LXXIII) have developed the vein along the strike for a distance of about 4,000 feet, and the difference in elevation from the highest outcrops of the vein to the lowest workings is not far from 1,500 feet. In all, the mine maps show over 4 miles of drifts and inclined shafts.

PHYSICAL NATURE OF VEIN ZONE.

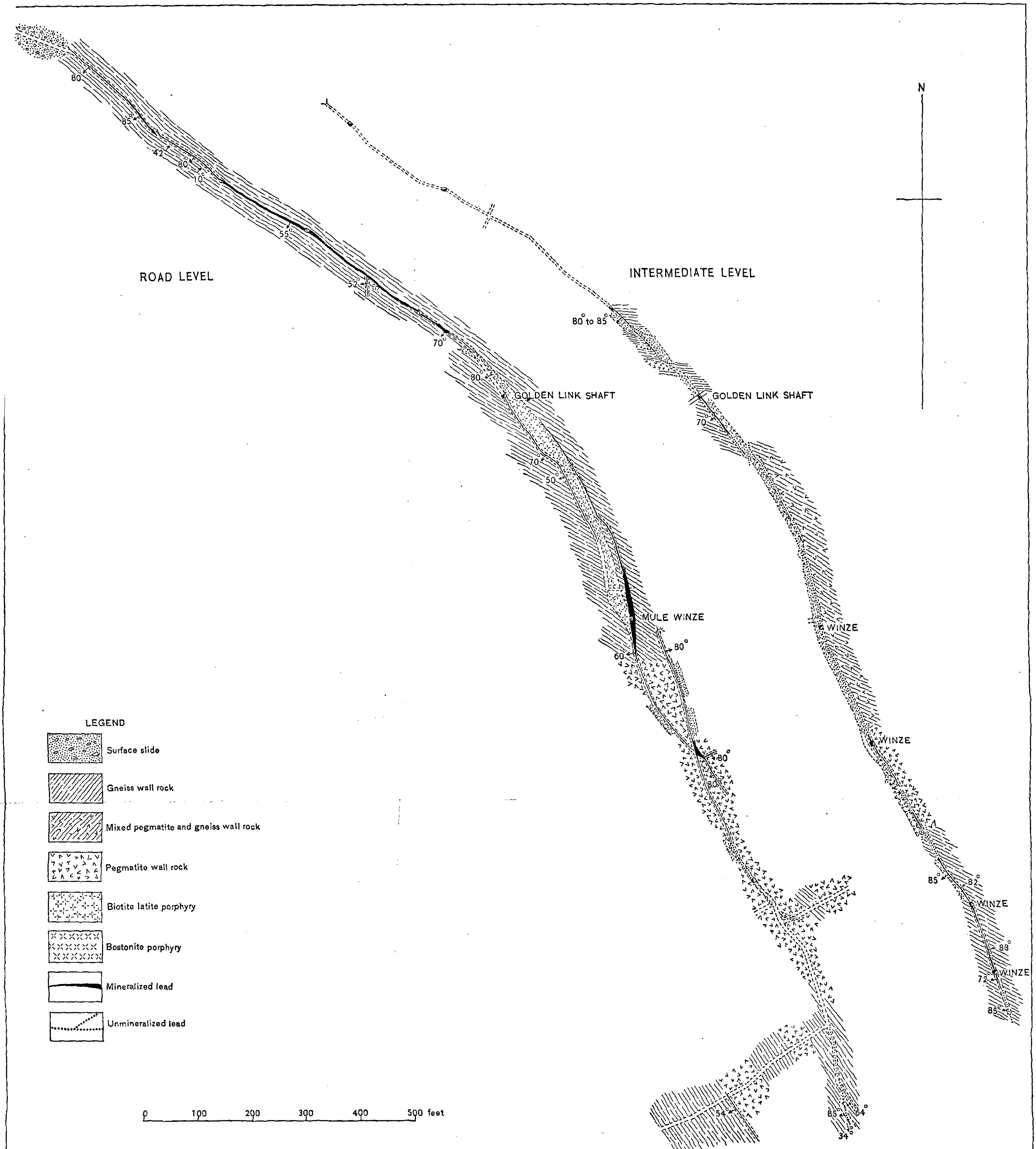
The Stanley vein follows a zone of crushing, sheeting, and faulting. This zone, as explained on page 130, is of compound origin and records repeated movements. The vein is formed mainly along a single zone, which in accordance with most of the veins of this region shows local branching. The most important branch noted underground is that which on the Road level is called the Joker vein. The junction of this vein with the main lode takes place about 750 feet southwest of the Golden Link shaft. The branch is nearly parallel with the trunk vein, but diverges from it in general in a northeasterly direction. It is a strong vein, which has been followed for more than 200 feet from the junction. The dip of the Joker vein on this level is 80° S., but that of the Stanley near the junction is 60° N., which is the normal dip for the trunk vein. The Joker vein therefore probably runs into and unites with the Stanley above the Road level. What is probably the same branch was noted on the Whale or Intermediate level, 83 feet above the Road level, but was not drifted on.

About 800 feet from the mouth of the Road level another branch diverges from the main lode, as shown in the plan (Pl. LXXIV). This branch is a fairly strong crushed zone containing several streaks of pyritic ore.

At the surface on the north side of Clear Creek the local splitting and reuniting of the Stanley vein is well illustrated.



HORIZONTAL AND VERTICAL PLANS OF STANLEY MINE WORKINGS.



GEOLOGICAL PLANS OF SEPARATE LEVELS, STANLEY MINE.

NATURE OF WALL ROCKS.

The principal wall rock of the Stanley vein is gneiss of different varieties, some siliceous and quartzose, some dark and biotitic, and some hornblendic. Considerable pegmatite is present, generally in small bodies intrusive into the gneiss. Two distinct varieties of porphyry occur also in places forming the walls. One of these rocks is a bostonite and the other a biotite latite.

COMPOSITION OF VEIN.

The chief gangue material is quartz; the metallic ores consist mainly of pyrite and also considerable galena and chalcopyrite. Tetrahedrite is reported to have been encountered in some places in important amount. The ore where it is now being worked is stated to have, after being sorted, an average value of $40 to the ton. It contains 1 to 2 ounces of gold, 20 to 40 ounces of silver, 25 to 30 per cent of lead, and 2 to 3 per cent of copper. The zinc in the mine is insufficient to figure in the smelter returns.

A little siderite was noted in the mine, some crystals of this mineral forming free in vugs. Cherty silica was also noted as one of the last minerals to be deposited, forming a coating in the walls and geodes.

STUDY OF THE DEVELOPMENT OF THE LODE.

Older wall rocks.—The oldest rocks of this region are gneisses, into which pegmatites have been injected. All these rocks are of pre-Cambrian age. In general the gneiss belongs to the Idaho Springs formation and consists of quartz, biotite, and feldspar in varying proportions, so that in some places the rock is hard and quartzose and in others soft and biotitic. In general the rock is fairly rigid and is of a character to yield strong and persistent fractures when stress is applied to it.

First porphyry intrusion.—The line of weakness occupied by the Stanley vein was, so far as we know, initiated at the time of the intrusion of the porphyry dikes, which occupy a belt in this country roughly coincident with the belt of mineral veins. The formation of the primary northeast fracture was followed by the intrusion of the porphyry dike. Only shreds of this dike are recognizable at present, as it has been torn apart and displaced by repeated reopening and differential movement along the original fissure zone. This older porphyry is a bostonite and has been recognized by Mr. Ball as similar to the other bostonite dikes which he has traced on the surface in this region. In hand specimens the rock shows large phenocrysts, many of which have a reddish tinge. A specimen from the wall of the Joker vein in the Road level shows under the microscope large feldspar phenocrysts, partly of orthoclase and partly of a finely striated feldspar, possibly anorthoclase. There are also pseudomorphs of decomposition products after entirely altered pyroxene. The groundmass has a trachytic structure and consists of moderately small crystals, mainly of feldspar. The edges of this dike are hard and dense on account of the more rapid cooling.

Two unconnected fragments of this dike have been recognized by Mr. Ball near the outcrop of the vein on the surface. These fragments, which occur on the ridge on the south side of Clear Creek, have a northeast strike and are aligned in a northeasterly direction.

Underground the bostonite porphyry is recognized on the Road level in two localities, one on the hanging or north wall of the Stanley and another on the south wall of the nearly parallel branch vein called the Joker. These two streaks are not aligned but are nearly opposite one another. They are shown by drifts and prospects to be also of limited extent. Their separation and lack of continuity is to be explained by the repeated faulting (essentially strike faulting but with minor concomitant transverse and oblique displacement) which is proved to have taken place since the bostonite intrusion. On the Intermediate level, 3 feet above the Road level, the bostonite porphyry is found on the north side of the Stanley vein from 850 to 1,050 feet southwest of the Golden Link shaft and not elsewhere. The position of the strips above described on the Road level is from 500 to 700 feet southwest of the same shaft. Thus a combination of the observations on the two levels shows that strips of the dike occur along the vein for a distance of 550 feet at least, and proves that the extension of this older dike is the same as that of the later dike, mineral vein, and friction conglomerate which will presently be described.

Later porphyry intrusion.—At a distinctly later time than the intrusion of the bostonite porphyry, the line of weakness occupied and cemented by the bostonite dike was reopened and again filled and cemented by a later dike of quite different composition and appearance. This later dike is a biotite latite. It incloses angular fragments of the earlier bostonite porphyry, as well as of pegmatite, gneiss, and alaskite. This later porphyry under the microscope shows a fine trachytic groundmass containing abundant phenocrysts of quartz, feldspar, and biotite. There is considerable magnetite and apatite; zircon has also been noted. This dike belongs to a series determined and mapped by Mr. Ball. The dikes of this series have a northeast strike and are aligned in a northeast direction along Chicago Creek, where they occur at intervals for a distance of more than 4 miles. The dike which occurs in the Stanley is the only one known of its kind outside of the group mentioned. It lies about 2½ miles northeast of the northeasternmost of the dikes in the group, at a point which is only a little out of line with the general trend of this string of dikes.

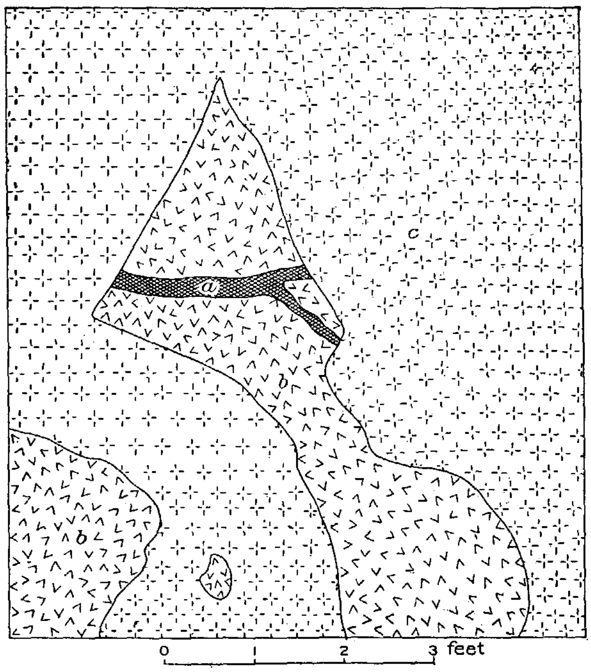


FIG. 131.—Biotite latite porphyry (*c*) from the Stanley mine, containing angular blocks of pegmatite (*b*) with galena-pyrite ore seams (*a*). Shows intrusion subsequent to ore deposition.

The Stanley latite dike was not recognized by Mr. Ball on the surface, although the exposures here are good. It is probable, therefore, that it does not outcrop, the upper portion of the dike having been faulted, brecciated, and effaced by the later differential movement along this line of weakness.

Periods of mineralization.—The data accumulated by a study of the Stanley mine point rather clearly to the conclusion that the formation of the Stanley vein took place mainly between the bostonite intrusion and that of the latite. Subsequent to the injection of the bostonite dike renewed stress in the rock reopened the old fissure and afforded a channel that was occupied and traversed by mineralizing waters, which finally cemented this new fissure with sulphides and quartz.

Observations show that the period of this mineralization was essentially subsequent to the bostonite intrusion and older than that of the latite. The breast of the drift on the Joker vein on the Road level shows the vein running through the middle of the bostonite dike, which is here only 3 feet thick and is hard and dense. The vein is a strong, unbroken one at this point, consisting of quartz with considerable pyrite.

On the other hand, angular inclusions of vein material corresponding exactly with the ore which has been mined have repeatedly been found in the younger porphyry. This fact has been proved both by observations on a large scale and by microscopic work. Fig. 131 shows large angular fragments of the vein embedded in the dike. Observations have also been made indicating that the flowage in the porphyry dike continued in some places after the catching up of old fragments into its mass. The result of this flowage of the viscous magma is especially noticeable near the contacts, where streaks of galena, pyrite, quartz, etc., have been drawn out together with the igneous rock into fine wavy metallic threads.

It is thus shown that a considerable amount of the ore deposition took place between the two periods of porphyry intrusion. Other considerations indicate that practically the whole formation of the vein was included in this interporphyry period. The strongest, widest, and best portion of the vein as a rule lies entirely within gneiss walls. The great stope seen on the Road level extends for 500 feet within gneiss walls, but becomes discontinuous and weak where the latite dike enters the vein zone, as seen on the plan. The general relation of dike to veins, as shown on this plan, suggests that the former has been intruded into the latter. Some ore is found at intervals on both sides of this intruded dike but without the same continuity as is characteristic farther northeast, where the dike is not present. The situation suggests that the mineral vein has been split open subsequent to the mineralization; that in places the chief fissure ran along the center of the vein, as the brittle sulphides were more easily fissured than the wall rocks; and that the igneous mass was injected into this fissure, to both walls of which fragments of the vein still adhered. This fissuring of the vein, leaving fragments of ore clinging to both sides of the opening, is exactly like what took place in the Griffith vein, as already described. The difference between the Griffith and the Stanley veins is that in the latter the fissure was filled by an igneous injection of porphyry and in the former it was cemented by a deposition of minerals from solution, which, however, were of a character so strikingly different from those of the original mineralization that the history of the vein is quite as clearly recorded for one period as for the other.

A considerable proportion of the drifts in the Stanley mine follow the contact of the latite dike. The dike shows the typical fluted contact due to a molding of the plastic magma into the laminæ of the gneiss, as was described in the discussion of the Colorado Central dikes. Considerable reaches of this contact are marked by no trace of mineralization, and where ore does occur between the dike and the gneiss it stops abruptly in many places as if cut off by the intrusion.

As further evidence that the main mineralization occurred previous to the latite intrusion is to be cited the fact that the latite shows very little subsequent mineralization and moreover is relatively fresh, as it could hardly be if it had been subjected to attack by strong mineralizing solutions. This is the freshest porphyry noted in the district in association with an ore deposit. The almost unfailing rule for the porphyry associated with the vein is that the igneous rock is highly altered, so that this is a striking exception.

In a few places the later porphyry was observed to be traversed by pyritiferous quartz veins representing the mineralization subsequent to its intrusion. One such instance was noted in a specimen taken from the foot wall of a dike, at the contact with the gneiss, in the crosscut on the Road level, about 60 feet northeast of the mule winze. The porphyry near these quartz veinlets is more altered than usual. However, there is no ore streak at this point, which is separated from the ore vein on the southeast by 10 or 15 feet of gneiss. This vein has been stoped and lies entirely in gneiss. It probably represents the main mineralization, older than the latite.

The watercourse along which the Stanley vein formed, in the interval between the intrusion of the bostonite and that of the latite, must have been in part an open rubble-filled fissure like that in which many of the veins of the Silver Plume region were, in part at least, formed, as, for example, the Mendota. This fact is indicated in the Stanley mine by the same phenomena as observed in the Mendota and other veins of this type. In the Hukill tunnel, and also in the Intermediate level, places were observed where the original vein consists of a cement of quartz, pyrite, chalcopyrite, and galena around angular fragments of gneiss, pegmatite, and bostonite porphyry.

Formation of friction conglomerate.—Subsequent to the injection of the latite dike the old fissure was again reopened by a renewal of rock stress similar to that which had caused the successive reopenings marked by the successive cementations by the bostonite porphyry, the mineral vein, and the latite porphyry. This postlatite reopening was marked, as were the earlier ones, by differential movement along the walls of the fissure zone, bringing about brecciation and faulting of the earlier cementing materials, including both the porphyries and the vein minerals. One of the most striking results of this last movement was a breccia, many of whose component fragments are subangular or even perfectly rounded, and which may therefore be called a conglomerate. The evidence is plain that these rounded forms are due to the rubbing of one fragment against another in the course of the differential movement of the walls, so that the deposit may be styled a friction conglomerate. This conglomerate zone runs along the vein or along the porphyry and ranges up to several feet in thickness. The fragments in this breccia consist of both the bostonite and latite porphyries, the various older wall rocks, and the vein materials. The crushing and subsequent dragging out by faulting have been locally at least very extensive, and large sections of the dikes and veins have been involved and mingled with fragments of gneiss in a heterogeneous mixture. As the exact plane of movement represented by this friction conglomerate did not always coincide exactly with the earlier movements along this zone, the breccia in some places follows the contact of the core of the porphyry and in others cuts obliquely across these older formations, shearing them off. For example, on the Road level near the mule winze the latite dike is cut off by the friction conglomerate. Farther on, along the same level near the principal crosscut to the south, the same breccia zone also faults the latite dike, separating it into two portions which are 15 to 20 feet from one another measured along the strike. Still farther southwest, beyond the point where the latite porphyry leaves the drift, the lead which has been followed consists only of a slip and breccia representing this last period of differential movement and containing practically no ore.

This portion of the drift is probably off from the original lode, which may lie to the south and from which the line of the last movement seems to have here, as elsewhere, locally deviated. An instance of deviation of the line of the friction conglomerate from that of the vein is shown in the Hukill tunnel, where there are two veins 15 feet apart but uniting at both ends so as to leave a horse of gneiss between. One of these veins is a solid lode of gneiss consisting of pyrite, chalcopyrite, and galena, and representing the main period of mineralization. The other vein is a breccia lode containing fragments of gneiss, pegmatite, and ore similar to that in the first-described vein, all inclosed in a gray clay matrix. Some of the angular fragments of ore in this breccia show, included within the ore, angular fragments of pegmatite and gneiss, to which the ore acts as a cement. These fragments, which are from the older solid vein, record the earlier period of opening, brecciation, and cementation; the soft breccia represents the postlatite movement.

The minor oblique and transverse faulting which accompanied the more important strike faulting accomplished by the postlatite movement is illustrated also on the Whale level about 180 feet northeast of the Golden Link shaft. Here, as seen on the map, the dike of latite porphyry is offset in such a way as to indicate faulting oblique to the vein. A specimen of the porphyry taken at this point and examined microscopically shows internal crushing and straining since cooling. The phenocrysts have been step faulted along minute close-setting fractures.

The general direction of movement along the zone of friction conglomerate is indicated by striations of the walls observed in two places on the Road level. Near the Mule winze striæ dip 60° SW., and at the end of the level they dip 34° SW.

At the time of this latest dislocation the rocks were frequently split open so as to leave open fissures. The records of these openings are especially plain in the prophyry, which was hard and brittle because it had not been subjected to the softening influences of alteration by earlier mineralizing waters. Many such open fissures in the porphyry were filled by deposits which can not be ascribed directly to crushing, but rather to infilling by water-borne detritus. The shape of these fissures indicates rending rather than shearing stress; yet the filling material is substantially of the same nature as other portions of the breccia zone where the materials have originated largely by grinding, and it is probable that the filling of the fissures was simply transferred by water from the supply of material due to attrition (fig. 132).

Under the microscope the detrital veins filling the fissures in the porphyry show the general structure of sandstone or arkose, containing rounded, angular, or subangular grains of kaolinized feldspar, quartz, microcline, etc.

Mineralization subsequent to formation of friction conglomerate.—In many places along the sides of the zones of friction conglomerate are solid residual fragments of vein material clinging to the original walls. Open fragments of this ore locally form a very large part of the breccia or conglomerate, and where present in sufficient abundance may be mined, although in many places they have been so scattered about in the breccia as to spoil the value of the vein. Aside from these fragments of included older ores, there is usually very little or no evidence of mineralization in the conglomerate. Nevertheless, there are indications that a certain subordinate amount of ore deposition has taken place, somewhat similar in quantity to that which has been inferred from observed data to be subsequent to the introduction of the latite dike. Here and there the arkose or conglomerate veins contain scattered or locally rather abundant sulphides, including galena and copper pyrite, which are not fragmental but have acted as interstitial cement to the rock fragments. This was noted both in the hand specimen and under the microscope. In the microscopic study it was observed that sulphides had thus formed in an arkose veinlet which had been injected along the fracture in the later porphyry.

In a few places this postconglomerate mineralization may have formed seams of sufficient size to be of economic value, or at least to encourage the miner to further search. On the whole, however, it has been of little consequence from an economic standpoint. More important than the deposition of sulphides has been that of silica, which has thoroughly cemented the fragmental material so as to form a rock that is in many places quite as hard and firm as the later porphyry or any of the wall rocks. Indeed, much of the hard, fine arkose is not distinguishable with great facility from some of the dense varieties of latite.

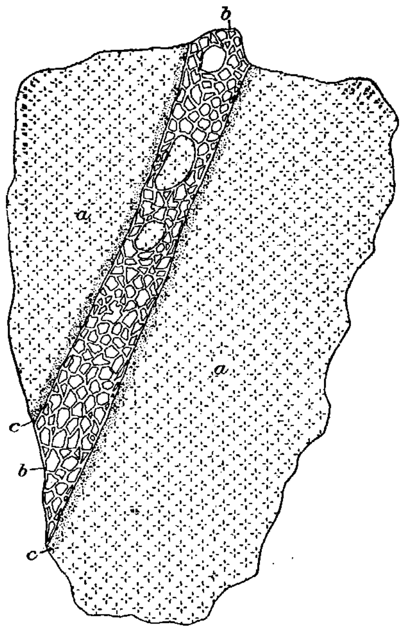


FIG. 132.—Sketch (actual size) of specimen from Stanley mine, showing biotite latite (*a*) cut by firmly consolidated small vein or dike (*b*) of fragmental material derived from granite, gneiss, pegmatite, ore, and porphyries. The biotite latite is bleached (*c*) near the walls of the dike by the waters accompanying the plastic material, which has been injected or squeezed into a fissure.

Alteration of rocks.—A specimen of gneiss from the wall rock of the lode in the Road level some distance from any porphyry when examined microscopically shows abundant calcite and chlorite as decomposition products. The original nature of the rock is not clear, but it may be a sheared and altered hornblendic gneiss. The extremely abundant calcite is probably derived from original feldspar, and the chlorite may be due to the alteration of hornblende. Orthoclase, which is present in subordinate amount, is fairly fresh, and biotite, which is more abundant, has been changed to a green color and clouded but otherwise not greatly altered. Fragments of the old gneiss forming walls to ore veinlets, the whole being included in the later porphyry (latite) dike, show under the microscope feldspars which have been entirely altered to sericite.

The bostonite porphyry is highly altered, as is rock of this type wherever it has been found elsewhere. The phenocrysts consisted chiefly of feldspar and pyroxene. The feldspar was apparently orthoclase with some finely striated probable anorthoclase. These minerals have been altered to kaolin, the alteration extending from the outside inward, so that many residual cores of comparatively fresh feldspar remain. One specimen shows the feldspar altered to kaolin and sericite. The pyroxenes in all specimens have been completely destroyed, and are represented by decomposition products, chiefly calcite, magnetite or hematite, and abundant deep-purple fluorite, which also occurs along cracks in the rock and is abundant in some particles in the groundmass. Fluorite has been frequently found by Mr. Ball in the dikes of this composition. The mineral in this case is closely associated with calcite and is of secondary origin. The presence of fluorine and carbonic acid in the waters which accomplished the alteration of the rock subsequent to its intrusion is suggested, and it is highly probable that these waters deposited the vein.

As before noted, the later porphyry is unusually hard and fresh, and the partial alteration which it has undergone is of a constant and characteristic nature. The biotites are almost invariably quite fresh. The feldspar includes both orthoclase and calcic feldspars in varying proportions in different sections, but the former on the whole predominating. Some of these feldspars are almost entirely clear and fresh. Others, though retaining their general freshness, are altered to a greater or less extent along the cleavage cracks, and locally the alteration has involved most of the feldspar. The calcic feldspars have yielded calcite on alteration; the orthoclase feldspars kaolin. In one specimen examined considerable brown carbonate was noted, taking the place of the calcite and especially abundant in the altered groundmass. In one exceptional specimen, where the porphyry contained subsequent pyritiferous quartz veinlets, the microscope showed that the feldspar phenocrysts were more altered than usual and contained secondary quartz with some sericite and kaolin.

Two interesting examples of the effects of different periods of alteration were found by microscopic study. A specimen of latite porphyry from the Intermediate level contains intrusive veinlets of arkose, whose grains are in part cemented by subsequent galena. The alteration of the porphyry is of the usual type, with fresh biotite and orthoclase almost entirely altered to kaolin, but among the fragments which occur in the arkose veinlets orthoclase of granitic or pegmatitic origin is also present and is only very slightly kaolinized. The difference of freshness presented by the veinlet and the intruded rock is striking and shows that the main alteration of the porphyry preceded the injection of the arkose.

Illustrating a different point is a specimen of latite porphyry from the Intermediate level, about 75 feet northeast of the Golden Link shaft. This porphyry incloses fragments of older ore and of older gneiss wall rock. The porphyry has fresh biotite phenocrysts and feldspar phenocrysts that are mainly fresh though partly altered to calcite. In the fragments included in the porphyry the gneiss wall rock of the veinlets contains relatively fresh orthoclase, singly striated feldspar which is partly sericitized, and blocks of entirely sericitized feldspar. This alteration is that typical of the wall rock of lodes in this region and it has been repeatedly described elsewhere in this volume. The striking difference in the alteration of the included gneiss and the porphyry shows that the gneiss was altered previous to its being taken up into the dike, and it is probable that its alteration was the effect of the solutions which deposited the vein.

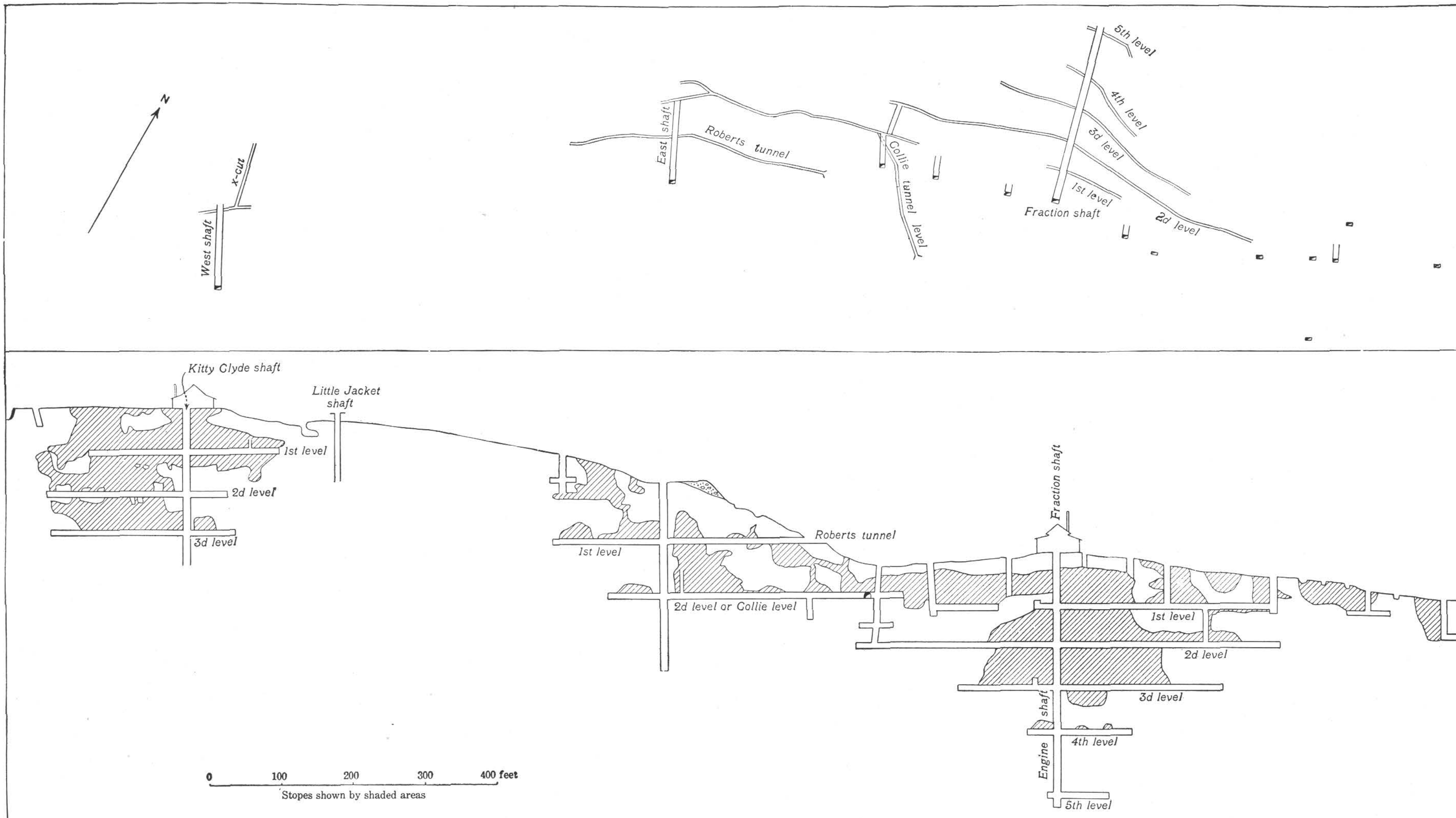
LOCATION OF ORE.

The stope projection of the Stanley mine shows an unusually irregular shaping of the principal ore bodies. The stopes do not go much above the Whale level. Above this on the Golden Link and York levels the vein is represented by a zone of breccia or friction conglomerate containing only broken fragments of ore. In this vein successive reopenings and brecciation subsequent to the main period of mineralization have worked the same result as in the Griffith. Large bodies of the original vein have been left intact or not much broken and mixed up. These constitute the greater part of the present stopes. In many places, however, the original vein has been entirely broken up for long stretches. The ore has been dragged out and mixed with so much rock breccia as to be unavailable for economic purposes.

Originally some of the best ore seems to have formed at the intersection of branches, as is common in mines in this region. On the Road level, at the junction of the main Stanley vein with the Joker vein, a large quantity of high-grade ore has formed. The first big stope in the Stanley vein coming in from Clear Creek is said to have formed by the junction of this vein with the Crockett. There was no ore on the Crockett near the junction.

SUMMARY OF GEOLOGIC HISTORY.

The history of this vein is one of repeated openings along a single zone of weakness, resulting in fissuring and accompanied by faulting. This process has been going on since a time before or at the beginning of the period of dike intrusion, and has probably not yet come to an end. The original formation of a zone of fracturing and faulting in the pre-Cambrian gneiss was followed by the intrusion of a dike of bostonite porphyry. Subsequent to the cooling of this dike the movement was renewed, the dike filling was ruptured, and oblique and strike faulting along the dike separated one portion from another, resulting in an intermittent dike marked by a string of



HORIZONTAL AND VERTICAL PLANS OF CONSOLIDATED FRACTION MINE WORKINGS.

disconnected fragments. This is the general character of dikes in this whole region, and is probably due to the same cause throughout. They were probably not originally intermittent, but have been made so by strike faulting. One of the consequences of the renewed movement was a series of porous zones of crushed material and open rubble-filled fissures. These became the channels for powerful mineralizing solutions which cemented the openings with quartz and metallic minerals. Again the renewal of strain brought about a reopening of the old break, and a dike of latite was intruded, splitting and brecciating the vein. Subsequent to the consolidation of the latite porphyry the same fissuring process was repeated, with, as before, attendant differential movement or faulting. The result was the formation of the friction conglomerate and of open fissures which were filled by detritus carried by waters from the crushed material or squeezed in, in the form of mud. Certain features in the mine, such as the presence of open fissures and watercourses, indicate that this movement has not yet entirely ceased and that the rock strains have not been fully relieved.

The main features of this history are the repeated, almost continual, movements along the same zones of weakness, and the openness and lack of great crushing along the fissures and faults. The latter feature is indicated by the evidence of the presence of open rubble-filled fissures following each violent dislocation. The friction conglomerates characteristic of many of the mines of this region have excited much comment on account of their rather unusual nature. Ordinarily the material along faults has been crushed to a paste by the tremendous shearing stresses. The fact that the fragmental material along the veins in this region has been affected almost exclusively by rubbing of one fragment against another in the course of the mass movement shows that there has been practically no grinding stress, and that the movement, even if attended by faulting, was one of rending rather than of shearing. A corollary of these deductions is that the friction conglomerate was formed relatively near the surface, and the same observation applies to a less extent to the older openings.

NIAGARA MINE.

The Niagara mine is located at an elevation of 8,440 feet in Spring Gulch, a little over 2½ miles N. 77° W. of the junction of the gulch with Clear Creek valley. The vein, which was formerly developed through a shaft, strikes N. 60° to 65° E. and dips 55° NW. The Niagara vein continues to the southwest as the Lord Byron vein; to the northeast it probably joins the vein exposed in the shaft on the crest of the hill to the northeast, which is termed the "Old Stanley shaft." The Niagara mine at one time produced considerable ore, but has long laid idle.

JAMES MINE.

The James mine, which is only in the prospect stage, is developed by two shallow shafts located in Spring Gulch, 700 or 800 feet east of the Niagara mine. The main vein, which, where exposed in the workings, has a trend of N. 62° E. and a dip of 55° to 60° NW., probably joins the main Stanley vein, of which it is either a branch or a continuation. The vein consists of a quartz and crushed rock lead 4 to 10 inches wide. Near the shaft on the James vein a branch vein enters the main vein from the N. 78° E.

LORD BYRON MINE.

The Lord Byron mine is located in Spring Gulch, at an elevation of about 8,600 feet, about 1,700 feet northeast of the Fraction engine shaft. The development consists of a shaft from which rather long drifts run on several levels. However, although extensive development work has been done, the mine is reported to have produced little ore. At the time of visit the workings were all filled with water within about 50 feet of the collar of the shaft. The vein on the surface appears to trend about N. 60° E. and to dip 75° to 80° NW.

The wall rocks in the vicinity and on the dump are chiefly gneiss, but a dike of bostonite porphyry outcrops beside the shaft house in a position corresponding to the hanging wall of the vein. The Lord Byron vein follows this porphyry more or less closely for 800 or 900 feet to the northeast, to a point where the vein splits. The southeast branch has been traced in a N. 62° E. direction continuously until it joins the vein in the Niagara mine; the northwest branch follows the southeast contact of the porphyry dike, which swerves to the N. 35° E. and was traced to the gulch several hundred feet distant.

This vein possibly continues across to the northeast side of the gulch, for a similar porphyry dike with a like trend is found on that side, and continues up the hill slope to a point between the Phoenix and England mines. A short distance northwest of the Lord Byron shaft house is a vein which, on the surface, trends N. 45° E. and dips 55° to 60° NW. This vein shows some signs of mineralization.

FRACTION AND KITTY CLYDE MINES.

GENERAL DESCRIPTION.

The Fraction and Kitty Clyde mines are located on the northwest side of Spring Gulch, a little over 2½ miles N. 80° to 85° W. of the town of Idaho Springs. These two mines develop a series of veins which formerly composed one of the most productive portions of the Stanley-Kitty Clyde vein system.

The main vein may continue to the northeast as the Lord Byron vein, but surface outcrops widely separated by the gulch to the southwest of the Lord Byron seem to indicate rather that the Fraction vein passes a short distance to the northwest of the Lord Byron shaft and thus either overlaps the Lord Byron vein or continues as a vein into which the Lord Byron runs. Between the main Fraction shaft and the Pierce shaft, about 400 feet N. 72° E., there seems to be a loop formed by the veins splitting and running around a large horse of rock.

Between the Fraction and Kitty Clyde shafts the vein swerves slightly to the south, and there is another branching, the forks diverging toward the west. The west or Kitty Clyde shaft is on the chief of these branches, which probably continues with about a S. 55° W. trend and a 48° NW. dip to the point where it is joined by the Gomer vein. Quartz leads showing some mineralization were also noted about 150 feet south of both the Kitty Clyde and Fraction shafts. These leads are approximately parallel to the main vein at the points observed, but possibly join the main vein or some of its branches farther northeast.

As little work has been done in either the Kitty Clyde or the Fraction mine for nearly fifteen years, they are practically inaccessible through caving and the filling of the lower levels with water. (See Pl. LXXV.)

NATURE OF WALL ROCKS.

No porphyry was observed either on the portion of the second level examined or on the mine dump, although about 250 feet east of the Kitty Clyde shaft a body of porphyry was noted on the foot-wall side of the vein. This porphyry, which probably forms a portion of the dike that runs fairly parallel to the vein to the vicinity of the Lord Byron shaft, was probably encountered in the underground workings of the Kitty Clyde mine, for a few pieces of porphyry were found on the dump of this mine. The gneiss from the Fraction mine was of both the micaceous and the granitic varieties, and some of it was highly garnetiferous. Garnets up to one-fourth inch in size were found.

CHARACTER OF VEIN FILLING.

On the second level of the Fraction mine, except where stoping had been done, the vein was a narrow quartz and pyrite lead, adhering tightly to the gneiss and pegmatite walls. Specimens of ore found in the ore bin were composed of galena and cupriferous pyrite associated with quartz and ferruginous rhodochrosite. Some of the ore also showed specks of tetrahedrite or polybasite. Quartz and pyrite stringers were moreover noted cutting micaceous gneiss. In every specimen examined the ore stringers were tightly "frozen" to the wall rocks.

Ore found on the dump of the Kitty Clyde mine consisted of galena, blende, and pyrite, in a gangue of quartz, ferruginous rhodochrosite, and some barite.

DEVELOPMENT AND PRODUCTION.

An idea of the amount of development work and stoping done in the Fraction and Kitty Clyde mines can best be obtained by examining the vertical longitudidnal section of the veins. (See Pl. LXXV.)

The estimated production of the Fraction mine is between $75,000 and $100,000; the Kitty Clyde mine is also said to have yielded about $75,000.

According to Dr. James Underhill,[a] both the Kitty Clyde and the Fraction mines show excellent examples of ore occurring at and beyond the junctions of veins, for in the Kitty Clyde two veins unite going northeastward to form a flat vein and ore body, and in the Fraction three veins unite going westward to form an ore body which is continuous with the ore shoot just mentioned as occurring in the Kitty Clyde mine.

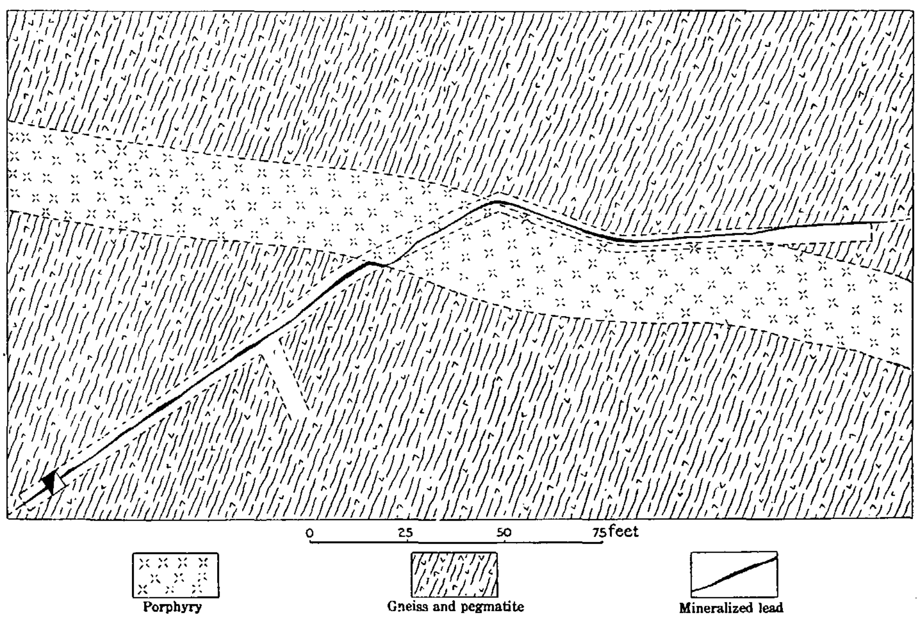


FIG. 133.—Sketch of first level of Gomer mine, showing deflecting influence of porphyry dike on vein where vein cuts through dike.

GOMER OR HEDDENSBURG MINE.

GENERAL DESCRIPTION.

The Gomer or Heddensburg mine is located in Spring Gulch at an elevation of 9,900 feet, about 3 miles west-southwest of Idaho Springs. The mine is developed by a shaft and drifts situated on a vein which is probably a branch of the Kitty Clyde-Fraction vein farther northeast. The shaft follows the vein, which dips 45° NW. for most of the way, but near the bottom steepens to 60° in the same direction. Water filled the shaft within about 180 feet of the collar. A drift between 240 and 250 feet in length leaves the shaft at the 180-foot level and runs eastward. (See sketch map, fig. 133.)

NATURE OF VEIN.

On this level the vein has a very irregular strike, owing to its deflection where it cuts across a dike of bostonite porphyry about 20 feet in width. As seen from fig. 133, the mineralized vein trends about N. 53° E. between walls of fractured gneiss and pegmatite, until it encounters the nearly east-west porphyry dike, whereupon it follows the south contact of the dike in a N. 64° E. direction for a short distance before cutting through the porphyry. On emerging on the north side of the dike the vein follows the north contact for 60 or 70 feet before it leaves the porphyry dike, and continues to the N. 83° E. with both walls pegmatite and granitic gneiss. The

[a] Oral communication.

vein near the center of the dike is narrow and contains only a small seam of quartz, crushed porphyry, and mineral, but as it approaches the margins of the porphyry mass it becomes stronger and in places carries considerable galena ore. What little mineral occurred along the vein near the center of the dike consisted of sphalerite mixed with some quartz and a little pyrite.

The ore, where observed along the vein, consists of small bunches irregularly distributed and a series of seams in gneiss and pegmatite.

CHARACTER OF ORE.

Specimens of massive, low-grade ore from the bins showed an intimate mixture of galena and green to black zinc blende, associated with considerable contemporaneous pyrite and pinkish to yellowish-brown ferruginous rhodochrosite. Some small specks of tetrahedrite and specularite were also observed.

In places the ore gives evidence of having been deposited in an open fissure partly filled by rubble, for comb quartz, though not abundant, is present and forms a layer about angular rock fragments as well as a coating on the walls of the fracture. Vugs are also common and may be lined with well-formed crystals of sphalerite and galena, but more generally with crystals of slightly later quartz, ferruginous rhodochrosite, or barite, which occur upon the faces of the galena and sphalerite crystals.

BANTY MINE.

The Banty mine is located in Spring Gulch between the Lord Byron and Metropolitan mines. The vein, which on the surface runs N. 60° E. and dips 65° NW., is developed by a shaft from which a series of short drifts have been driven. The mine was closed at the time of visit. The country rock in the vicinity and on the dump consists chiefly of granitic gneiss.

Some specimens of ore found in the ore bin showed quartz and pyrite occurring as stringers in gneiss; others showed angular fragments of quartz and pyrite ore embedded in a cementing matrix of dull-yellow jasper-like quartz; a few showed galena, zinc blende, cupriferous pyrite, and specks of tetrahedrite. Considerable ferruginous rhodochrosite was also observed.

METROPOLITAN MINE.

The Metropolitan mine is located on the northwest side of Spring Gulch, about 800 feet northwest of the Lord Byron shaft house. The walls of the vein, which in this mine runs about N. 75° E. and dips about 70° NW., consist mainly of granitic gneiss. The vein is developed by a shaft on the vein and by short drifts from this shaft.

A small quantity of granulated-appearing quartz, heavily impregnated with pyrite, was observed in the mine dump. The mine, which was not working at the time of visit, is reported to have produced a little ore.

PHOENIX MINE.

The Phoenix mine and vein are located in Spring Gulch about 300 to 400 feet northwest of the Niagara vein. The vein, which is worked through a shallow shaft, strikes about N. 70° E., and if it continues in this direction would join the northwest branch of the Lord Byron vein.

ENGLAND MINE.

LOCATION.

The England mine consists simply of a tunnel level, the mouth of the tunnel being located at an elevation of 8,550 feet on the northeast side of the mountain spur a little more than a mile due west of Idaho Springs.

WALL ROCKS.

The wall rocks adjacent to the vein consist entirely of gneiss and pegmatite, although on the surface a short distance east of the tunnel there are two parallel porphyry dikes about 150 feet apart which appeared to trend S. 20° W. The western one of these dikes is about 10 feet wide and consists of a grayish porphyry the variety of which was not determined; the eastern dike is about 30 feet in width and is composed of reddish bostonite porphyry. In the mine the gneissic structure is in general parallel to the vein.

VEIN AND VEIN FILLING.

The strike of the vein, which is developed by a drift approximately 400 feet in length (fig. 134), is about S. 60° W. and its dip is about 45° to 50° NW. The vein is not an especially strong one, being formed of a series of connected minor fractures. Locally the vein consists of a series of stringers of quartz, here and there showing comb structure, in gneiss; elsewhere it consists of gray quartz containing a few angular fragments of wall rock and showing some little replacement by mineral. The vein is only slightly mineralized, but in places carries a little ore consisting of galena, pyrite, quartz, and both brown and resin zinc blende.

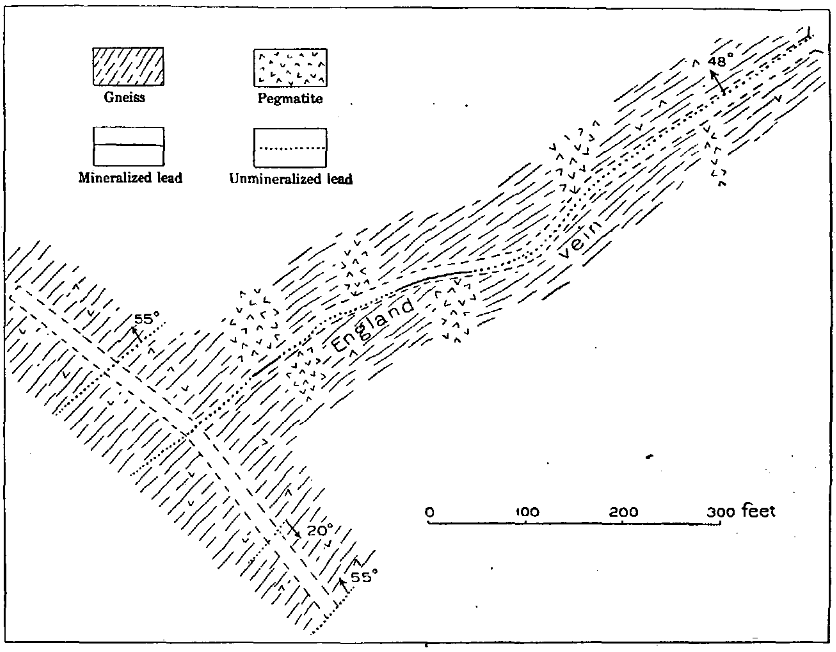


FIG. 134.—Geological plan of tunnel on England vein.

CARDIGAN MINE.

The Cardigan mine is located in a ravine termed Cardigan Gulch, on the south side of Clear Creek, 1 mile west of Idaho Springs. It is developed by three tunnel levels, aggregating about 2,000 feet of workings. However, the mine has long laid idle and nearly all the workings are inaccessible through caving.

Most of the rock in the vicinity appears to be gneiss, chiefly of the micaceous variety, the attitude of which corresponds in general to that of the vein. In places a mixture of gneiss and pegmatite having a gnarled or crumpled appearance was observed. Specimens of pinkish bostonite porphyry were found on the dump of the lower tunnel, so it is possible that a dike of this porphyry was encountered in the mine, especially as such a dike is present on the surface southeast of the shaft. Near the shaft on the lower leve', where two nearly parallel leads were noted, the vein consists of leads of crushed gneiss and clay 2 inches to 1½ feet in width. In places these leads contained vein quartz and pyrite. The general trend of the vein, as seen from the mine maps, was about N. 60° E. and the dip about 40° NW.

GLADSTONE TUNNEL.

The Gladstone tunnel is situated on the south bank of Clear Creek, near the point where Cardigan Gulch joins the valley of this stream. The wall rocks consist entirely of gneiss and pegmatite.

The main vein strikes about S. 65° W. and dips from 60° to 70° NW. The vein consists of a quartz lead, ranging from 2 inches to over a foot in width, which locally is made up solely of quartz with a little pyrite, though elsewhere it is composed of quartz, pyrite, galena, and brown sphalerite.

About 325 feet from the mouth of the tunnel a crosscut spur to the northwest cuts a clay and crushed gneiss lead several inches wide, which carries some pyritiferous quartz. Near the point where this spur leaves the tunnel the main vein is joined from the west by a clay lead several inches wide, which runs in contact with the vein for about 50 feet and then crosses it and disappears in the foot-wall gneiss. A considerable number of small stopes occur scattered along the vein and indicate that the mine produced some ore in times past.

About 300 feet N. 35° W. of the Gladstone tunnel is a small tunnel called the Donna Juanita, which was driven for about 250 feet S. 65° W. on a small vein dipping 40° NW. Two minor veins striking N. 80° E. and N. 25° E. were encountered in a short tunnel located between the Gladstone and Donna Juanita tunnels.

SALISBURY MINE.

The Salisbury mine is located on the north side of Clear Creek, about 600 feet north-northwest of the main Stanley shaft. The developments consist of a crosscut tunnel about 175 feet in length, and a drift on the vein about 400 feet in length which connects with winzes and raises (fig. 135). The country rock consists chiefly of gneiss, principally of the micaceous variety. The schistosity of the gneiss ranges in strikes from N. 65° E. to east and west, but as a rule is nearly parallel to the vein; the dip is between 45° and 55° N.

The vein is a strong one. It dips 30° to 45° N. and has a very irregular strike, which in general is a little south of east. The lode consists of a quartz and crushed rock vein, which at many places splits into foot-wall and hanging-wall leads. About 250 feet east of the tunnel there are two heavily mineralized leads 8 to 10 feet apart. Considerable stoping has been done along the vein, both above and below the tunnel level, at various points along a distance of 350 feet east of the tunnel. Most of the mineral observed along the vein consisted of both massive and crystalline copper-bearing pyrite, and possibly some chalcopyrite, associated with quartz, and occurred as seams running through fractured gneiss. A little galena is present. In places the chalcopyrite in the ores has been altered to a grayish-black or bluish-black mineral, probably chalcocite.

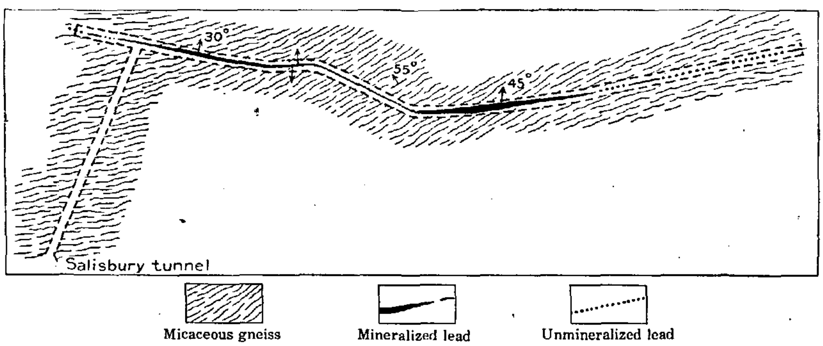


FIG. 135.—Geological plan of Salisbury tunnel.

The Salisbury mine formerly produced considerable ore and for a long time supplied most of the ore used in running the 10-stamp mill located on Clear Creek a short distance above the mine.

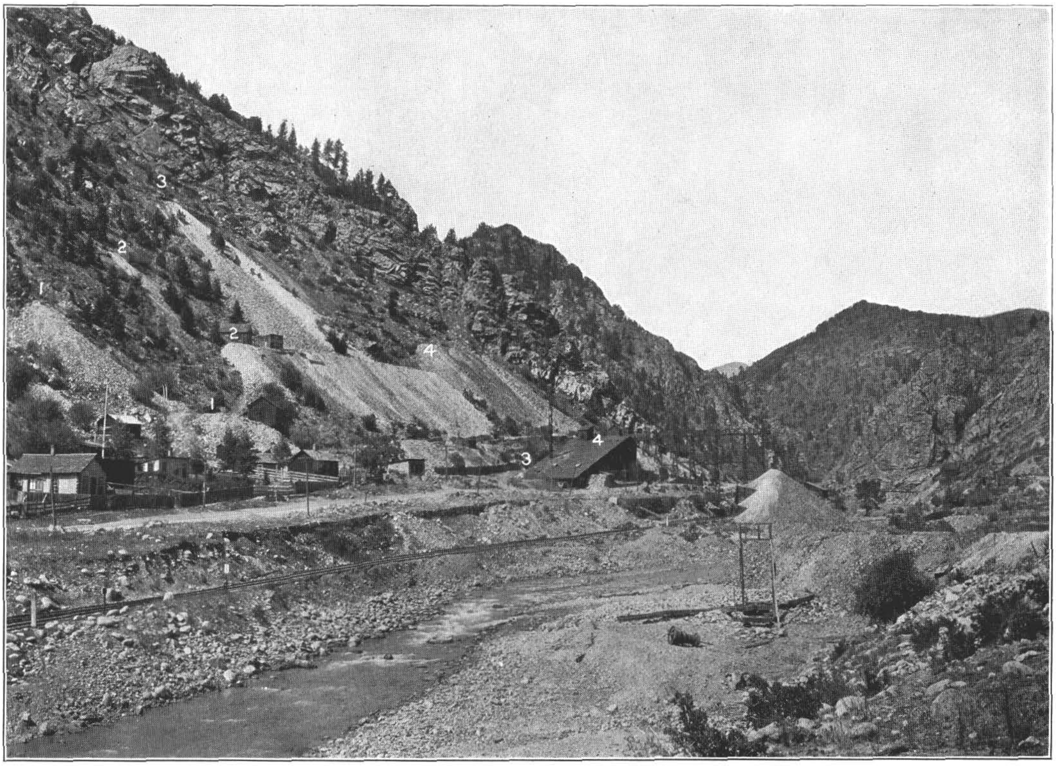
LINCOLN GROUP.

GENERAL DESCRIPTION.

The Lincoln group of veins (Pl. LXXVI, *A*) is located on the southwest side of Clear Creek, between 1,000 and 2,000 feet below the mouth of Trail Creek. The group consists of the Lincoln, South Lincoln, Josephine, and Barber and Elliott veins. These veins, which have a general northeast-southwest trend and a comparatively flat dip to the northwest, are located in an area of gneiss, usually of the micaceous variety, which has been intruded by small bodies of pegmatite. Porphyry of the biotite latite variety occurs along both the Josephine and South Lincoln veins, but is absent from the workings on the other veins.

LINCOLN VEIN.

The main Lincoln vein, which is the westernmost of the group, has on the lower tunnel level a trend of about N. 35° to 40° E. and a dip of only 25° to 35° NW. for the whole length of the tunnel, which was followed to a point about 950 feet southwest of the mouth, where a cave dams back the water and prevents access to the workings beyond. The levels connecting with the



A. MINES OF LINCOLN GROUP OF VEINS, LOOKING WEST FROM CLEAR CREEK 1 MILE ABOVE IDAHO SPRINGS.

1, Elliott & Barber mine; 2, Josephine mine; 3, South Lincoln vein; 4, Lincoln mine and mill.

B. WALTHAM MINE TUNNELS.

Showing two northeastward-dipping vein leads in much fractured pegmatite and gneiss.

shaft sunk from the lower tunnel were also inaccessible, as was the intermediate tunnel on the Lincoln vein. The upper level on the Lincoln vein consists of a single drift and stope about 250 feet in length, connected by an 80-foot crosscut with the upper tunnel which runs on what is termed the South Lincoln vein. In these upper workings the Lincoln vein trends N. 52° E. and dips 45° to 52° NW. On the surface, however, owing to the flat dip and the steepness of the hill slope up which the vein runs, the outcrop trends about N. 20° E. The walls of the vein, so far as observed, consist entirely of siliceous or granitic phases of gneiss, to which the quartz and mineral streak appeared in general to adhere rather tightly.

Extensive stopes occur along the vein on the lower tunnel level and the yield from this part of the mine is said to have been large, although no definite figures concerning the production were

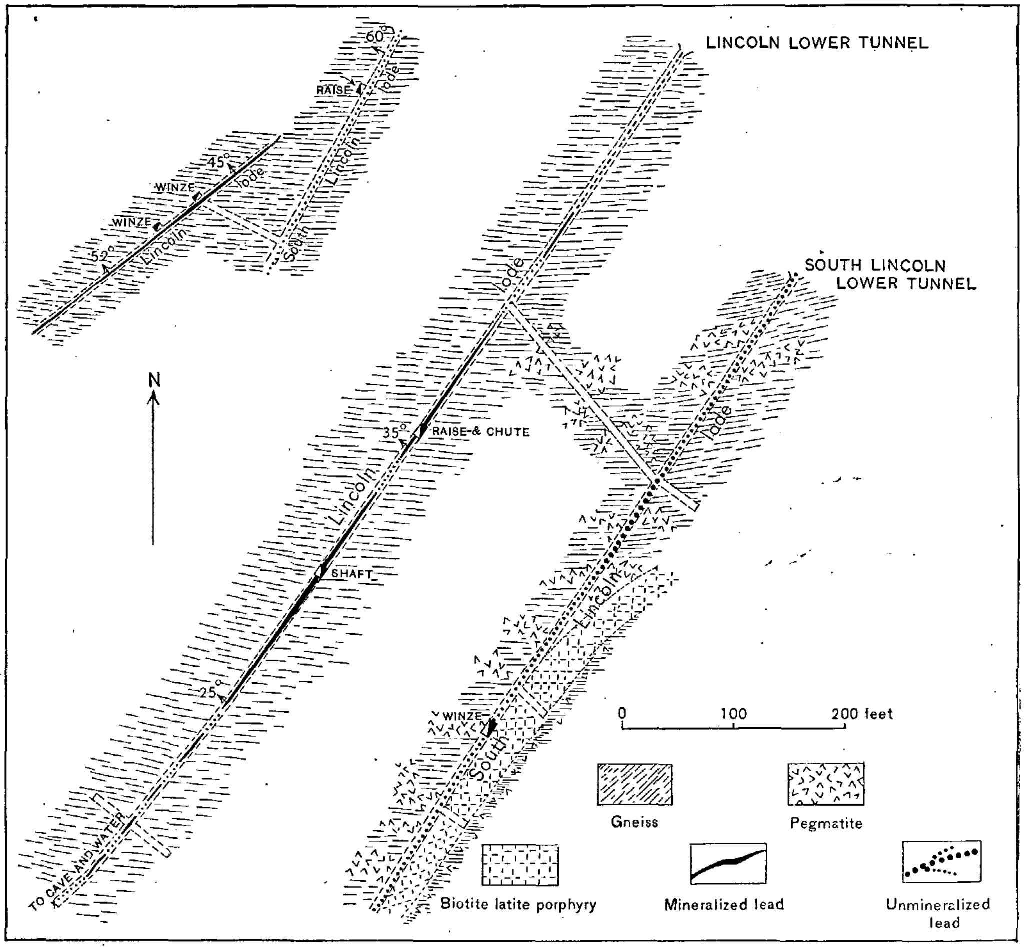


FIG. 136.—Geological plans of separate levels, Lincoln veins.

obtainable. On the lower level in leaner portions of the vein where only drifting had been done, so that the vein material was still observable in the roof and walls, it was found to consist entirely of pyrite and quartz. Patches of pyrite and quartz were found adhering to the walls of some of the stopes. No galena was observed on this level.

On the upper level (fig. 136) at the time of examination two lessees were stoping on an 8-inch streak of cupriferous pyrite, which carried a little galena and contained scattered vugs or dissolution cavities filled with a black pulverulent sulphide, possibly chalcocite (Cu_2S). The copper-bearing pyrite was tarnished in places by a varicolored film probably resulting from the oxidizing influence of underground waters. The ore being removed was said to carry 6 or 7 ounces of silver to the ton and enough gold to bring the values up to an average of about $14 to the ton. The most gold appeared to be associated with highly cupriferous pyrite, while the black sooty sulphides were reported to carry little if any more values than the plain pyrite ore, as some ore especially rich in them returned values of only $19 to $27 to the ton. Near the surface the vein filling for a shallow belt consists of a porous gossan or quartz heavily impregnated and stained with iron oxides.

Years ago a 15-stamp mill, located just north of the mouth of the lower Lincoln tunnel, was run on ore from the Lincoln mine, but this mill, like the lower workings of the mine, has long been idle. The present output from the upper level is small.

SOUTH LINCOLN VEIN (POSTMINERAL BRECCIA).

The mouth of the lower tunnel on the South Lincoln vein is located on about the same level as the lower Lincoln tunnel and only about 225 feet S. 35° E. of the entrance to the latter. The vein, which strikes N. 35° E. and dips about 60° NW., runs parallel to the Lincoln vein, which is about 200 feet farther southeast, and is followed by the two tunnels for their whole lengths of 700 and 225 feet. The vein is a strong breccia lead ranging from 6 inches to several feet in width, and consists chiefly of fragments of pegmatite and gneiss embedded in a matrix of clay or soft gouge, although here and there bowlders of pyritiferous quartz occur in the soft matrix. For the most part the walls are of siliceous gneiss, micaceous gneiss, and later pegmatite. The schistosity of the gneiss strikes northeast. On the lower level the foot wall of the vein for a distance of 250 to 300 feet from the breast of the tunnel is formed by a porphyry dike about 17 feet wide. The dike is of biotite latite, in which both the phenocrysts and the groundmass have been highly altered. Although small pyrite and quartz stringers cut the gneiss, running somewhat parallel to the dike, they are invariably separated from the porphyry by a clay seam which runs along the contact. Near the point where the dike at the northeast swerves abruptly to the east behind a considerable thickness of gneiss and pegmatite which comes in as the foot wall the clay and breccia lead begins to widen, and it reaches a maximum width of 10 feet at a point, 225 feet from the mouth of the tunnel, where the main vein is joined by a branch lead from the north. On the southeast side of the 17-foot dike a small clay lead runs parallel to the dike, but though at some places this lead is in contact with the porphyry, at others it cuts through the gneiss and leaves lobes of gneiss in undulations along the surface of the dike. No fragments of the biotite latite porphyry were noted in the breccia zone. No stoping has been done on this breccia zone, which is called the South Lincoln vein, and no ore was noticed except the fragments of pyrite and quartz in the breccia lead and the small pyrite stringers cutting the gneiss. The zone probably represents a faulting subsequent to the main period of ore deposition.

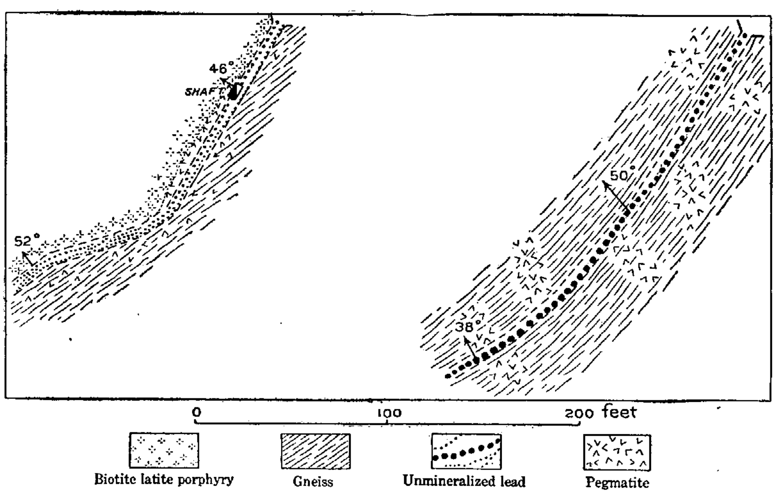


FIG. 137.—Geological plans of separate levels, Josephine vein.

JOSEPHINE MINE.

The Josephine vein, which lies about 200 feet southeast of the South Lincoln, is developed by three short tunnels, the lowest of which, however, was caved shut a short distance from the mouth at the time of visit. The middle and upper tunnels are only 200 and 150 feet in length, respectively. A shaft is sunk from the intermediate level at a point 50 feet from the mouth of the tunnel.

Except where porphyry is present the wall rocks are gneiss and pegmatite, the attitude of the gneiss in general being approximately parallel to that of the vein. On the middle and lower levels biotite latite porphyry forms the hanging wall of the vein in places, but is separated from the vein at other points by horses or lenses of gneiss and pegmatite. In the upper tunnel (fig. 137) the vein lies entirely in gneiss and pegmatite. The porphyry on the hanging wall of the Josephine is similar in character to the porphyry forming the foot wall of the South Lincoln vein and may be a portion of the same porphyry mass, as the trend of the dike in both mines is very irregular. The vein, which varies in dip between 40° and 50° from the horizontal in both the upper tunnels, trends S. 35° W. for most of the way and then swerves slightly more to the west. On the middle level this bend corresponds somewhat closely to a bend in the porphyry dike forming the wall. The vein is a breccia lead ranging from a few inches to 2 feet in width at various points and consisting of angular fragments of gneiss, pegmatite, granite, pyrite-bearing quartz, and highly altered porphyry embedded in a white to gray clay or gouge. In places the vein filling is well indurated through silicification subsequent to the movements which caused the breccia, but as a rule it is comparatively soft. The fact that angular fragments of porphyry are included in the vein would indicate that movements have taken place since the intrusion of the porphyry. Aside from the few angular fragments of pyritiferous quartz found in the breccia lead and a few small pyrite stringers running alongside of and parallel to the breccia lead, no mineral was observed on the two upper levels of the mine. Nothing could be learned concerning the lower inaccessible workings. This so-called vein is probably a breccia zone which has developed subsequent to the main period of mineralization.[a]

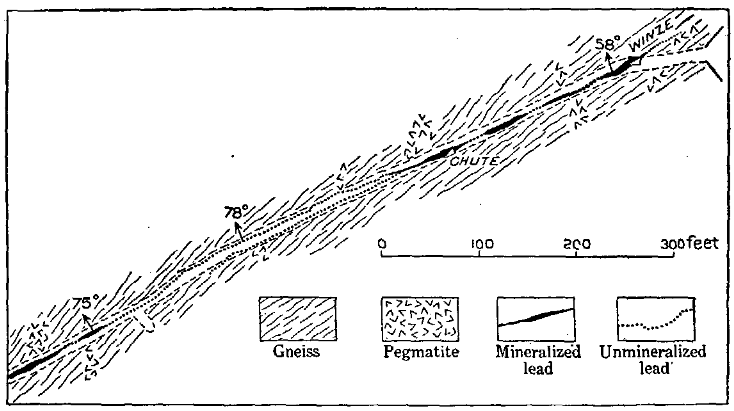


FIG. 138.—Geological plan of intermediate tunnel, Barber and Elliott lode.

BARBER AND ELLIOTT MINE.

The veins developed in the Barber and Elliott mine are located 150 to 200 feet southeast of the Josephine mine workings. The development consists of three tunnels. Neither of these tunnels, however, was accessible for its whole length, owing to caving at points between 300 and 400 feet from the mouth.

The wall rocks consist entirely of gneiss, with small intrusive masses of pegmatite. The schistosity of the gneiss is approximately parallel to the vein. The veins in general strike about N. 60° to 65° E. and dip from 50° to 75° NW. On the lowest level, and also for a distance of 175 feet from the mouth of the intermediate level (fig. 138), the vein consists of a single strong vein, but at the latter point on the intermediate level it splits into foot and hanging leads, which diverge as they proceed southwestward until, at a point about 100 feet distant, the foot-wall lead, which is the less mineralized, enters the foot-wall side of the drift. On the upper tunnel level two veins run parallel and only about 20 or 25 feet apart, and these may represent the two leads formed by the splitting of the vein on the intermediate level.

The vein consists usually of a narrow quartz and pyrite lead adhering tightly to the wall rocks, but in places is composed of a quartz and clay streak several inches wide. Near some of the stopes the quartz and pyrite vein filling contains specks of galena scattered through it, so the best ore probably also carried galena. Considerable stoping has been done along the vein on all the levels. On the intermediate level the main stope is just east of the point where the two leads make a junction going east; on the upper level the stope on the northwest vein is just southwest

[a] See, in the description of the Stanley mine (pp. 345–346), the account of the "friction conglomerate" which corresponds to the Josephine vein and which also was formed subsequent to the intrusion of a dike of biotite latite, itself later than the main mineralization period.

of the point where the vein is joined by two minor branches from the northeast. Vein junctions have therefore probably had an important influence on ore deposition in this vicinity.

The fact that in the Barber and Elliott and the Lincoln mines, where no porphyry was found, the veins consist of continuous quartz and ore streaks tightly adhering to the wall rocks, whereas in the Josephine and South Lincoln mines, where porphyry occurs, the veins consist solely of a breccia lead containing scattered angular fragments of porphyry and of pyrite and quartz ore, would indicate that at least a part of the movement along the veins in the Josephine and South Lincoln mines is subsequent to both the porphyry intrusion and to the period of formation of the solid quartz and ore veins. Possibly the intrusion of the porphyry was also subsequent to the formation of the earlier pyrite and galena veins, as was found to be the case with the same variety of porphyry in the Stanley mine.

LITTLE MATTIE-NEWTON VEIN SYSTEM.

GENERAL DESCRIPTION OF VEINS.

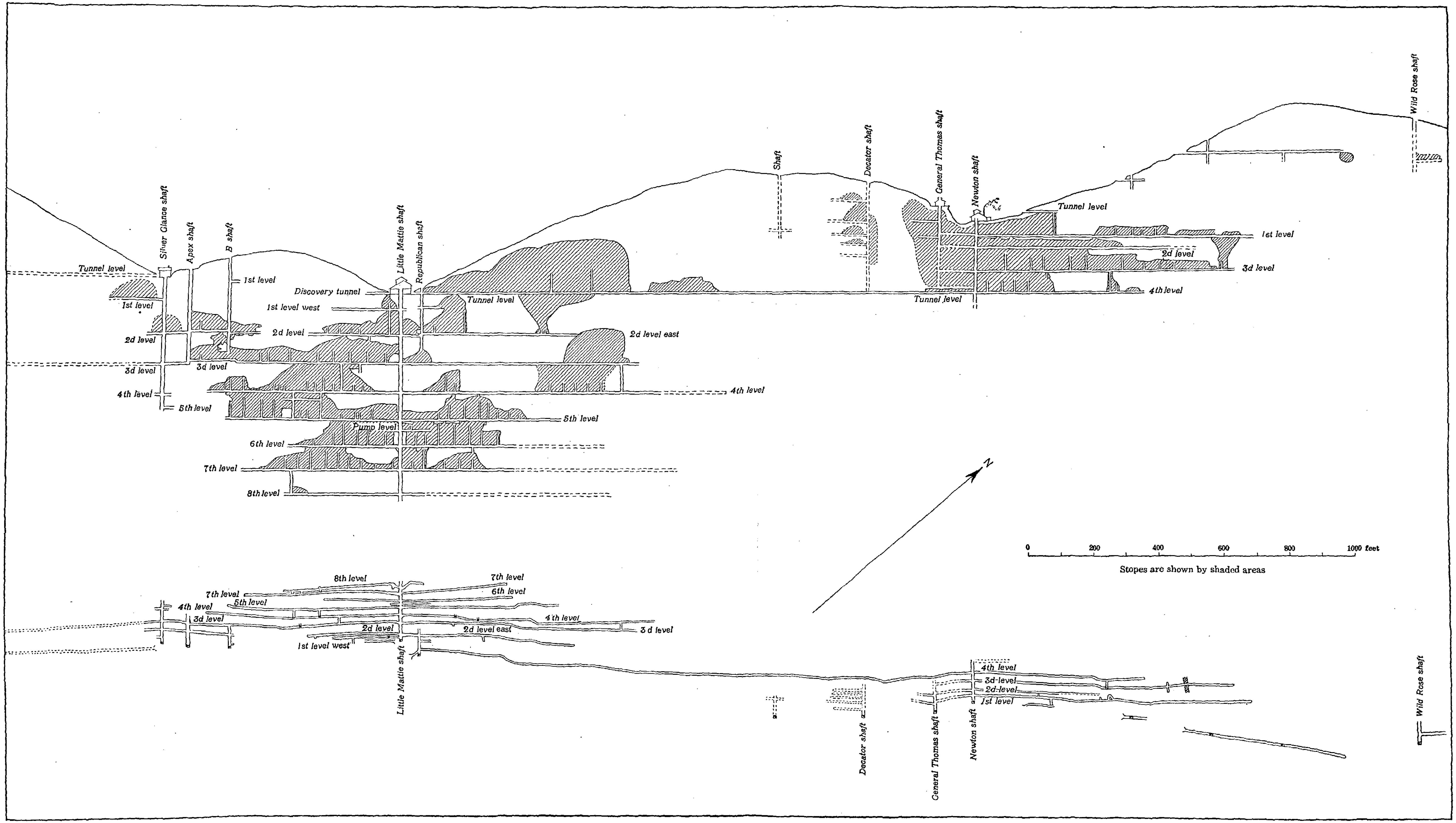
The Little Mattie-Newton group is so named because the principal vein has been most extensively developed in the Little Mattie and Newton mines, which are located from 2 to 2½ miles west-southwest of Idaho Springs, in steep gulches running southeastward to the valley of Chicago Creek.

The group consists essentially of a single exceptionally strong and well-mineralized northeast-southwest vein and the branches into which this main vein breaks up at the two ends. Throughout its course the vein is intimately associated with one or more porphyry dikes. Northeast of the Little Mattie mine the main vein follows in a general way the line represented by the Great Republican, Decator, General Thomas, Newton, and Wild Rose claims. In the Wild Rose claim the vein becomes hard to follow, owing to the lack of surface outcrops and to the fact that the vein, after crossing the ridge extending northeastward from Alpine Mountain, probably splits into at least two branch veins which continue northeastward and cross Spring Gulch. Two probable branches are distinguished in the Star and Red Lyon tunnels. These branch veins probably follow approximately the course of two porphyry dikes which run some distance apart and then join near the summit of the ridge just southwest of the Bullion King shaft.

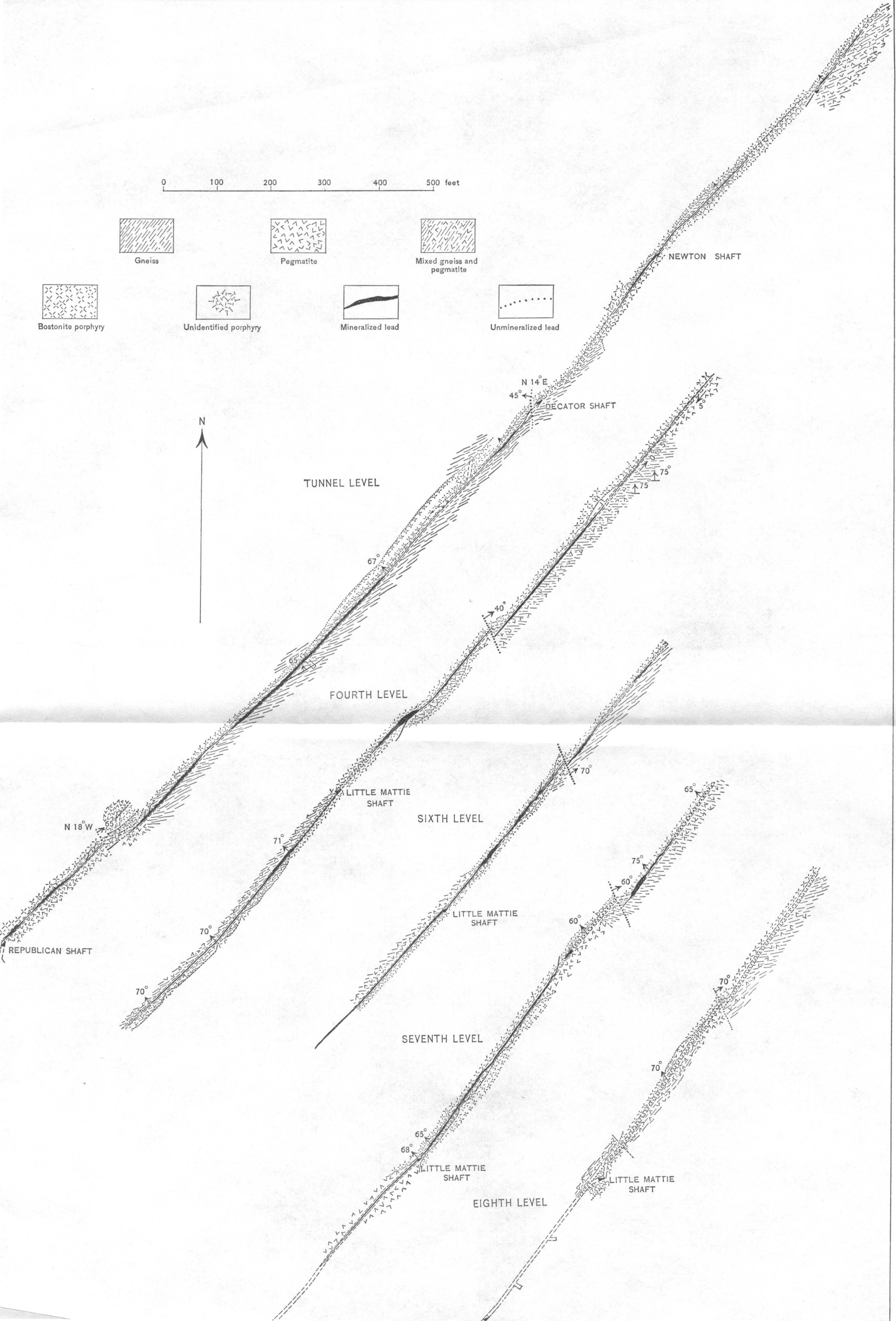
It is very likely one of the branches of the same vein system which is developed by the workings of the Bullion King and Mayflower mines. Another minor vein follows the porphyry dike, which swerves northward and may possibly be the same as one of the porphyry dikes found in the Stanley mine.

Southwest of the Little Mattie mine the main vein is strongly developed in the workings of the Silver Glance mine, but a short distance farther southwest it breaks up into several well-marked but less highly mineralized fractures, of which one is represented by the vein in the Arthur mine and another by the vein in the King Solomon and Dorritt workings. The junctions of these branches with the main vein were not seen by the writers, but it is claimed by some of the old miners familiar with the mines in the vicinity that the splitting of the main vein takes place in the now inaccessible levels in the southwestern part of the Silver Glance mine.

The Little Mattie-Newton vein, together with the lodes into which it splits, is opened at short intervals for a distance of about 3½ miles along the strike. In the Little Mattie mine the lode has been developed mainly by a shaft which extends to a vertical distance of about 650 feet below the surface in the lowest part of the gulch and by a series of eight levels, which are represented by drifts that extend along the vein in both directions from the shaft. Besides these workings a tunnel between 2,300 and 2,400 feet in length follows the vein northeastward into the hill to a point 500 or 600 feet beyond the Newton shaft, with which it connects. The drifts and tunnels in the Little Mattie mine (Pl. LXXVII) alone aggregate about 10,000 feet in length, and most of them are still open. Besides these and the several hundred feet of development in the Silver Glance and Decator mines (which were inaccessible), the vein has been opened up on the Newton and General Thomas claims by more than 4,000 feet of drifts run from shafts. The Newton and General Thomas shafts, which reach depths below the



VERTICAL AND HORIZONTAL PLANS OF LITTLE MATTIE WORKINGS.


0
100
200
300
400
500 feet
Gneiss
Pegmatite
Mixed gneiss and pegmatite
Bostonite porphyry
Unidentified porphyry
Mineralized lead
Unmineralized lead
N
NEWTON SHAFT
N 14° E
45°
DECATOR SHAFT
TUNNEL LEVEL
FOURTH LEVEL
SIXTH LEVEL
SEVENTH LEVEL
EIGHTH LEVEL
LITTLE MATTIE SHAFT
N 18° W
65°
REPUBLICAN SHAFT
67°
65°
40°
75°
75°
70°
71°
70°
70°
65°
75°
60°
60°
70°
70°
65°
68°

surface of 275 and 250 feet, respectively, have not been used for a good many years, the development on these properties having been carried on through the Little Mattie tunnel, which intersects the Newton shaft about 230 feet below its collar.

NATURE OF WALL ROCKS.

The country rock along the Little Mattie-Newton vein is mainly pegmatite, gneiss, and porphyry. (See Pl. LXXVIII.) In places the pegmatite occurs by itself for long distances, but at other points it is intimately mixed with the gneiss. The gneiss is chiefly of the dark micaceous variety. Its strike varies considerably, but in general corresponds somewhat to the trend of the vein, or runs a little more toward the east and is intersected by the vein fracture at a very low angle. The dip as a rule is between 60° and 75° NW. However, just southwest of the cross vein on the seventh level the gneiss strikes S. 50° E. and dips northeast. Altered porphyritic granite or "corn rock" is common in the vicinity of the "cross vein."

At many places porphyry forms one or both walls of the vein. There are either two dikes which in places come into contact with each other, though usually parallel and separated by from 2 to 25 or 30 feet of country rock, or else one large porphyry dike which splits into two or more parts that loop around large masses of pegmatite and gneiss and then reunite. Where there are two distinct belts the one to the northwest is usually the broader. On the surface the southeast dike appears to be about 10 feet wide, and the northwest dike ranges from 10 to 20 feet or more. In places the surface of the dikes is in uneven rolls, and at certain points, as on the seventh level of the Little Mattie, the margins show a banded structure, probably due to flow.

Apophyses of porphyry are in a very few places given off from the main porphyry mass. One of these narrow spurs of porphyry was observed intruded between the laminæ of the gneiss a short distance northeast of the cross vein on the tunnel level. In the breast of the fourth level on the Little Mattie is a 4-foot porphyry belt separated from the main hanging-wall porphyry dike to the northwest by 1 foot of crushed gneiss. Traced westward, this 4-foot belt of porphyry narrows and disappears. In the Little Mattie tunnel porphyry forms the hanging wall of the vein, or is only a short distance northwest of the vein for the whole length of the level—about 2,400 feet. On this same level porphyry is also found on the foot wall for several hundred feet both to the east and to the west of the Newton shaft. On the different levels run from the Little Mattie shaft porphyry forms portions of both walls. It is more common on the foot wall near the shaft and along the vein to the southwest, but more prevalent as a hanging-wall rock to the northeast of the shaft.

The porphyry, which falls in the class of bostonites, is, when comparatively fresh, pinkish gray to reddish brown, with usually conspicuous phenocrysts of feldspar. The feldspar crystals, however, are generally altered to a pale-greenish color. A few altered barlike crystals of darker silicates are present. In much altered forms the rock mass bleaches to a white or light-gray color, except where stained brown by iron oxide or black by manganese oxide. Under the microscope the groundmass in most of the specimens of the porphyries shows the trachytic texture characteristic of this class of rocks.

NATURE OF VEIN.

The Little Mattie-Newton vein has formed along a strong fault line, the course of which was determined by one or more preexisting dikes of bostonite porphyry. The strike of the vein is approximately N. 40° E., but on the surface the direction of the outcrop is about N. 47° E., with divergences to the northwest here and there when crossing gulches, owing to its northwest dip. The dip usually ranges between 65° and 70°, but in places the vein rolls slightly, as shown by the fact that the shaft, which follows the average dip, is about 15 feet southeast of the vein on the eighth level. Movement along this fault plane is shown by discordances in the wall rocks on the two sides of the vein and by the zones of brecciation and trituration which are general throughout the underground workings. Slickensides and striæ on these smooth polished surfaces also indicate movement. The attitude of the movement striæ ranges from horizontal to a dip 15° SW.

The fault along which the vein subsequently formed followed along, close to, or entirely within one or the other of the porphyry dikes for the whole distance now covered by the main vein, which disappears by branching at the two ends.

The vein, while consisting locally of a single mineralized fracture, as a rule belongs to the double-wall type of veins (see p. 99), which consist of a vein zone from 1 foot to several feet wide, bounded by definite hanging and foot walls. The leads along the two walls are about 2 to 4 feet apart on an average, but the distance between them ranges from a few inches to 14 feet in some places. The vein filling, which in the mineralized areas consists chiefly of gouge and crushed wall rocks, gives way to quartz and then to quartz and ore as the ore bodies are approached. The crushed vein filling as a rule consists chiefly of gneiss and pegmatite, but in some places contains fragments or bowlders of porphyry.

The vein follows in the main the contacts of the two porphyry dikes with pegmatite and gneiss on either side. Many portions of it, however, lie entirely within the horses or longer belts of country rock included between the two parallel dikes. A much smaller part of the Little Mattie-Newton vein is entirely in porphyry and the vein may consist of a single fracture plane or may be represented by two distinct fractures bounded on the outside by two definite walls of porphyry and with a belt of porphyry 4 or 5 feet wide between them, as in the second tunnel northeast of the Newton shaft. Here also was noted a lens of pegmatite 2 feet wide about 2 feet northwest of the hanging-wall lead and apparently embedded entirely in porphyry.

The irregular distribution of the porphyry along the vein, as well as the great variation in the apparent thickness of the individual dikes, may be due to a series of strike or oblique fault planes following the weak zone represented by one of the porphyry dikes, and to horizontal displacement along these planes, causing the irregular slices or slabs of porphyry to be entirely lacking in one place while they overlap in others and produce an apparent thickening of the dike, in a manner somewhat similar to the occurrence in the Pelican-Bismarck vein system at Silver Plume. This would account for the occurrence of the porphyry in the tunnel east of the Newton shaft. The irregular distribution of the porphyry is also shown on the fourth level of the Little Mattie, where a 5-foot dike in the northeast breast of the drift narrows toward the west and disappears. In certain places where the surface of the porphyry dike is in a series of rolls the vein is in contact with the crests of the rolls or undulations, and disconnected masses of gneiss and pegmatite occupy the hollows between the vein and the porphyry. Except where the vein follows a porphyry dike, the contact of the porphyry with the adjacent pegmatite or gneiss is very tight and practically no gouge or other indication of movement is present.

Between the Little Mattie and Newton shafts on the surface two porphyry dikes run along for some distance, separated only by 2 to 4 feet of pegmatite and gneiss. This same condition was locally observed underground, where the contacts with the two dikes represented the foot-wall and hanging-wall sides of the vein.

STRUCTURE OF VEIN.

Where the vein belongs to the double-wall type, the material between the two walls may originally have been comparatively solid rock around which the fractures looped, or a fractured or crushed and pulverized rock mass filling the space between the vein fractures.

From the hanging and foot fractures the mineralizing solutions penetrated the rock mass between and probably first caused the alteration and replacement with ore minerals of the intensely crushed and fractured portions of vein zone, at the same time that the harder and less fractured horses of rock were being bleached and altered so that later they offered little resistance to impregnation by metallic sulphide or to complete replacement by vein materials. The walls bordering the vein zone were also altered for short distances on either side, and in a few places were impregnated with sulphides to such an extent that portions of the walls immediately adjacent to the vein paid well for extraction. In places where the vein zone between the two walls is rather wide, the mineralized portions consist of foot- and hanging-wall streaks of ore connected by a network of minute stringers or seams of ore which intersect the intervening mass of fractured rock and mineralize it to such an extent that practically the whole zone can be shipped as ore. Such an ore body occurred about 140 feet east of the shaft on the sixth level, where a continuous streak of galena-tetrahedrite ore was found on each wall and where about 65 per cent of the 10-foot zone, with ore stringers all through it, was shipped directly as ore. On the same level west of the shaft the ore zone was 3 to 11 feet wide and 75 per cent of the material was sent directly to the sampler. The ore streaks along the foot-wall side are said to be usually a little better developed, but may play out, and a seam of ore may cross over to the hanging-wall side and continue along in the same direction. Quartz usually coats the wall rocks next to the vein fracture and also forms a thin layer between the ore and the angular fragments of country rock in the vein zone.

Just southwest of the Little Mattie shaft on the fourth level a 5-foot belt of crushed pegmatite and gneiss occurs between a dike of porphyry which forms most of the foot wall of the lode and a 2-foot porphyry dike which lies to the northwest. Still farther northwest, beyond the 2-foot porphyry dike, is more pegmatite and gneiss. The main lead here is between the 5-foot pegmatite and gneiss belt and the 2-foot porphyry dike to the northwest. Followed southwestward this rock belt between the two porphyry dikes narrows to 2 feet and first becomes highly silicified and then changes to quartz and ore. To the east of the shaft also the same crushed pegmatite and gneiss seam narrows, becomes silicified, and changes to quartz and ore as the two bordering dikes approach within 6 inches to 1 foot of each other. In this group of mines narrow belts of crushed rock bounded on two sides by porphyry dikes seem to have been locations favorable to the deposition of ore.

Where the foot and hanging leads of the vein occur along the two sides of a porphyry belt only 2 or 3 feet wide, the fractured porphyry has been highly altered, silicified, and in some localities either replaced more or less completely by metallic sulphides and gangue minerals or mineralized to such an extent along the infinite number of cracks in the fractured porphyry that the whole mass can be profitably mined.

COMPOSITION OF VEIN.

The ores from the main vein of the Little Mattie-Newton group are predominantly gold bearing along certain portions, but silver is of greater value in others. It is claimed that in the Little Mattie mine the ores to the west of the so-called "cross vein" generally yield a greater percentage of silver than gold, whereas to the east of the same fault gold is the more valuable constituent of the ore, although there are a few exceptions to these general statements.

Quartz is the chief and practically the only gangue mineral. The metallic constituents comprise galena, zinc blende, tetrahedrite (gray copper), polybasite, and possibly small quantities of argentite (silver glance); pyrargyrite (ruby silver) has also been found. Both native silver and native gold occur in a few places. About 100 feet east of the shaft on the seventh level of the Little Mattie mine was found a small pocket, 4 or 5 feet wide, of finely fractured quartzose rock associated with a brownish to yellowish clay which carried $32 in values and on panning showed free gold. On the same level ore stoped west of the "cross vein" is said by Mr. Sutherland, the superintendent of the mine, to have averaged between 100 and 300 ounces of silver and 2 or 3 ounces of gold, whereas to the east of the "cross vein" the ore generally carried only 7 to 30 ounces of silver with a gold content of about 2½ ounces.

In the double-wall veins, where mineralized, there is usually a solid streak from 1 inch to several inches wide of high-grade smelting ore on one or both walls, with values averaging between $200 and $400, and the fractured zone between the two walls has stringers of ore throughout and is in many places sufficiently well mineralized to make good milling ore. Small pockets of ore, however, have at various times within the history of the mine yielded several hundred pounds of ore running more than $1,000 to the ton. Some of this ore carried from 30 to 42 ounces of gold, 400 to 600 ounces of silver, 5 to 10 per cent of lead, and 5 to 10 per cent of copper. Near the surface some of the ores were of the soft oxidized kind; lower down were found some streaks of the soft black sulphides locally called "black sulphurets," which were associated with the galena, blende, and other heavy sulphides. Lobes or patches of ore consisting largely of these soft black sulphides were obtained as far down as the sixth level, where in the Pike & Rowe lease, nearly 750 feet below the surface of the ground, the vein filling consisted of 6 inches to 3 feet of black sooty sulphides and galena ore mixed with crushed quartz and angular fragments of silicified gneiss, pegmatite, and porphyry, which had been cemented to some extent by quartz. Ore from the Little Mattie mine that is of too low grade to ship directly to the smelter is treated in the 20-stamp concentrating and amalgamating mill belonging to the same company.

RELATION OF ORE DEPOSITION TO DEPTH.

The highest grade of ore and the largest ore bodies in the Little Mattie mine, according to Mr. Sutherland, the superintendent, were found between the fourth and seventh levels, the portions of the ore shoots in the vicinity of the sixth and seventh levels being especially good. The ore bodies in places extended continuously from these lower levels to the surface, but above the fourth level were of no better grade and were not as wide as between that point and the seventh level. Moreover, some of the ore from the second level ran only $40 to $60 to the ton, whereas immediately beneath on the sixth level ore running over $200 to the ton was obtained. At the time of the examination considerable óre, said to average about $200 to the ton, was being obtained from the Pike & Rowe lease near the east breast of the sixth level of the Little Mattie mine.

Below the seventh level the ore, so far as development has shown, has been decidedly leaner in values, although some milling ore has been obtained just above the lowest or eighth level.

FAULTS.

In the Little Mattie mine workings the main vein is faulted from 18 to 20 feet on the fourth level, and from 6 to 12 feet on the other levels of the mine, by a strong but only slightly mineralized vein, termed in this mine the "cross vein." This is supposed to be the same vein which is being followed in the Star tunnel, driven in the direction of the Little Mattie from Chicago Creek. This vein, where intersected on the Little Mattie tunnel level, about 280 feet from the mouth, has a strike of N. 28° W. and a dip of 65° NE. On the other levels the trend varies somewhat from that on the tunnel level, and the dip, while always to the northeast, ranges from 40° to 70°, the flattest inclination recorded being on the fourth level.

The "cross vein" carries no pay ore, although assays of $2 to $6 in gold have been obtained from some of the material of the fault zone. The material filling the fracture consists of crushed and pulverized country rock or gouge. The wall rocks in the vicinity of this fault are highly altered for 5 to 30 feet from the fault plane, especially on the foot-wall side. Altered pegmatite or coarse porphyritic granite ("corn rock") is a characteristic wall rock in the vicinity of this "cross vein." Where porphyry is cut by this fault the dike is displaced and is badly fractured for some distance from the crossing.

Another fault in the main vein was noticed in the Little Mattie tunnel about 25 feet southwest of the raise to the Decator shaft. The strike of the fault mine was about N. 12° E. and the dip 45° W. Here also the northeast portion of the main vein appears to have been offset a short distance to the south.

In a stope worked to the surface, near the Thomas shaft, the main vein is intersected by a cross fracture dipping northeastward only 35° from the horizontal and trending S. 70° E. This flat fault offsets the northeast portion of the Little Mattie-Newton vein and the porphyry dike forming its foot wall about 5 feet to the S. 70° E. Movement striæ on the slickenside along this fault plane dipped to the southeast 10° from the horizontal. About 40 feet farther northeast a parallel cross vein caused a step fault by offsetting the northeastern portion still farther to the southeast.[a]

Another strong fault line is represented by the Old Chicago-Bismarck "vein," a wide soft zone which crosses the Little Mattie-Newton vein several hundred feet east of the Newton shaft. As no work had been done in the Newton, General Thomas, and Decator shafts for many years,

[a] Possibly one of the above-described faults constitutes the so-called Guy Irving vein, which is supposed to be a flat vein said to cross the Little Mattie-Newton vein a few hundred feet west of the Newton shaft.

the levels extending from them were inaccessible and the relations of these faults to the main vein were here undetermined. The mine maps show, on the third level of the Newton, about 660 feet east of the shaft a cross "vein" that probably corresponds to the Old Chicago-Bismarck "vein," which on the third level of the Bismarck mine had a strike of N. 70° W. and a dip of 60° NE.

It is reported that no difference was noticed in the character of the ore in the Newton, on the two sides of the Old Chicago-Bismarck zone. This fault zone is practically unmineralized where it crosses the Little Mattie-Newton vein.

ARTHUR MINE.

The Arthur mine is situated nearly 3,000 feet S. 45° W. of the Little Mattie shaft house, at an elevation of 8,400 feet. The mine is located on a branch of the Little Mattie-Newton vein that is almost directly in line with the main vein, which splits several hundred feet west of the Silver Glance shaft house. The Arthur vein is developed by a shaft from which several levels run, and also by a tunnel about 450 feet in length that starts near the shaft house and runs northeastward on the vein. The levels from the shaft were not examined.

On the tunnel level the wall rocks consist entirely of gneiss and pegmatite, which in many places form an intimate mixture having a gnarled appearance. No porphyry was observed underground on this level, but Mr. Ball found a dike of bostonite porphyry on the surface a short distance north of the mine and traced it to its junction with the Little Mattie porphyry dike. The general strike of the vein is N. 50° to 55° E. and the dip about 75° NW. The vein is a lead of crushed gneiss, pegmatite, and clay, 6 inches to 2 feet wide, which gives way in places to a silicified gneiss or quartz streak of the same width carrying some galena and zinc blende, the latter usually of the black or dark-brown variety, termed "black jack." In places the vein consists of mineralized stringers of quartz showing comb structure, scattered through a belt of gneiss and pegmatite.

A small stope has been made about 100 feet from the breast of the tunnel level and a little drift stoping has also been done at places along this same level. Somewhat more ore was shipped from the shaft workings.

DORRITT AND KING SOLOMON MINES.

The Dorritt and King Solomon mines are located on one of the branch veins southwest of the Silver Glance mine which result from the splitting of the Little Mattie-Newton vein at its southwest end. A crosscut tunnel run on the boundary line between the King Solomon claim on the east and the Dorritt claim on the west enters the hill from a point about 3,000 feet S. 30° W. of the Little Mattie shaft and intersects the vein at about 380 feet from its mouth. A drift on the vein to the northeast, on the King Solomon claim, shows the vein trending N. 40° to 45° E. and dipping 75° NW., while a drift in the opposite direction shows the vein with the same strike but a dip of only about 58° NW.

The country rock is gneiss and pegmatite, with a porphyry dike running along or a short distance northwest of the hanging wall of the vein. This dike, which consists of bostonite porphyry containing pseudomorphs of serpentine after pyroxene, is 4 or 5 feet wide on the King Solomon claim, but in the Dorritt workings narrows in places to only 6 inches to 1 foot. Where the vein is not adjacent to the dike the contact of the dike with the country rock is a very tight flow contact with no gouge or mineral lead intervening.

The vein, which is usually a crushed rock and gouge lead, changes in places to a quartz or silicified gneiss streak 2 inches to 1 foot wide, containing specks and streaks of dull-brown zinc blende and galena scattered through it. In certain parts of the mine the vein consists of a fairly well indurated belt or zone of material composed of numerous slightly rounded to angular fragments of pegmatite and gneiss up to 1½ inches in diameter, in a gray matrix of pulverized rock consolidated by silicification.

Small ore bodies have been found and worked out nearer the surface along this vein on both the King Solomon and the Dorritt claims, but at the time of visit there was only one man working.

WILD ROSE MINE.

The Wild Rose mine is located on the north slope of the ridge between Spring Gulch and Chicago Creek, about 1,500 feet N. 50° E. of the Newton shaft. The workings, which are now inaccessible on account of caving, follow, according to Mr. Tarr, owner of the Red Lyon mine, two veins 20 feet apart that are branches of the Little Mattie-Newton vein, which splits near the crest of the hill between the Newton and Wild Rose shafts.

RED LYON MINE.

The Red Lyon mine is located in Spring Gulch on the west side of the creek, at an elevation of about 8,300 feet. It is about 300 feet northeast of the Star mine. The developments consist of a short tunnel and a winze from which short drifts run.

The workings develop two veins which follow in a general way the contacts on the two sides of a dike of red mottled bostonite porphyry very similar to that in the Newton and Little Mattie mines. These veins are probably branches of the Little Mattie-Newton vein, which forks to the northeast near the top of the ridge between the Newton and Wild Rose mines. The dike of porphyry in the Red Lyon workings splits just southwest of the winze. The east branch of the dike dips 75° NW. and trends on the surface N. 55° E. It is probably the dike encountered in the Star tunnel, where from a point 150 feet from the mouth of the tunnel to the breast it forms the hanging wall of the vein. The other or west branch of the dike runs N. 40° E. up the hill slope, where in places it is separated from the east dike by about 200 feet of pegmatite and gneiss. Near the crest of the ridge northwest of the Bullion King shaft house, however, the two dikes appear to reunite, forming a single dike nearly 30 feet wide.

The Red Lyon mine has produced no ore. Some mineralization has taken place, however, on both sides of the porphyry dike, but mainly along the southeast contact.

STAR MINE.[a]

The Star mine is located in Spring Gulch at an elevation of about 8,300 feet, approximately 300 feet northeast of the Red Lyon tunnel. The workings consist of a shallow shaft and a tunnel about 250 feet in length, which runs N. 40° E. on a vein that dips 70° to 80° NW. In the first 150 feet of the tunnel the wall rocks of the vein consist entirely of pegmatite and gneiss, but along the last 100 feet altered bostonite porphyry forms the northwest or hanging wall of the vein and pegmatite and gneiss the foot wall.

The vein is a strong lead marked by quartz, pyrite, and clay, which in places gives way to fractured gneiss and pegmatite cemented by ore. There is also usually present an unconsolidated postmineral breccia zone 6 inches to 1 foot wide, consisting of clay, crushed rock, and angular fragments of quartz and ore. Remnants of the ore streak left adhering to the wall show seams of galena ore cementing fragments of highly silicified and pyritized gneiss. Little veins in the galena ore show specks of slightly later tetrahedrite (gray copper) or polybasite and also well-formed quartz, siderite, and pyrite crystals coating the galena. The mine has produced a little ore, but has not been worked for some time.

The vein in the Star tunnel is probably another one of the branch veins resulting from the splitting of the Little Mattie-Newton vein northeast of the Newton mine. The porphyry dike forming a portion of the hanging wall near the breast of the tunnel is probably the east branch of the bostonite porphyry dike which splits just southwest of the winze in the Red Lyon mine workings. This dike was traced up the hill slope to the northeast and over the crest of the ridge to a point about 100 feet west of the Bullion King shaft.

BULLION KING MINE.

The Bullion King mine is located at an elevation of over 400 feet near the top of the north slope of the ridge separating Clear Creek from Spring Gulch, about 1,700 feet S. 20° W. of the ore house of the Stanley mine. An underground study of this mine was not made, as the openings

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[a] To be distinguished from the Star tunnel on Chicago Creek (p. 366).

to the mine were closed and the owners were not to be found. The rock in the vicinity of the vein on the surface is all pegmatite and granite, although a dike of bostonite about 18 feet wide occurs about 100 feet west of the shaft house.

The vein seems to have a general N. 55° E. trend. It is probably a branch of the Little Mattie-Newton system of veins and joins the vein along the porphyry dike, which is located farther southwest. It is probably also the same vein as is developed in the Mayflower mine to the northeast.

The low-grade ore found on the mine dump contains galena, pyrite, and black sphalerite, and occurs as small seams running through granite and pegmatite or as a cementing material inclosing angular fragments of the same rocks. A few small specks of tetrahedrite or polybasite were also found associated with the galena.

Considerable ore is reported to have been obtained from the Bullion King workings.

MAYFLOWER MINE.

The Mayflower mine is located on the south bank of Clear Creek about 1¼ miles west of the central part of the town of Idaho Springs. Although on the surface a dike of bostonite

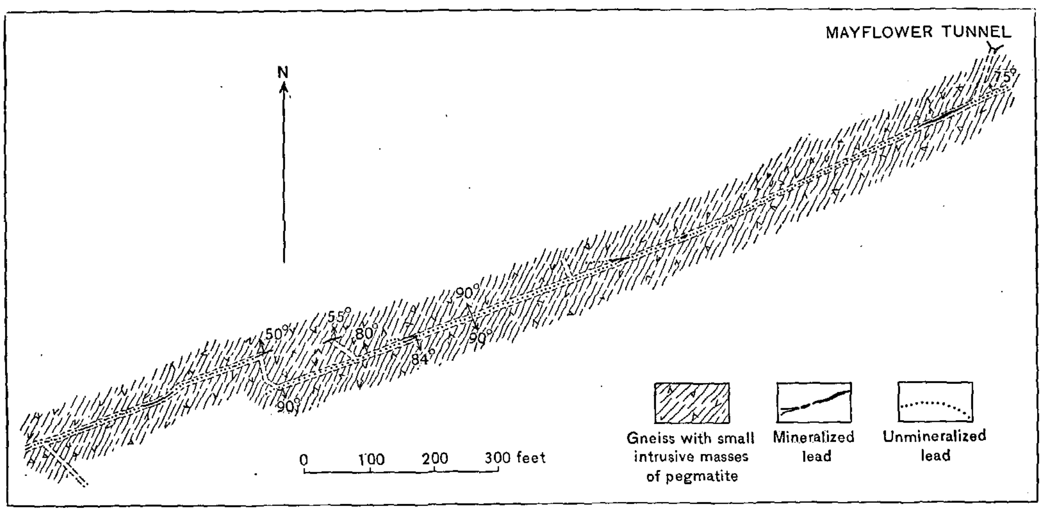


FIG. 139.—Geological plan of Mayflower tunnel.

porphyry is found a short distance away from the point where the vein should outcrop, the wall rocks of the vein, as shown in the underground workings on the tunnel level, consist entirely of gneiss, cut by small intrusive masses of pegmatite.

The development consists of about 1,800 feet of tunneling and drifting. A crosscut tunnel about 90 feet long connects with a drift following a vein which strikes N. 86° E. and ranges in dip from 75° NW. to 84° SE. Near the breast of this drift a crosscut to the northwest about 60 feet in length, connects with a drift extending 400 feet S. 70° W. along another well-developed vein which dips 50° to 55° NW. (See fig. 139.) This second vein possibly connects with the southeast vein followed by the tunnel farther to the northeast, either through cross fractures between the two or by swerving slightly to the south until it joins the southeast vein. Several minor branch veins were noted entering the southeast vein from the west, and one of these may represent the point of junction of the two main veins.

Both of the principal veins consist of clay and crushed-rock leads only a few inches in width, which in places give way to quartz or to quartz and ore. The ore found along the southeast vein consisted of galena, resin, zinc blende, and cupriferous pyrite, associated with quartz and siderite or ferruginous rhodochrosite gangue. Of these minerals the galena and zinc blende appear to have been the earlier to be deposited, for although some cupriferous pyrite is associated with these two minerals most of the pyrite occurs in small veinlets or seams cutting them.

The carbonates, siderite, and rhodochrosite also occur in veinlets of later origin than the galena and sphalerite.[a] Quartz and pyrite crystals, associated with specks of galena and sphalerite, were found in vugs along the northwest vein.

About 100 feet from the mouth of the tunnel an ore body was encountered and stoped for a distance of nearly 100 feet along the vein to the southwest. Aside from this body of ore, however, little mineralization was encountered on either of the two main veins, although small streaks of ore were found here and there near the junction of minor branches with the main leads.

The mine is reported to have produced considerable ore, but most of it evidently came from the lower workings connecting with the shaft, which is now filled with water.

STAR TUNNEL.[b]

The Star tunnel enters the north hill slope bordering Chicago Creek about 1½ miles above the entrance to Spring Gulch. The tunnel for most of its length follows a large soft vein considered to be the continuation of the so-called "cross lode," or postmineral fault zone, which intersects and faults the Little Mattie vein from 10 to 20 feet. Toward its inner end, however, the tunnel leaves the "cross vein" and becomes a crosscut run for the purpose of cutting the vein developed in the Columbia mine, located on the surface a little more than 2,500 feet N. 53° W. of the mouth of the tunnel. Owing to the northward dip of the Columbia vein the distance to be driven at the depth of the tunnel, which is between 700 and 800 feet lower, would be somewhat greater. Although the tunnel is reported to be in the supposed neighborhood of the Columbia vein, no vein recognized as the lode sought had been encountered.

Some mineralization has been found along the main tunnel lode in places, but this vein has yielded but little pay ore. Work was suspended on the Star tunnel during the fall of 1905.

COLUMBIA MINE.

The Columbia mine is situated at an elevation of 8,550 feet on the south slope of the ridge separating Chicago Creek from Spring Gulch, about 800 feet N. 75° E. of the Little Mattie shaft house. The vein, which is developed by a shaft and three short levels aggregating 600 feet in length, trends from east and west to N. 75° E. on the different levels and dips slightly to the north. It splits on the upper level about 40 feet west of the shaft, the branches diverging to the west. A similar split is noticed on the 180-foot level, at a point about 100 feet west of the shaft.

The vein as a rule is very narrow and consists of a seam of comb quartz, clay, and iron oxides one-half to 1 inch wide, but in places where the best ore occurs it widens to 2 to 4 inches of dark-gray quartz which carries considerable pyrite. Locally, however, the vein changes to a silicified streak 6 or 8 inches wide, composed of crushed, fractured, and altered pegmatite and gneiss, heavily stained with iron oxides and carrying low values. The best ore is the dark-gray quartz and pyrite ore which occurs in narrow seams. Most of its values are in gold, and fine specimens which show thin leaves of gold along small cracks in the quartz have been obtained.

Although the pay streak is very narrow, considerable stoping has been done, but most of it is confined to the immediate vicinity of the split in the vein, where the junction of the two branch veins has evidently had a favorable influence on ore deposition. The ore occurs both on the main vein and on the branches for a short distance from the junction.

In the shaft about 40 feet below the third or lowest level a veinlet or seam of chloropal 1 to 1½ inches in width cuts across the ore-bearing vein nearly at right angles to the strike and enters the gneiss and pegmatite walls on either side. The material composing the mass (which is of later origin than the ore of the veins) is a bright yellowish-green granular substance. Under the microscope this is shown to be composed of aggregates of little rounded green grains showing radiating or spherulitic structure. Many of the spaces between these aggregates are occupied by opal. Associated with the chloropal, which is a hydrated iron silicate, is some alumina.

[a] This is possibly a "compound" vein. See p. 364.

[b] To be distinguished from the Star mine in Spring Gulch (p. 364).

BLACK EAGLE AND BISMARCK VEINS.

DEVELOPMENT.

The Black Eagle and Bismarck veins are developed by workings connecting with shafts located at an elevation of about 8,550 feet on the south side of the ridge between Spring Gulch and Chicago Creek, 1,000 to 1,200 feet east of the Newton shaft. As the Bismarck mine[a] had been closed for some time, only the portions of the mine directly connected with the Black Eagle mine workings were observed.

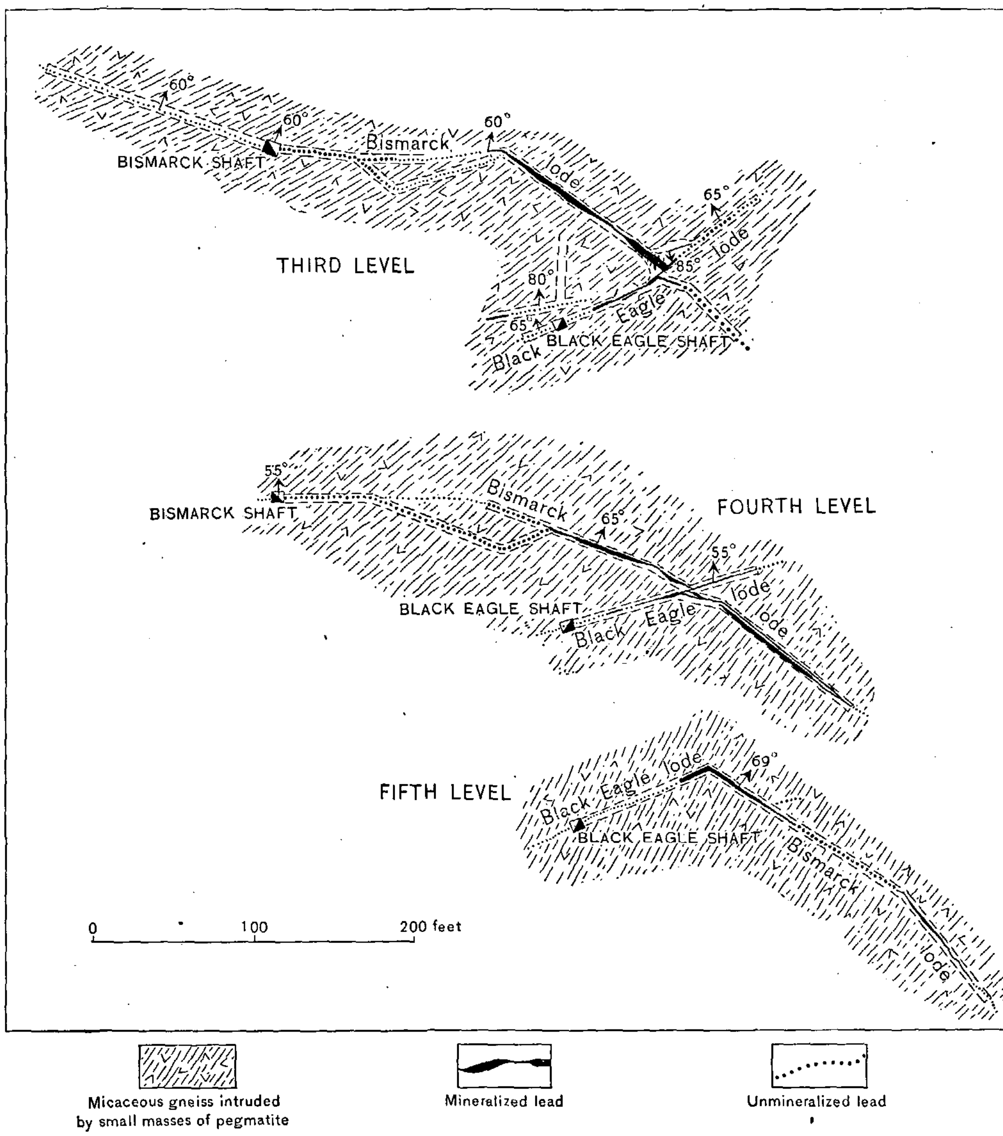


FIG. 140.—Geological plans of separate levels, Black Eagle-Bismarck veins.

The Black Eagle mine consists of five levels connected with a shaft sunk on the Black Eagle vein. A mill was constructed by the company owning the mine to treat the ore. This mill, which contains five stamps, amalgamating tables, and cyanide tanks, however, has proved to be not well adapted to treat the ore from the mine.

DESCRIPTION OF VEINS.

The Black Eagle vein dips 60° to 80° NW., strikes N. 60° to 75° E., and intersects and crosses the Bismarck vein, which strikes northwest, so that the junction of the two is, on some

[a] To be distinguished from the Bismarck lode at Silver Plume, near Georgetown (p. 186).

levels at least, nearly at right angles. Where the Black Eagle vein crosses the Bismarck the latter, as is well shown on the third and fourth levels (fig. 140), is faulted about 6 feet, the southeast portion being offset to the southwest. Near the point of intersection the Bismarck vein, which dips 55° to 65° NE., strikes about N. 60° W., but about 100 feet northwest of the junction it splits into two veins which loop about a horse of rock and then unite and continue almost due west to one of the shafts on the Bismarck vein. This shaft, which is about 275 feet along the Bismarck vein from the junction, or 200 feet N. 60° W. of the Black Eagle shaft, has a dip of 55° to 60° N. and is connected with the workings of the Black Eagle mine on the third and fourth levels. On the third level a drift on the vein extends N. 70° W. for 150 feet from the shaft and probably represents the general direction of this vein to the point where it crosses the Little Mattie-Newton vein a short distance northeast of the Newton shaft.

WALL ROCKS.

The wall rocks of both veins consist entirely of micaceous gneiss and pegmatite, the former being in many places intruded by the latter in such a way as to give the wall rock a gnarled or crumpled appearance.

LOCATION OF ORE.

Both veins, where not especially mineralized, consist of a crushed-rock and clay lead several inches wide containing a little quartz and scattered specks of mineral. The ore on the levels examined was confined to the immediate vicinity of the junction of the two veins. The largest body of ore was encountered on the third level immediately at the junction, along the Bismarck vein for a distance of 125 feet northwest, and along the Black Eagle for 50 feet southwest. On this level little ore occurred on the veins to the southeast and northeast of the crossing. The stope immediately at the junction on the third level was about 20 feet in width, having followed a series of ore stringers into the fractured wall rock adjoining the main veins.

On the fourth level ore occurred on all four arms of the crossing veins, but most of the ore was a short distance from the junction, and the Bismarck vein was the more heavily mineralized of the two. On the fifth level the intersection of the two veins is not well shown, but stoping has been done on portions of the veins corresponding to the Black Eagle southwest of the junction and to the Bismarck southeast of the junction. Both of these intersecting fault leads are therefore older than the main mineralization. Several minor branches which join the main veins near their crossing may also have had some influence on the deposition of ore.

CHARACTER OF ORE.

The ore which is being mined at present consists of galena, black sphalerite, and a little pyrite, and is said to average about $20 to the ton. The values are chiefly in silver, as the ore usually carries only about 0.01 ounce of gold for every 35 ounces of silver. However, assays which gave 0.35 ounce of gold and 100 ounces in silver to the ton have been obtained. Considerable native silver is found at times; it occurs either as wire silver in vuglike openings associated with black sooty sulphides or as flakes along small cracks in the fractured wall rock.

UTE CREEK-CHICAGO CREEK GROUP.

CECIL-ARGO GROUP.

DESCRIPTION OF GROUP.

The Cecil-Argo group of veins is located in Ute Canyon and on the hill slopes due south of the mining village of Lamartine. It consists of the veins developed in the Cecil, Wallace, Argonaut, Argo, Ouida, Sappho, and Gold Coin mines. The main vein, which is developed extensively by the Cecil and Argo mine workings, is a very broad, strong vein with a rather irregular strike which ranges from N. 45° E. to N. 65° E. The dip, as nearly as could be determined from surface outcrops and shafts, ranges from nearly vertical to northwest.

To the southwest the main vein evidently breaks up into the Ouida, Sappho, and several other veins, which diverge slightly in going southwestward. The Gold Coin is a transverse lode which either joins or crosses the Sappho lode. Except in the Sappho and Gold Coin mines, no work has been done on these veins for years, and practically none of the extensive workings on them are accessible.

Northeast of the main Cecil shaft is a line of prospect pits on the vein which trend N. 45° E. If this direction is maintained by the vein underground, it is possible that its continuation would join the vein in the Invincible mine, which is located on the road between Lamartine and Idaho Springs about 2,500 feet east of the Lamartine shaft. The Invincible vein in turn may be a continuation of the Brighton or Freeland Extension vein. However, although these vein segments when plotted on the map seem to have the same general alignment, the correlation of portions of veins so widely separated by unexplored ground can only be guess work, for a slight variation in the strike or dip might within half a mile throw the vein several hundred feet to one side or the other of the projected path. Therefore these vein outcrops, which resemble one another somewhat both in character of the lodes as well as in strike and dip, may be proved by future development to belong to portions of somewhat parallel veins, rather than to connecting veins.

CECIL MINE.

The Cecil mine was opened by extensive drifting from a shaft and by tunnels, but all of these are inaccessible either through caving or through being filled with water. The Cecil shaft is about 2,400 feet S. 7° E. of the main Lamartine shaft. The general trend of the vein at the Cecil shaft is N. 45° E. and corresponds to the line of prospect pits to the northeast.

The country rock in the immediate vicinity is composed of micaceous and granitic gneiss cut by dikes of quartz monzonite, granite, and pegmatite.

To judge from the material on the dump, the vein consists of a broad zone of crushed, highly altered and silicified rock, or of quartz and ore stringers running through the fractured and altered rock mass. Specimens of ore found show galena and zinc blende associated with pyrite. The blende is chiefly of the black variety, although some resin blende is present. According to a miner who had worked in the Cecil, most of the ore produced was of a comparatively low grade and carried only a small percentage of lead, although small amounts of ore averaging 200 ounces of silver to the ton were at times obtained. Small bunches of native silver in flakes and wires were also occasionally found.

Little is known of the production of the Cecil, but E. O. Leech, Director of the Mint, in his report for 1892, represented the yield as follows: Gold, $740; silver, $9,578; lead, $2,295.

ARGO MINE.

The main Argo shaft is about 1,000 feet S. 65° W. of the Cecil shaft. The vein to the northeast has a trend of N. 65° E. and a dip ranging from vertical to a few degrees northwest, as is shown in the Wallace shaft located about halfway between the Cecil and Argo shafts. Southwest of the main Argo shaft the vein, from surface indications, appears to curve around to almost due southwest for a short distance before splitting up into several branches. The large dumps are evidence that extensive development work was done in the mine also, but as in the Cecil the underground workings are now inaccessible. The ore streak is reported to have ranged in width from 3 or 4 inches to 2 feet and to have been composed of black zinc ore, usually carrying less than 5 per cent of lead. Where lead ore itself was obtained it carried only 50 to 60 ounces of silver. Here and there, however, a small streak of soft, black, sooty sulphide ore came in between the hanging wall and the zinc ore, and some of this carried several ounces in gold per ton. The production of the Argo mine has been fairly large, but as for many of the other mines of the district the records are either not obtainable or are incomplete. The following estimates of production are from the reports of the Director of the Mint:

Production of Argo mine.

1887: Gold, $4,040; silver, $27,357	$31,397.00
1888: Gold, $414.40; silver, $13,549.88; lead, $582.56	14,546.84
1889: Gold, $4,500; silver, $32,322.50; lead, $1,900	38,722.50
1890: Gold, $30; silver, $291	321.00
1892: Gold, $640; silver, $3,044	3,684.00
	88,671.34

ARGONAUT AND WALLACE CLAIMS.

The workings on the Argonaut and Wallace claims are inaccessible, but are known to be rather extensive. Moreover, the vein at these points also has produced considerable ore. According to Leech, the Argonaut yielded in 1890 gold, $1,400; silver, $10,443; total, $11,843; and in 1892 gold, $1,954; silver, $16,381; lead, $157; total, $18,492; and the Wallace, which in 1887 was reported to have yielded only $43 in silver, was estimated to have produced during 1892 $600 in gold, $10,965 in silver, and $1,275 in lead, or a total of $12,890 for the year.

OUIDA VEIN.

The Ouida vein, which is probably a southwest branch of the Argo vein, is a short distance northwest of and runs somewhat parallel to the Sappho vein, trending up the hill to the south of Ute Canyon in a S. 41° W. direction. About 150 feet southwest of the mouth of the lower tunnel a small ore shoot, which is said to have yielded in the neighborhood of $63,000, was encountered near the surface, and another body of ore still farther southwest produced about $3,000 worth of ore. The ore, the chief values of which were in silver, consisted mainly of small stringers of galena-zinc ore in quartz monzonite.

SAPPHO VEIN.

The Sappho mine is located about 4,500 feet S. 20° W. of the Lamartine shaft on the southwest side of Ute Creek. The vein is developed by a tunnel about 550 feet in length that intersects the vein at a distance of about 150 feet from the mouth and then continues along the vein to the breast. The wall rocks are chiefly quartz monzonite, which here is a dark granite-like rock containing abundant crystals of black mica. The vein, which has a strike of S. 32° W., consists mainly of a crushed-rock lead that in places gives way to quartz or to quartz and ore. One small stope on the tunnel level yielded $3,500 worth of ore. This ore body seems to have been due largely to the entrance of a small branch vein into the main vein from the north, for the ore occurred on the main vein just beyond the junction. In two other places a slightly increased amount of quartz and mineral formed at the junction of minor veins with the main vein. At the time of visit a few sacks of ore were being obtained from a level about 40 feet above the tunnel. This ore, which consisted of quartz specked with resin zinc blende and a mineral resembling tetrahedrite, was said to carry values amounting to $118 in silver and $4 in gold per ton. Some barite is also associated with the quartz gangue in the ores of this mine.

GOLD COIN VEIN.

The Gold Coin lode is developed by a shaft from which a number of levels run and also by a tunnel level. The wall rocks are mainly quartz monzonite and pegmatite. The vein, which appears to strike S. 70° W. and to dip 60° NW., probably either joins the Sappho vein or crosses the Sappho, Ouida, and other branches of the Argo-Cecil vein. The ore bins show a considerable quantity of low-grade ore high in its content of resin zinc blende, which ranges in color from yellow to brown. Considerable galena and traces of pyrite are also present. The ore appears to be chiefly a breccia containing fragments of ore and wall rock cemented by quartz, much of which shows comb structure. The Gold Coin has produced considerable ore, some of which is said to have carried several hundred ounces of silver to the ton.

HUMBOLDT-MARY FOSTER VEIN.

DESCRIPTION OF VEIN.

The Humboldt-Mary Foster vein is developed rather extensively from a point several hundred feet west of the Mary Foster shaft, which is located at an elevation of about 9,750 feet on the crest of the ridge separating Cascade and Ute creeks, northeastward through the workings of the Humboldt mine to a point where it crosses Ute creek. Many of the workings of both mines are caved shut, as, except for desultory work by one man, the mines have been idle for years. The lower or mill adit on the Humboldt mine, which is open for about 900 feet, is entirely in dark mottled quartz monzonite, with a few masses of intrusive pegmatite.

The average strike of the vein is S. 51° W. and the dip is 80° NW. The vein on the lower level consists of a clay and crushed quartz monzonite lead, giving way in places to quartz and silicified crushed rock or to a series of quartz stringers in fractured quartz monzonite. A little lean ore occurs near the breast of the lower tunnel, but no stoping of importance has been done on this level. The best and largest bodies of ore were found near the boundary line between the Humboldt and Mary Foster claims. According to Mr. Julius Hell, ore extended continuously along the vein on the Mary Foster claim for a height of 60 feet and a length of 100 feet immediately southwest of the 150-foot shaft sunk on the boundary between the Humboldt and Mary Foster claims. Ore was also stoped for a distance of 150 feet northeast of the same shaft along the upper Humboldt tunnel level, which is about 150 feet above the lower tunnel.

CHARACTER OF ORE.

The ore is a galena and zinc blende ore carrying some pyrite associated with quartz. Tetrahedrite and polybasite are also present in the best ores. Mr. Hell stated that the ore northeast of the line between the two claims carried only from 10 to 30 ounces of silver, but that toward the southwest the amount of "gray copper" (tetrahedrite) and the silver content in the ore increased, so that many ore samples from the Mary Foster carried between 200 and 400 ounces of silver. The regular mill runs ranged from 16 to 111 ounces of silver as a rule. One small mass of ore from a depth of 50 feet below the surface near the crest of the ridge is said to have carried 10 ounces in gold and 1,300 ounces in silver. Specimens of native gold in fine grains associated with resin blende are also reported to have been obtained from the Humboldt mine.

ALEXANDER LODE.

The Alexander lode runs somewhat parallel to the Humboldt vein and about 500 feet farther to the northwest. Its strike is in general S. 65° W. and its dip 80° NW. The country rock in the vicinity is quartz monzonite. The ore consists of small streaks of quartz containing specks of galena and some tetrahedrite in fractured quartz monzonite. A little ore running between 200 and 300 ounces in silver to the ton has been obtained from this vein.

SILVER HORN OR GOLDEN HECLA MINE.

LOCATION AND DEVELOPMENT.

The Silver Horn or Golden Hecla mine is located in the valley of Ute Creek at an elevation of about 9,000 feet. The workings, which are mainly in quartz monzonite, cut by a few dikes of pegmatite, consist of a shaft from which drifts between 100 and 200 feet long are run on two levels, and of a tunnel level (see sketch map, fig. 141) which consists of a short crosscut tunnel and about 700 feet of drifting on the two veins encountered.

SILVER HORN VEIN.

The main vein developed by the mine workings is the Silver Horn vein, which immediately northeast of the shaft trends N. 55° E. and dips 75° NW., but which between 200 and 400 feet east of the shaft swerves slightly more to the north and then turns again and continues in a N. 68° E. direction until it disappears in the breast of the drift. About 400 feet northeast of the shaft the Silver Horn vein comes into contact with a broad vein termed by the miners the "soft lode," which is a large, unconsolidated lead from 1 foot to several feet wide, composed of clay, quartz, and crushed country rock, bearing only faint evidence of mineralization. Its general strike, which is S. 60° W., would carry it a short distance northwest of the shaft. Slickensides and movement striæ dipping northeast at 2° from the horizontal, together with the crushed-rock vein filling, indicate that the "soft lode" is a fault line along which movement has taken place since the deposition of the ore in the Silver Horn vein. Although a little ore is found in places along this "soft lode," it usually occurs as isolated fragments or as lens-shaped slices of quartz and crushed galena-blende ore resembling in nature the ore from the Silver Horn vein. As the latter vein loses its identity for a distance of about 25 feet, where it comes into contact with the "soft lode," it is probable that the "soft lode" cuts off a portion of the Silver Horn vein at the point where it curves farthest to the west (see fig. 141), and that the ore occurring along the "soft lode" is simply "drag" from the crushed vein filling of the Silver Horn lode.

The Silver Horn vein itself is comparatively narrow, consisting either of a single crushed-rock and quartz lead which in places gives way to quartz and ore, or of foot- and hanging-wall leads separated by 1 to 3 feet of country rock which is intersected by a series of small quartz or quartz and ore stringers.

On the first level below the tunnel level, about 60 feet northeast of the shaft, a small pegmatite dike intrusive into the quartz monzonite forming the wall rocks has been step faulted and irregularly dissected by a series of fractures which include the foot- and hanging-wall leads (fig. 142). Some of these fractures are filled with narrow seams of clay; others are occupied by slightly mineralized quartz.

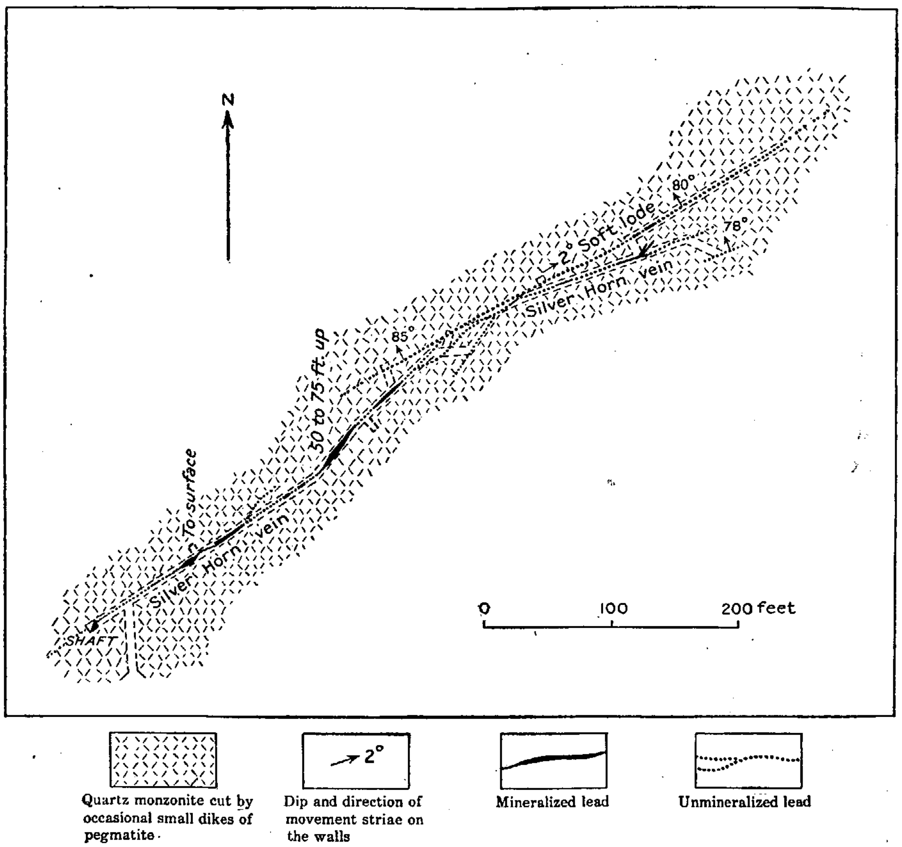


FIG. 141.—Geological plan of Silver Horn (Golden Hecla) tunnel.

The ore consists of galena and zinc blende, carrying a little pyrite and some tetrahedrite. Quartz is the chief gangue mineral. The zinc in some of the ore is high and ranges from a yellow or a brown to a peculiar reddish variety of sphalerite. The red sphalerite was especially prevalent in a streak of zinc ore encountered in sinking the shaft. The ore, while usually occurring in narrow seams which must be mined along with considerable country rock, is of comparatively high grade. Exceptionally high values in both gold and silver are reported as having been obtained from picked samples, and the mill run showing the lowest values consisted of ore averaging 0.5 ounce in gold and 70 ounces in silver to the ton. Small shipments, however, are said to have showed as much as 6 or 7 ounces of gold to the ton. But little stoping has been done in the mine, and most of it was confined to the tunnel level. The largest and best ore body was located about 240 feet east of the shaft and was stoped out for a length of about 35 feet and a height of 50 to 75 feet. At several other places, however, on the tunnel level the vein is stoped up from a few feet to 25 feet.

About 25 feet east of the breast of the drift on the Silver Horn vein, in the face of a short spur, was found a veinlet of hematite and calcite about 1 to 1½ inches wide. On the foot-wall side of this stringer was a 2-foot dike of pegmatite carrying some included magnetite which appeared to be a primary constituent of the pegmatite. The hematite was probably of secondary origin, due to the action of underground waters on the primary magnetite in the pegmatite or on the pyrite in the vein.

ARGUS VEIN.

A short distance southeast of the Silver Horn shaft house is a broad stained, crushed, and friable rock lead called the Argus vein. This vein, which has a nearly vertical dip, crosses the valley of Ute Creek in a S. 53° W. direction. It shows only faint signs of mineralization.

NORMAN VEIN.

Several hundred feet east-northeast of the Silver Horn mine is the Norman lode, which has a trend on the surface ranging from N. 60° E. to N. 68° E. and a dip of about 80° NW. This lode is developed by a shaft 95 feet deep with short drifts at the bottom. The lead consists

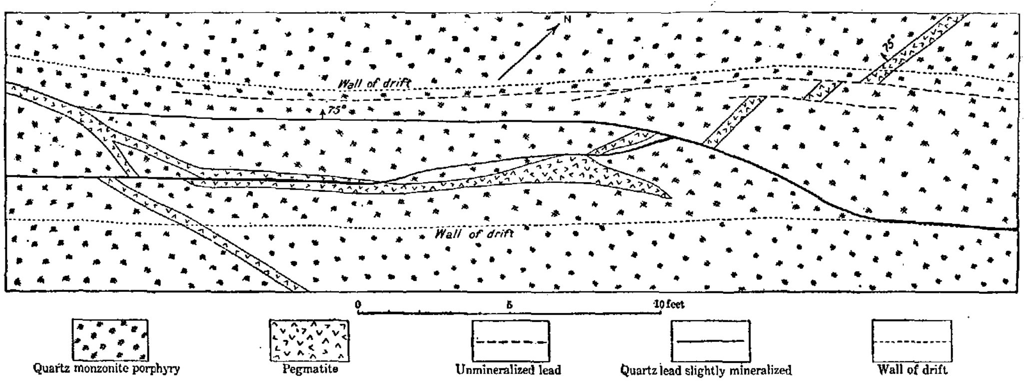


FIG. 142.—Horizontal plan of portion of 50-foot level, Silver Horn mine, showing horizontal offsetting of pegmatite dike by the vein faults of the ore zone.

of crushed rock recemented by silica. The little ore taken from the vein consisted of galena and zinc blende carrying small amounts of a gray mineral which is probably tetrahedrite or specularite.

"M AND M" TUNNEL.

The "M and M" tunnel is located in the valley of Ute Creek about 400 feet above the Silver Horn (Golden Hecla) mine. The development consists of a very tortuous crosscut tunnel between 700 and 750 feet in length, which in places follows slips in the fractured country rock, and short drifts along three somewhat parallel veins. The country rock consists chiefly of quartz monzonite cut by pegmatite dikes.

What is called the Little Helen vein is intersected at a point between 400 and 450 feet from the mouth of the tunnel, and has been drifted on for about 125 feet. This vein has a strike of N. 70° E. and a dip of 80° to 85° NW. It consists of a 1- to 2-inch quartz streak in a crushed rock lead 1 foot wide.

Near the breast of the tunnel what is termed the "M and M" vein was encountered. It strikes N. 66° E., dips 80° NW., and so far shows only faint signs of mineralization. A small, slightly mineralized vein runs parallel to the "M and M" vein about 60 feet to the southeast. The mine has produced no ore, although narrow seams of black zinc blende, associated with comb quartz and a little galena, have been found cutting fractured quartz monzonite and pegmatite along the vein zone.

A shaft on the road above and to the north of the "M and M" tunnel is probably sunk on one of the veins exposed on the tunnel level.

ELLA M'KINNEY MINE.

The Ella McKinney mine is located in the valley of Ute Creek between 500 and 600 feet southeast of the Silver Horn (Golden Hecla) mine. The development consists of about 700 feet of tunneling and drifting. The first 500 feet of workings consist of very tortuous crosscut drifts in hard, fresh quartz monzonite. The inner 200 feet follow a weak crushed-rock lead 2 to 4 inches wide, which in places carries a little quartz and pyrite. The quartz in spots was stained black, but showed no recognizable galena or zinc blende. This mine has evidently produced no ore.

CHARTER OAK MINE.

The Charter Oak vein is developed through a shaft located at an elevation of about 9,550 feet on the summit of the ridge separating Cascade and Ute creeks. This mine was closed down at the time of visit, but had been in operation only a year or so previously. The underground workings, though probably in good condition, were not visited.

On the surface in the vicinity of the shaft house two veins a short distance apart were found running parallel to each other with a strike of N. 65° E. and a dip of 80° NW.

The ore found on the dump consisted of galena, resin blende, and pyrite, associated with quartz, barite, and a considerable amount of oxides of iron (both hematite and limonite) and manganese. The ore occurs both as stringers traversing quartz monzonite and pegmatite and as a cementing material about angular fragments of these rocks. Some of the specimens show crustification in which galena associated with a little blende is of earlier deposition than the pyrite. Magnetite, probably of primary origin, was noted in some of the pegmatite masses from the mine. Hematite seams of secondary origin which cut across stringers of ore were also observed. The mine has yielded considerable ore.

KITTY EMMET MINE.

The Kitty Emmet mine is located at an elevation of about 9,250 feet on the south slope of the bridge bordering Cascade Creek, 1 mile N. 70° W. of the junction of Cascade and Chicago creeks. The vein, where opened up on the surface, trends N. 50° E. and dips 75° NW., and is composed of a quartz and crushed and stained rock zone. The country rock was mainly quartz monzonite. The mine has been idle for some time.

MARY MATILDA AND LITTLE FLAT MINES.

The veins on the Mary Matilda and Little Flat claims are developed by a tunnel about 325 feet in length and by a very flat inclined shaft from which short levels run. The country rock is quartz monzonite. The vein in the tunnel consists of a series of connecting fractures which trend in general N. 55° to 60° E. These irregular fractures show but little mineral, except at a point about 200 feet from the mouth of the tunnel, where a streak of good-looking quartz and galena ore 2 to 5 inches wide extends for a distance of about 30 feet along the vein, which here dips flatly to the northwest. The ore from this streak consists of a fine breccia of country rock cemented by galena, which is associated with small amounts of sooty black sulphides and iron oxides. Crusts and small crystals of ferruginous rhodochrosite lining small vugs are also occasionally found in this ore.

The shaft, which follows the flatly dipping vein for much of the way, dips only 15° NW. near the top, but lower down has an inclination of 23° from the horizontal. Short drifts are run on four levels. The longest two of these are on the bottom or fourth level. One drift on this lowest level follows the vein to the N. 55° E. for about 70 feet, while the other extends irregularly to a point about 100 feet S. 45° W. of the shaft. The vein on the bottom level consists of two black selvage leads 2 to 6 feet apart, with crushed and very highly altered quartz monzonite between. About 1 inch of dark-gray quartz showing faint indications of mineral is associated with the black selvage streaks, but no ore has been obtained from any of the shaft workings.

BURNS-MOORE TUNNEL.

The mouth of the Burns-Moore tunnel is located on the north side of Chicago Creek between Ute and Cascade creeks. At the time of visit the tunnel, which was being actively driven, was about 2,200 feet in length. The whole tunnel was driven in comparatively fresh, massive quartz monzonite. No veins of importance had been encountered in the whole distance, although between 1,100 and 1,200 feet from the mouth of the tunnel some drifting had been done on the so-called Modoc vein, which here strikes N. 66° E. and consists of a series of small white clay slips in fractured quartz monzonite.

About 100 feet south of the Burns-Moore tunnel is a shaft from which a drift runs 60 feet to the southwest on a vein striking S. 54° W. and dipping 50° NW. Near the breast of the drift, on the northwest side, was a small streak of galena-sphalerite ore carrying a little tetrahedrite (gray copper), and to the southeast of this was a 2-foot belt of fractured quartz monzonite with minute pyrite stringers running throughout, which formed the rest of the vein zone. Quartz is the chief gangue mineral of the ore.

DUMBARDIN MINE.

The Dumbardin mine is located at an elevation of about 8,900 feet on the crest of the ridge separating Maximilian Gulch from the valley of Chicago Creek. It develops a vein which on the surface runs in a general northeast-southwest direction and to the southwest probably joins the N. 54° E. vein found in the shaft located about 100 feet south of the mouth of the Burns-Moore tunnel. The Dumbardin mine is said to have produced about $8,000.

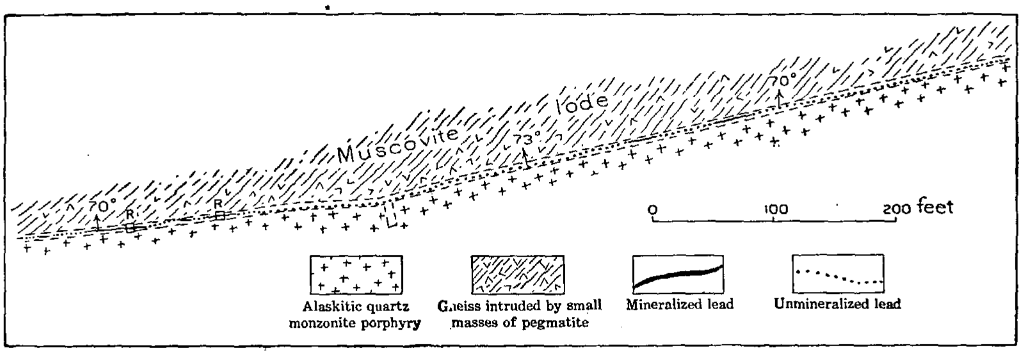


FIG. 143.—Geological plan of lower Muscovite tunnel. R, Raise.

MUSCOVITE-SILVERINE LODE.

GENERAL DESCRIPTION.

The Muscovite-Silverine lode crosses the head of Eclipse Gulch at an elevation of about 9,050 feet. From the upper workings on the Muscovite, on the ridge to the west of the gulch, to the openings on the Silverine, on the ridge to the east, the vein on the surface strikes N. 60° E. except where it swerves slightly to the northwest in the gulch, owing to its average dip of about 72° NW.

The Muscovite mine consists of tunnels on the part of the vein lying southwest of the gulch; the Silverine mine is composed of tunnels located on the northeast part.

CHARACTER OF VEIN.

The lowest tunnel on the Muscovite (fig. 143), which is more than 800 feet in length, runs S. 80° W. and follows a strong lead of crushed quartz, gneiss, and pegmatite. This vein, though containing considerable quartz, is for the most part but slightly mineralized. For most of the way it follows immediately along the northwest contact of a 10- to 14-foot porphyry dike, though in a few places lenses or horses of pegmatite and gneiss come in between the vein and the porphyry. In the upper tunnel of the Muscovite the vein has the same general relation to the porphyry dike. Across the gulch to the east, in the workings of the Silverine mine, the vein consists of 1 to 2½ feet of clay, crushed granite, and porphyry, which in places gives way to quartz. Slightly mineralized quartz stringers were also observed forming a network in fractured granite. The porphyry in general forms the foot wall of the Silverine vein also, but evidently has been cut in places by the vein, which is of later origin, as shown by angular breccia fragments of porphyry in the lead and also by small quartz, siderite, and galena stringers cutting the porphyry. The porphyry along the vein in both the Muscovite and the Silverine mines corresponds to the rock in a dike that Mr. Ball found on the surface and classified as alaskitic quartz monzonite porphyry.

CHARACTER OF ORE AND PRODUCTION.

According to miners working in the vicinity, lessees took out something like $120,000 worth of ore from the lower level on the Silverine. The values in this ore were chiefly in gold, although considerable silver was present. Some of the ore is said to have carried between 7 and 8 ounces in gold. No work has been done in the Silverine mine in recent years and nearly all the workings are caved shut.

But little ore has been produced by the portion of the vein southwest of Eclipse Gulch, but at the time of visit a small amount was being obtained from the upper tunnel of the Muscovite mine. This ore, which occurred in small bunches irregularly distributed along the vein and was composed of dark-gray pyritiferous quartz and silicified fragments of wall rock carrying galena and dark-brown sphalerite, was said to carry values between $100 and $120 to the ton, of which $70 to $80 was in silver. A characteristic feature of the Muscovite-Silverine vein, according to the miners, was that the ore to the west of Eclipse Gulch carried more values in silver than in gold, whereas on the east or Silverine side of the gulch the reverse was true.

ROCKY CLIFF LODE.

About 100 feet northwest of the Silverine lode is situated a minor vein termed the Rocky Cliff lode, which runs in granite parallel to the Silverine vein. No production is reported.

BUCKEYE TUNNEL (ON ALPS MOUNTAIN).

The Buckeye tunnel is located about 250 feet north of the lowest workings on the Silverine lode and consists simply of a crosscut tunnel 200 feet in length, which was being driven for a vein found outcropping on the surface several hundred feet farther north.

ECLIPSE MINE.

DESCRIPTION.

A mine located about 250 feet south of the lower tunnel on the Muscovite vein, near the head of Eclipse Gulch, was termed the Eclipse mine by miners in the vicinity, who also stated that the production of the mine had been considerable. The development appeared to be extensive and to consist of a tunnel level and of a shaft connecting with lower levels, but the mine had not been worked for a considerable length of time and the workings were not accessible. The vein runs approximately parallel to the Muscovite vein and strikes about S. 67° W. and dips 70° NW.

CHARACTER OF THE ORE.

The specimens of ore found in the shaft house and on the dump consist of galena, black zinc blende, and pyrite, associated with a little tetrahedrite and argentite. In some places the ore evidently occurred as small stringers cutting granite and gneiss; in others it was a partial replacement of these same rocks.

BIG FORTY MINE.

The Big Forty mine is located in Maximilian Gulch, near its junction with the valley of Chicago Creek. Its development consists of a crosscut tunnel about 550 feet in length, which runs about N. 40° W., and short drifts along the three small veins intersected by the tunnel.

The workings are all in gneiss, consisting both of the soft biotitic and hard granitic varieties. The schistosity of the gneiss ranges in trend from N. 80° E. to N. 55° E., and in places is parallel to the veins. The three veins or leads, which, in the order encountered in driving the tunnel, have strikes of N. 75° E., N. 45° E., and N. 55° E., respectively, are narrow quartz and crushed-rock leads only 1 to 3 inches wide, which show but slight mineralization. About 150 feet due east of the mouth of the Big Forty tunnel is a tunnel 40 feet or so in length, which runs northwestward to strike a clay and crushed-rock lead striking from N. 65° E. to N. 45° E. and dipping 85° NW. Near the breast of the 150-foot drift on the vein a dike of dark-gray brittle porphyry comes in on the northwest side and forms the hanging wall to the vein. The porphyry has conspicuous black biotite phenocrysts and belongs to the biotite latite porphyry class.

GOLDEN GLEN MINE.

The Golden Glen mine is located in Golden Glen Gulch at an elevation of about 8,600 feet, on a northeast-southwest vein. The production of the mine has been about 10 tons of ore, averaging $95 to the ton. The ore, in which the values are about equally divided between gold and silver, is a quartz and pyrite ore containing specks of galena and here and there a little tetrahedrite (gray copper).

BEAVER MINE.

LOCATION AND DEVELOPMENT.

The Beaver mine is located at an elevation of a trifle over 8,000 feet on the north side of Clear Creek valley, a little more than a mile above the entrance to Spring Gulch. The development consists of an inclined shaft about 250 feet deep and levels aggregating 800 feet in length connecting with the shaft.

WALL ROCKS.

The workings are run in a complex of gneiss, granite, and pegmatite. The gneiss is both granitic and micaceous; where schistosity is developed it strikes about N. 60° E. and is in places parallel to the vein but usually dips 60° to 85° NW., the vein being much flatter.

ROLLING CHARACTER OF MAIN VEIN.

The vein, which is very flat and strikingly irregular, is developed by a shaft which follows it for most of its length, and by several very tortuous drifts which leave the shaft at irregular intervals. The great irregularities in the workings are due to the nature of the flat vein, which at many places changes both its strike and dip within exceedingly short distances. The vein not only forms a series of wavelike rolls along the length of the shaft to the north, but also undulates where drifted on to the east and west. At a point 190 feet from the collar of the shaft the vein, just beyond the lowest drift, after dipping 15° to 30° N. for nearly its whole length, flattens to horizontal and then begins to rise, changing its dip to 15° S., so that the shaft in following the vein starts up hill and rejoins a drift that follows the vein first to the west and then to the north and northwest from the point where the lowest level leaves the shaft. At this point the vein is in the back of the drift and shaft and dips to the south, so that the change in dip has been very decided.

The dips in general range up to 35° from the horizontal in a series of steplike rolls. Near the northeast breast of the lowest level an inclination as great as 60° from the horizontal was observed, but this is an exception to the general dip. An idea of the abrupt changes in dip, however, can best be obtained from the dip readings as plotted in the sketch of the underground workings shown in fig. 144.

DESCRIPTION OF OTHER VEINS.

The shaft was sunk for a distance of about 100 feet on the incline before the main vein was encountered at a point where it appeared to be cut off to the south and southeast by a clay and crushed-rock cross lead striking N. 85° W. and dipping 50° S. About 75 feet west of the shaft on the first level a clay and crushed-rock lead emerges from the north wall and simply comes into contact with or else barely cuts through the ore filling of the Beaver vein, and then swerves and leaves the Beaver vein again on the same side as it entered, trending S. 75° W. for 150 feet to the point where it enters the breast of the drift on it. This so-called cross vein, which is termed the Washington vein, carries some ore near the west end of the level, where small stope and raise 27 feet in height connect with a shaft to the surface. A vein near the west breast of the lowest level of the mine, with a strike of S. 85° W. and a dip of 32° N., has an attitude corresponding somewhat to that of the Washington vein on the level above, but seems to cross the Beaver vein and to fault it slightly, so that the portion of the Beaver vein to the south of the cross vein is about 6 inches lower than the north portion. This cross vein consists of a gray to black gouge streak one-half inch wide, associated with several inches of crushed pegmatite and granite stained by iron oxides, or of a series of minute reddish blende stringers in hard granite.

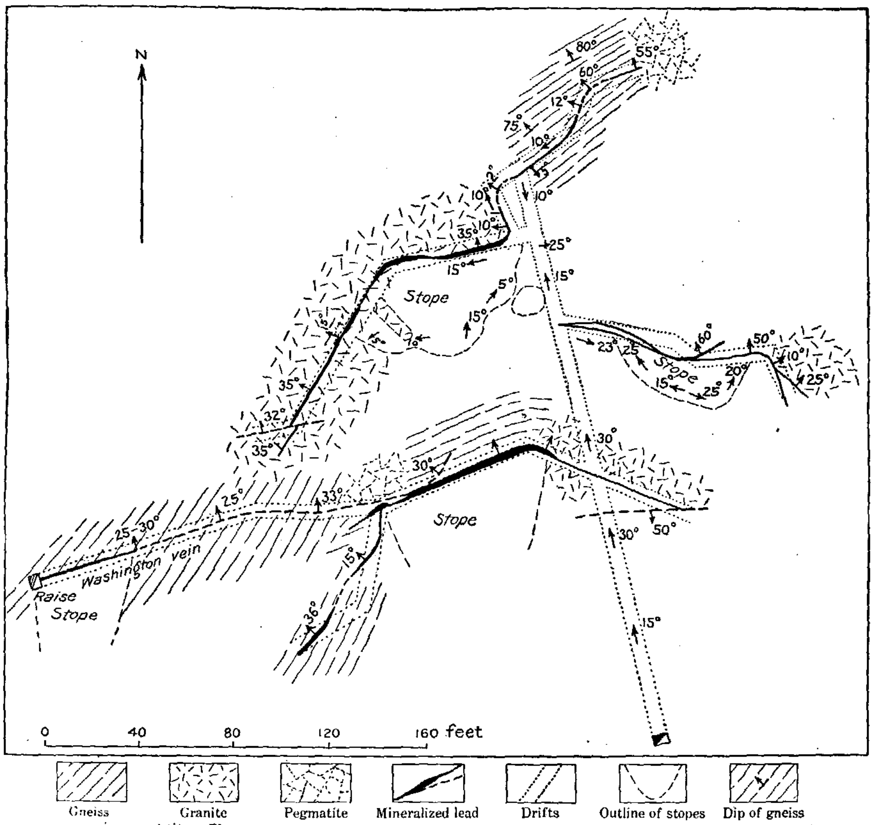


FIG. 144.—Geological plan of Beaver mine. The undulations of the vein are shown by arrows (showing local dips).

CHARACTER OF ORE.

The ore obtained from the mine consists of coarse to fine grained galena, black sphalerite, and pyrite, associated with some black sooty sulphides. The ore of the first class (sorted), which is comparatively free from zinc blende and contains considerable fine-grained galena, is said to run 65 per cent of lead, 90 ounces in silver, and 0.35 ounce in gold. However, a small shipment of sorted coarse galena ore showed 80 per cent of lead, 65 ounces of silver, and 0.45 ounce of gold. The ore streak, as a rule, is narrow, rarely attaining a thickness of 4 or 5 inches.

LOCATION OF ORES.

A striking peculiarity in connection with the distribution of the ore was mentioned by Mr. F. F. Hoban, the manager of the mine, who stated that where the vein descends in a series of steplike rolls or waves and comparatively level stretches of the vein connect places of steeper dip, the most and best ore is located at the crest of the roll. (See fig. 144.) A possible explanation for this is that movement took place subsequent to some mineralization along the vein, and that this movement, instead of causing a reopening of the vein in a manner similar to that occurring in other veins of the district, resulted in a buckling or folding of the vein and inclosing rocks due to some compressive force which had developed. The effect of the buckling or folding being most strongly felt on the crests of the folds, fractures or openings formed there, in which the main ore deposition took place.

BLACK SWAN MINE.

The Black Swan mine is located on the north side of Chicago Creek 4,000 feet west of the point where the valley is joined by Spring Gulch. The mine consists of a crosscut tunnel about 125 feet in length and a very tortuous drift on a vein running N. 50° W. for about 535 feet. The vein usually consists of a quartz and pyrite lead one-half inch to 2½ inches wide in gneiss. At a distance of about 275 feet from the mouth, however, there is a small stope about 50 feet in length which yielded some ore. Owing to its flat dip its course on the surface is N. 70° to 75° W.

P. T. MINE.

GENERAL DESCRIPTION.

The P. T. mine lies at an elevation of about 8,000 feet on the spur separating Spring Gulch and the valley of Clear Creek, and is distant about three-fourths of a mile S. 75° W. from the junction of these two valleys. The mine develops an irregular east-west vein, by means of a shaft and three short levels aggregating about 500 feet in length. The vein, which dips from 50° to 55° N., on both the 50-foot and 150-foot levels has a dike of porphyry as a foot wall for most of the way.

ALTERATION OF PORPHYRY.

This porphyry on microscopic examination proves to be a bostonite which shows a trachytic groundmass of lath-shaped feldspars, partly altered to kaolin and sericite and containing secondary adularia, pyrite, and quartz, both in veinlets cutting the groundmass and as small, isolated patches in it. Possibly some of the pyrite in the rock is an original constituent, for well-formed crystals of the mineral contain inclusions of feldspar; moreover, some of the crystals have been fractured and the cracks cemented by the later quartz and adularia veinlets.

RELATIVE AGE OF DIKE AND VEIN.

The bostonite porphyry was evidently intruded prior to the vein formation, as much of the vein filling consists of a clay and crushed porphyry, pegmatite, or gneiss lead. Furthermore, on the 150-foot level west of the shaft narrow lenses of porphyry 6 inches to 1¼ feet wide occur in the vein zone, and the mineralized leads loop about them.

CROSS LEAD.

On the 50-foot level just west of the shaft the main vein and the porphyry foot wall both seem to end abruptly against a N. 38° E. lead which cuts across and possibly faults the vein a short distance. The mine workings on this level were not sufficient to show the extent of the faulting. The cross vein, however, probably corresponds to the N. 45° E. vein found about 75 feet east of the shaft on the 100-foot level, where it comprises foot- and hanging-wall leads dipping 50° to 65° SE. and connects the N. 83° W. portion of the main vein with the east portion, which strikes S. 75° E. and is located about 15 feet farther north.

CHARACTER OF ORE.

The ore obtained from the mine consists of copper-bearing pyrite and quartz, associated with considerable tetrahedrite and siderite. The minerals are in many places well crystallized. The tetrahedrite and siderite are of a later period of deposition than the pyrite and quartz, and occur only in vugs coating crystals of these minerals. Much of the pyrite ore, especially where cupriferous, is coated by a dark-blue to iridescent film which is probably chiefly chalcocite, a sulphide of copper. The last shipment of first-class sorted ore ran 4.41 ounces in gold and 3.71 ounces in silver to the ton.

The vein is stoped almost continuously from the 50-foot level to the surface, and for a length of 75 feet, and smaller stopes have been made on both of the lower levels. The mine has produced about $70,000 and is still shipping ore.

QUITO MINE.

The Quito mine, which is located on the north side of Chicago Creek about 3,000 feet west of Spring Gulch, is one of the first mines to produce ore in this part of the area. The vein, which runs approximately east and west through an area of gneiss and pegmatite and dips very slightly to the north, probably joins on the west the extension of the vein developed in the P. T. mine. The mine workings below the tunnel level are filled with water. The Quito has produced a good many thousand dollars' worth of ore, but the exact amount could not be ascertained.

TORPEDO MINE.

The Torpedo mine is located at an elevation of 8,150 feet in Spring Gulch, about 1 mile N. 85° W. of the junction of Spring Gulch and Chicago Creek. The wall rocks consist of fresh, hard, black gneiss and pegmatite. The strike of the vein where it outcrops on the surface is S. 52° W. and the dip is 65° NW. The lead, where mineralized, consists in the main of dark-gray quartz, inclosing small masses of galena, sphalerite, and pyrite. However, small veinlets of telluride ore have also been found. Specimens on the mine dump showed a series of small quartz and mineral veinlets cutting fractured gneiss and frozen or adhering tightly to the wall rocks. Although extensive development work has been done on this mine, through a tunnel and also through drifts connecting with a shaft, it has produced little ore.

WALTHAM MINE.

The workings of the Waltham mine are located on the southeast slope of the low spur separating Chicago and Clear creeks, near the junction of the two streams. The development consists of three short tunnels and a shaft 200 feet in depth from which short drifts run. (See Pl. LXXVI, *B*.)

On the upper tunnel level two short tunnels, about 20 feet apart, expose two veins striking N. 43° W. and N. 58° W., both of which dip 65° NE. The 140-foot level connecting with the shaft shows two somewhat parallel veins running N. 38° W. and N. 44° W. and dipping 60° to 65° NE. These two veins are connected by a cross vein running N. 80° W. and dipping 60° N. The southwest vein on this level consists of a clay and crushed-rock lead 6 inches to 1½ feet wide, containing scattered nodules of pyritiferous quartz. The northeast vein consists of a crushed-rock zone 4 to 6 feet wide, which in places carries stringers of mineral, consisting chiefly of pyrite with some galena. The wall rocks are gneiss, pegmatite, and sheared diorite. They are much fractured and altered between and around the different veins, and are in many places impregnated with pyrite to such an extent that the whole mass carries slight values in gold. The pay streaks, however, are so far confined to the immediate vicinity of the veins, especially near places where the wall rocks are firmer and less fractured.

The ore, which has been of comparatively low grade, was first obtained from an open cut at the surface where the vein zone was worked for a width of 25 feet, but as this ore contained too much waste for profitable treatment the work is now limited to ore derived from the immediate vicinity of the vein fractures. The output, which so far has been small, has been run through an amalgamating and concentrating mill just below the mine, and the tailings derived from the mill have been treated in the large cyanide plant adjacent to it.

The vein zone developed by the workings of the Waltham mine is considered to be a part of the broad cross lode which has been traced on the surface for a long distance, and runs about N. 57° W., cutting the main northeast-southwest belt of veins. The vein is probably the same as the one developed on the Ward, Michigan, Little Mack, and other claims.

SODA CREEK GROUP.

To the southeast of Idaho Springs along the valleys of Soda Creek and its tributaries are a number of small mines. Little ore, however, has ever been produced by this section of the mineralized area, and therefore, although considerable work has been done in some of the mines, practically all of them can be considered only as prospects.

SODA CREEK MINES.

In the main valley of Soda Creek several mine openings are to be found, and among the most prominent of these are the Columbia and the Coming Nation. Both of these are said to have produced some ore, the Columbia having yielded some free gold. The Coming Nation mine is interesting because a little nagyagite, a sulphotelluride of gold and lead, is said to have been found in it. The veins in both of these mines have a general northwest-southeast trend.

BARBOUR FORK VEINS.

A few veins were also encountered in Barbour Fork valley about a mile above the point where it joins Soda Creek. Among the properties located here are the Gold Leaf, Gold King, and Maple Leaf.

Some of these are reported to have carried a little native gold in the oxidized portions of the veins near the surface. All the workings have been abandoned for years, however. The main veins observed were very irregular in trend, owing to the flat dips of 10° to 35°. The veins near the surface consist of a soft yellowish to purplish streak of crushed rock and quartz heavily stained by oxides and carbonates.

A few prospects of minor importance have also been developed to some extent in both Soda Creek Valley and Squirrel Gulch, above the junction of the two.

LEXINGTON MINE.

The Lexington mine, situated at an elevation of about 9,000 feet on the divide between Squirrel and Warren gulches, develops the most important vein opened up so far to the southeast of the town of Idaho Springs. The vein is in an area composed chiefly of biotite granite, but containing considerable pegmatite of both the biotitic and muscovitic varieties, and also a little gneiss. The main vein is extensively developed by a shaft from which several levels run. The workings, however, are inaccessible owing to filling by water and to excessive caving during a long period of idleness. The main vein at the shaft has a strike of N. 75° W. and a dip of 48° N. About 350 feet northwest of the shaft, however, the vein where it outcrops on the surface splits, one branch trending S. 85° W. and dipping 50° N., while the other branch runs N. 45° W. with a like dip for a short distance and then in turn splits up into still other branches.

The mineral found on the dump consisted entirely of pyrite, associated with massive gray quartz or with comb quartz in the form of stringers in the country rock.

LITTLE RICHARD MINE.

The Little Richard mine is located about 2,000 feet northeast of the Lexington shaft in Warren Gulch, at an elevation of about 8,250 feet. It consists of a shaft 600 feet deep and of a long tunnel level. The tunnel follows a N. 70° W., slightly mineralized lode for a distance of 500 or 600 feet, to the point where a split in the vein takes place. Beyond that point the tunnel becomes very tortuous and follows several mineralized slips in biotite gneiss but in general becomes a crosscut drift heading in an irregular way for the Lexington and Preacher lodes, which lie a considerable distance to the southwest. A little ore, averaging about $15 to the ton, was found along the tunnel vein for a distance of 60 feet southeast of the point where the vein splits. The production, however, has been slight.

BLIZZARD LODE.

Directly across Warren Gulch from the Little Richard mine is the Blizzard lode, which has a strike of about N. 40° W. and a dip of 70° NE. This vein is reported to have yielded several thousand dollars' worth of ore, the chief values being in gold and copper, although some of the ore carried up to $2 per ton in silver.

INTERNATIONAL LODE.

On the southwest slope of Santa Fe Mountain, in the valley of Little Bear Creek, is the International lode, a broad soft lode of clay gouge and crushed and altered country rock that dips 50° to 60° NE., and where observed on surface was headed due northwest. This vein is regarded as a continuation of the Columbia and Sterling lodes in Soda Creek Valley. The vein where developed in the International mine has produced considerable ore, but the ore has been of very low grade. From material found on the dump and in the ore bins, the ore appears to consist entirely of pyrite and quartz or of altered gneiss impregnated with pyrite. The International mine was not being worked at the time of visit, although it had been closed but a comparatively short time.

CHAPTER V.

THE EMPIRE MINING DISTRICT.

GENERAL GEOLOGY.

By S. H. Ball.

LOCATION.

The Empire mining district lies in the vicinity of Empire, Colo., in the southwestern portion of the Central City quadrangle, which adjoins the Georgetown quadrangle on the north. (See Pls. LXXIX, LXXX, LXXXI.)

TOPOGRAPHY.

Topographically the district is similar to the Georgetown quadrangle and has had a similar history. (See p. 30.) The most striking land forms are the broad valley of the West Fork of Clear Creek, which is filled in with glacial and postglacial deposits, and the level crest of the ridge east of North Empire Creek, a remnant of the old mountainous upland.

DESCRIPTION OF FORMATIONS.

PRE-CAMBRIAN ROCKS.

The pre-Cambrian rocks of the Empire mining district include the Idaho Springs formation, the hornblende gneiss, the gneissoid granite, the Silver Plume granite, and the granite-pegmatite. These are identical with the formations of the Georgetown quadrangle bearing the same names. (See pp. 37–96.) All the members of the Idaho Springs formation are represented, the lime-silicate area on Douglas Mountain being a granular intergrowth of epidote, quartz, and garnet. The conglomeratic facies outcrops east of the Gold Dirt tunnel. In the northeast portion of the district dikes of the Silver Plume granite cut the gneissoid granite. On the ridge east of Miller Creek the feldspar phenocrysts in the Silver Plume granite are 1 inch long.

INTRUSIVE PORPHYRIES.

The Empire mining district is included in the belt of intrusive porphyries already delimited (see pp. 67–70), and within it are many dikes and stocks of rocks which are similar lithologically to those of the Georgetown quadrangle and are probably contemporaneous with them. The generalizations concerning the form and structure of dikes already made apply with equal force to those of the Empire district.

QUARTZ MONZONITE AND ITS DIFFERENTIATION FACIES.

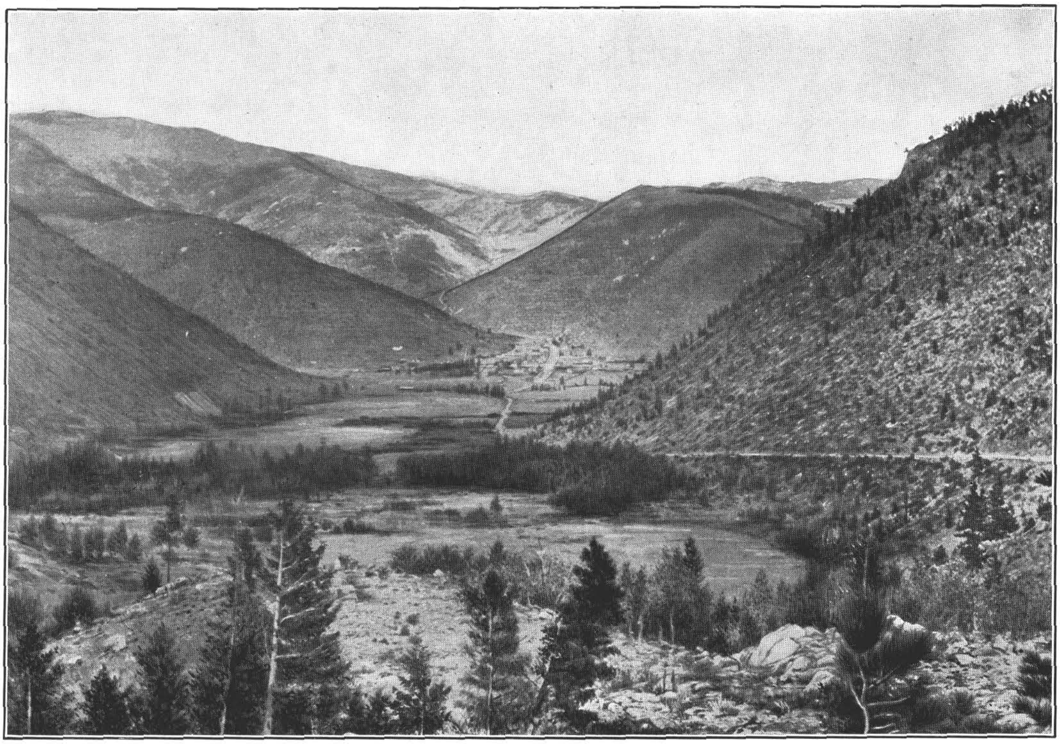
Distribution and structure.—A stock of monzonite 1½ miles in diameter extends into the western portion of the Empire mining district; a smaller stock lies between Lion and North Empire creeks, and a small mass is situated east of Miller Creek, near its mouth. The largest stock is approximately circular, although it sends a few lobes into the pre-Cambrian rocks. In various parts of the area surrounding Empire are quartz diorites and andesitic rocks that are in all probability simply differentiation phases of a magma corresponding in character to the quartz monzonite. As these dark-colored basic facies are rather distinct in character, they have been mapped as dikes of andesite porphyry. Messrs. Spurr and Garrey found some of these quartz diorites of closely related character in the Aorta tunnel of the Gold Dirt mine and in the Silver Mountain mine. The mass in the Aorta tunnel is probably an independent intrusive body which does not reach the surface; that in the Silver Mountain mine may be an offshoot from the mass between Lion and North Empire creeks. Syenitic rocks associated with the quartz monzonite and aplitic dikes cutting the same rock probably represent the more feldspathic phase formed by the differentiation of the quartz monzonite magma.

Petrography.—The monzonite is typically a gray rock of medium grain, composed essentially of feldspar and hornblende, much of the latter mineral occurring in columns. The feldspar in some hand specimens is white plagioclase, and in others pink orthoclase. In consequence, though the rock is usually monzonite, some of it has dioritic and some of it syenitic affinities. Hornblende varies in amount considerably from place to place, but rarely exceeds 25 per cent, and is locally almost absent. Quartz is usually and biotite in some places macroscopically visible, and titanite and magnetite are common accessories. Facies of the large stock contain dark-gray feldspar phenocrysts, and monzonite from the area between Lion and North Empire creeks contains tabular crystals of pink orthoclase 1½ inches long. These inclose, zonally, small hornblende rods. The monzonite is usually well jointed and breaks down into cubes with rounded angles. Granular aggregates of epidote in some places blotch the rock and epidote films develop upon joint faces. The monzonite is cut by aplitic dikes, some of which are sinuous. This aplite resembles the monzonite in a general way, although finer grained and richer in orthoclase, and in consequence commonly pink in color.

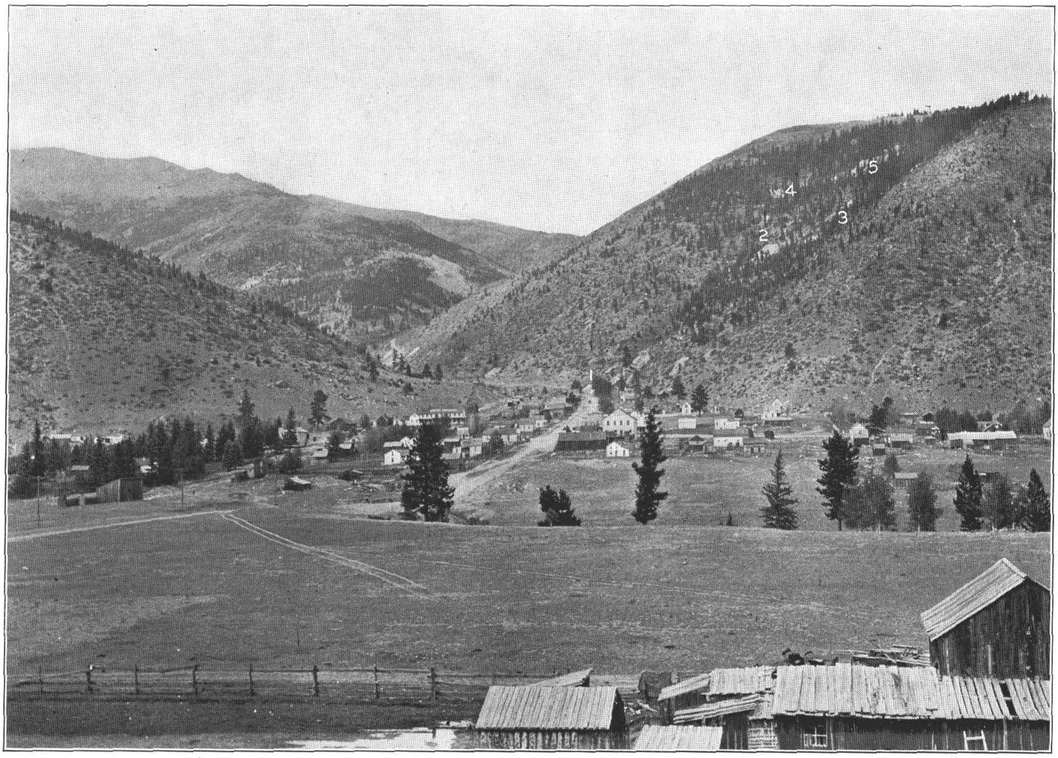
Under the microscope the rock is seen to vary from syenite to quartz diorite, although quartz monzonite is most widely distributed. Notwithstanding the range in composition, indicating considerable differentiation of the original magma, the various types occur at haphazard throughout the mass and appear to bear no definite relation to its form. Though locally allotriomorphic, the rocks are usually hypidiomorphic through the partial development of crystals of plagioclase or hornblende and augite. The order of solidification was ordinarily zircon, apatite, ilmenite and titanite, pyroxene, hornblende and plagioclase, and orthoclase and quartz. Some titanite occurs in large irregular granules, wrapping around plagioclase and hornblende, and in such places was one of the last minerals to crystallize. Plagioclase, which ranges in composition from oligoclase to andesine, is in some specimens zonally built. Orthoclase, in optical orientation with one set of the albite twins, not unusually rims the plagioclase. Orthoclase, much of it microperthitic, occurs also in irregular grains or areas which micropoikilitically inclose plagioclase and pyroxene. Carlsbad twins are common. Some of the feldspars are slightly cracked and more rarely they show faint undulose extinction. Of their alteration products, kaolin predominates over sericite, and calcite is unusual. Large irregular plates of muscovite may completely or partly replace orthoclase. Both light and deep green augite are present, the darker variety probably containing a little of the ægirite molecule. Pyroxene alters to hornblende, with or without quartz, and calcite, to biotite, and to a serpentine-like mineral. Much of the hornblende is original and alters to biotite or to epidote, zoisite, and calcite. Biotite, besides being a secondary mineral, probably produced prior to the final consolidation of the magma, is also in places original, occurring in hexagonal plates or in irregular areas which crystallized after orthoclase. Quartz, present in most thin sections, is nowhere abundant. Titanite is constantly present, and in some areas is as abundant as augite or hornblende. Apatite, ilmenite, and titaniferous magnetite are constant accessories, and allanite and zircon are present in many specimens. Crystals of allanite are locally large and abundant. Fluorite occurs here and there in wedges between the other constituents, and then has the habit of quartz in granite. This fluorite appears to be original, but other fluorite in tiny areas replacing feldspar was probably introduced by gases after the rock solidified.

The aplite under the microscope proves to be a quartz monzonite, more acidic and probably richer in soda than the normal rock of the stocks. Its texture is between the hypidiomorphic granular and the porphyritic.

Age.—The monzonite cuts the supposed pre-Cambrian rocks, and from its massive character is evidently younger than any of them. In the Silver Mountain mine it has been found grading into quartz diorite porphyry, a condition similar to that observed by the writer in the late Creta-



A. TOWN OF EMPIRE AND MINES IMMEDIATELY EAST.



B. TOWN OF EMPIRE AND GOLD BUG GROUP OF VEINS.

1, Empire City tunnel; 2, Golden Chariot; 3, Jackpot; 4, Oro Cash; 5, Gold Bug.

ceous quartz monzonite and the quartz monzonite porphyry of Lincoln Mountain in the Georgetown quadrangle. (See p. 73.) The two granular rocks are practically identical. Furthermore, the rock is closely allied to late Cretaceous diorites of Leadville, Colo., described by Cross,[a] and like them is characterized by the presence of allanite. In consequence the monzonite is considered of late Cretaceous age—in short, a granular phase of the intrusive porphyries, although it may possibly be the youngest of the pre-Cambrian rocks.

QUARTZ MONZONITE PORPHYRY.

Distribution.—Dikes of quartz monzonite porphyry are confined to Douglas and Lincoln mountains, the valley of Miller Creek, and the ridge between Lion and North Empire creeks. Similar rocks, which, however, are perhaps best described as andesite, occur in dikes 6 miles east of north of Empire, and on the ridge east of Miller Creek. In the Empire tunnel are dikes of quartz diorite porphyry, evidently differentiation products of the same magma. (See p. 387.)

Petrography.—The porphyry of the dikes on Douglas and Lincoln mountains is similar in every way to that already described from the Georgetown quadrangle. (See pp. 73–83.) Phenocrysts are so abundant in the quartz monzonite porphyry from Miller Creek that the rock has a granitic aspect. Under the microscope the groundmass appears as a mosaic of orthoclase, quartz, and plagioclase, and the phenocrysts are plagioclase (oligoclase-andesine), orthoclase, quartz, and biotite. The dike west of the monzonite stock between Lion and North Empire creeks is a porphyritic rock containing phenocrysts which equal in volume the finely granular greenish-gray groundmass. The most conspicuous phenocrysts are rounded tablets of pink feldspar three-fourths of an inch in length. These feldspars, which are Carslbad twins containing tiny plates of biotite, are exceeded in bulk by smaller white plagioclase phenocrysts and aggregates of biotite which have the form of hornblende and reach a maximum length of one-fourth inch. Under the microscope the groundmass is seen to be finely microgranitic, consisting of orthoclase, quartz, plagioclase, and biotite. A few rounded quartz and ragged biotite phenocrysts are associated with those already mentioned. The phenocrysts with the form of hornblende are aggregates of green hornblende and biotite, or of biotite and epidote. The biotite occurs as diversely oriented plates, which are in such sharp contact with epidote granules that it is probable that the two minerals were formed contemporaneously from hornblende prior to the final solidification of the rock.

The andesite dikes on the ridge east of Lion Creek south of the 9,950-foot hill are formed of a medium-gray rock with numerous phenocrysts of feldspar and hornblende, the latter being in flow orientation. Under the microscope this andesite shows a pilotaxitic groundmass composed of plagioclase and orthoclase. The feldspar phenocrysts (plagioclase) are much altered to sericite and epidote. The brown hornblende columns are almost wholly altered either to actinolite or to chlorite (pennine in part) and epidote. Apatite and magnetite are accessory minerals.

Correlation.—The quartz monzonite porphyry resembles in mineralogical composition the monzonite of the near-by stock, and like it is characterized by large pink orthoclase phenocrysts. The other quartz monzonite porphyries are similar to rocks which on Lincoln Mountain in the Georgetown quadrangle appear to grade into quartz monzonite, probably to be correlated with the monzonite of the Empire mining district. The quartz diorite porphyry in the Empire tunnel grades into quartz diorite, a member of the monzonitic series. Therefore one and the same magma solidified in stocks as a quartz-bearing monzonite or diorite and in dikes as quartz monzonite porphyry, quartz diorite porphyry, or andesite.

BOSTONITE AND BOSTONITE PORPHYRY.

Bostonite and bostonite porphyry, differing in no essential particular from those of the Georgetown quadrangle, form a number of dikes in the northern portion of the Empire mining district and occur also near the south end of the ridge east of Lion Creek. One of these dikes was encountered underground in the Golden Chariot mine.

[a] Cross, Whitman, Mon. U. S. Geol. Survey, vol. 12, 1886, p. 334.

GRANITE PORPHYRY.

A few dikes of granite porphyry have been found underground.

ALASKITIC QUARTZ MONZONITE PORPHYRY.

A few of the dikes of the Empire mining district consist of much altered alaskitic quartz monzonite porphyry. Underground rocks probably of this class occur in the Empire City, Golden Chariot, Gold Bug, Oro Cash, and Conqueror mines.

ALASKITE PORPHYRY.

Alaskite porphyry similar to that of the Georgetown quadrangle (see p. 77) occurs as a stock 0.6 mile long 1 mile west of Empire, and as dikes on the ridge east of North Empire Creek and on the divide between North Empire and Mill creeks. The stock, from its form, probably intrudes the monzonite, an inference in harmony with the age relations of the quartz monzonite porphyry and the alaskite porphyry at Silver Plume. (See p. 131) Alaskite porphyry was found underground in the Empire City tunnel, the Golden Chariot tunnel, and the Oro Cash mine. Specimens from the Empire City tunnel show beautiful flow banding and, under the microscope, a devitrified glassy groundmass.

BIOTITE LATITE.

A dike of biotite latite 2½ feet wide showing considerable flow banding was encountered in the Elizabeth tunnel. It is a brown flinty rock. Tiny phenocrysts of feldspar and biotite and probably of quartz are visible. Geodes of quartz fill large cavities which are probably vesicules. Under the microscope the groundmass appears as a fresh glass containing tiny phenocrysts of orthoclase and andesine. These grade into larger phenocrysts, with which are associated biotite crystals. Microscopically the rock is strikingly similar to the biotite latite of the Georgetown quadrangle. It appears, however, to be more siliceous than that of Chicago Creek. (See p. 81.)

PLEISTOCENE DEPOSITS.

The Pleistocene deposits of the Empire district (see Pl. LXXX) include drift of the earlier glacial epoch; drift, kames, and overwash gravels of the later glacial epoch; and alluvium, filled in behind moraines of the later glacial epoch. Lateral morainal drift (see pp. 85–86) deposited by the earlier Clear Creek and West Fork glaciers occurs in patches along Clear Creek below an elevation of 10,000 feet—approximately 9,500 feet at the east border of the district.

Of the later glaciers the Mad Creek, West Fork, Bard Creek, and Clear Creek glaciers terminated within the Empire mining district, but the Mill Creek Glacier passed through its northeast corner. A considerable area of later glacial overwash gravels is located south of Empire, and three small areas lie south of the mouth of Miller Creek. On West Fork of Clear Creek, 5 miles below Empire, is a gently undulating kame tract. The material is of glacial origin, and though imperfectly assorted and stratified was clearly deposited by water at the front of the West Fork Glacier. Similar material on the east border of the district was deposited by the retreating glacier of Clear Creek

ECONOMIC GEOLOGY.

By J. E. Spurr and G. H. Garrey.

EMPIRE TUNNEL.

The Empire tunnel starts in below Empire near the level of West Fork of Clear Creek, and runs in a northwesterly direction, with the design of cutting at considerable depth the principal lodes of the Empire district. At the time of examination this tunnel was in about 3,000 feet and had not yet reached the region of the more productive veins.

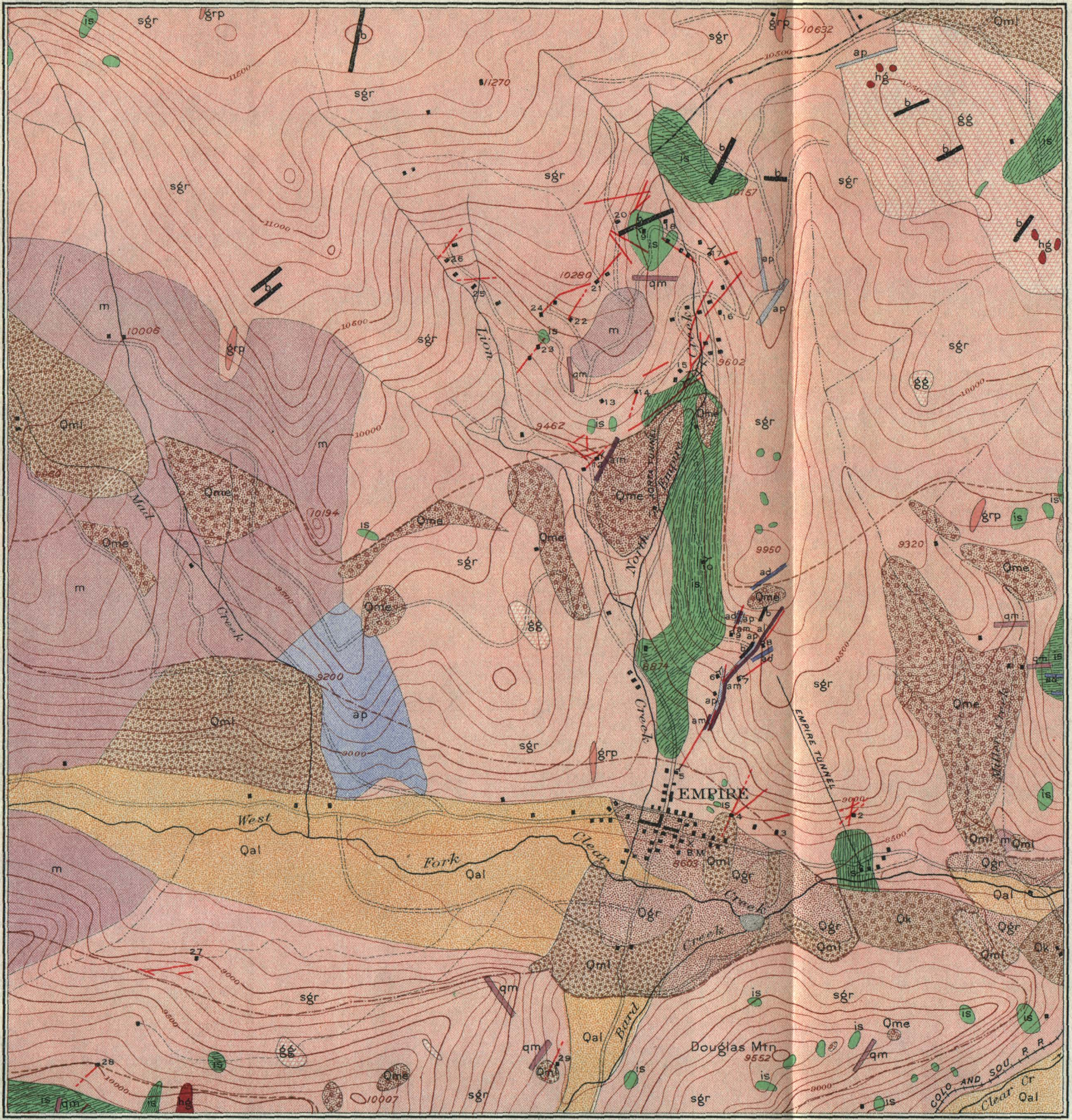
MINES AND TUNNELS.

1. Empire tunnel.
2. Harrison mine.
3. Hecla mine.
4. Mint and Cashier mine.
5. Empire City tunnel.
6. Golden Chariot tunnel.
7. Jackpot tunnel.
8. Gold Bug tunnel.
9. Oro Cash tunnel.
10. Elizabeth tunnel.
11. Aorta tunnel of Gold Dirt mine.
12. B. B. tunnel.
13. MacGregor mine shaft.
14. Benton mine shaft.
15. Silver Mountain mine shaft.
16. Gold Fissure mine.
17. Badger tunnel.
18. Conqueror mine.
19. Union tunnel.
20. Rosecrans tunnel.
21. Atlantic mine.
22. Comet Extension mine.
23. Crown Prince mine.
24. Cleopatra mine.
25. Apex-Surprise mine.
26. Three Friends mine.
27. Hidden Treasure mine.
28. Allen mine.
29. Headlight (Mickmack) mine

Shaft

Tunnel

Buildings



LEGEND

SEDIMENTARY ROCKS

QUATERNARY

Recent

Qal — Alluvium (in flood plains of present streams)

Pleistocene

Ogr — Overwash gravels (valley trains of later glacial period)

Qml — Moraines of later glacial period

Qk — Kames of later glacial period

Limit of glaciers of later glacial period

Qme — Moraines of earlier glacial period

Limit of glaciers of earlier glacial period

PRE-CAMBRIAN

is — Idaho Springs formation (biotite-sillimanite schist, biotite schist, and quartz gneiss of sedimentary origin. Wavy lines indicate general direction of schistose cleavage)

IGNEOUS ROCKS

LATE CRETACEOUS (BOSTONITE PERHAPS TERTIARY)

b — Bostonite and bostonite porphyry (dikes)

am — Alaskitic quartz monzonite porphyry (dikes)

ap — Alaskite porphyry (stock and dikes)

ad — Andesite and dacite (dikes)

qm — Quartz monzonite porphyry (dikes)

m — Monzonite (stocks)

PRE-CAMBRIAN

grp — Granite-pegmatite and associated granites and granite porphyry

sgr — Silver Plume granite (biotite granite, often porphyritic)

gg — Gneissoid granite (light-colored medium-grained granite, usually gneissic)

hg — Hornblende gneiss (dark-gray fine-grained gneissic rock, a mashed dolerite)

Metalliferous veins (Tertiary or late Cretaceous)

Topography from Central City sheet U.S.Geological Survey

TOPOGRAPHIC AND GEOLOGIC MAP OF THE EMPIRE MINING DISTRICT, COLORADO

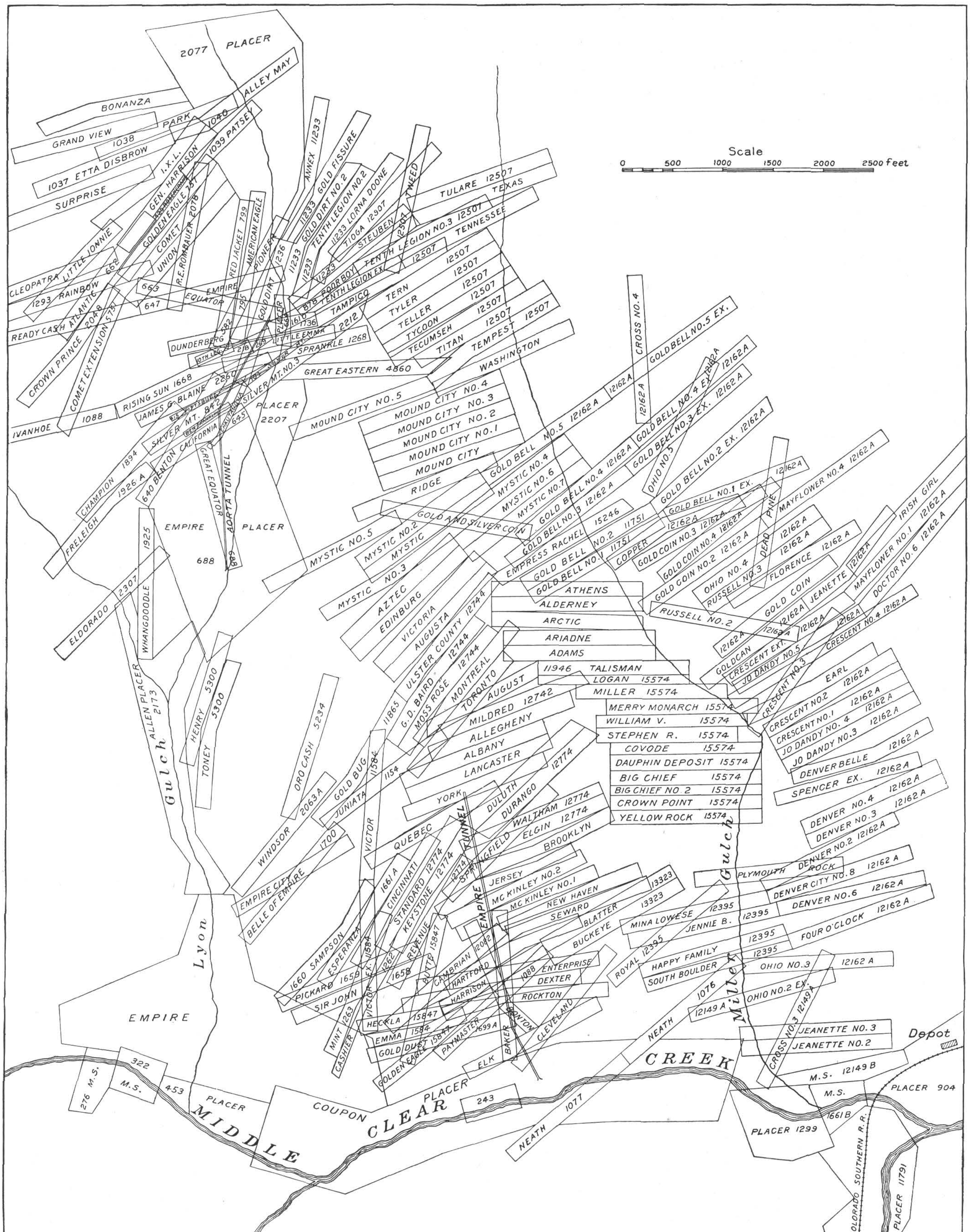
0 500 1000 2000 3000 4000 5000 6000 feet

Contour interval 100 feet

Datum is mean sea level

1906

Geology by S.H.Ball assisted by O.H.Hershey Surveyed in 1904
Veins by J.E.Spurr and G.H.Garrey



MAP OF MINING CLAIMS IN EMPIRE DISTRICT.

NATURE OF ROCKS.

General description.—Probably the oldest rock encountered in the Empire tunnel is a coarse black gneiss containing a large proportion of biotite. This rock occurs abundantly. It is usually intermixed with seams of pegmatite which are of later age and are a phase of the intrusion of porphyritic granite described below.

Gneissoid granite forms part of the material through which the tunnel has passed. This rock in the Empire district, as elsewhere, is younger than the biotite gneiss and older than the rocks described in the following paragraphs.

One of the most important rocks in the tunnel is a biotite granite, typically more or less porphyritic. This rock is intrusive into the biotite gneiss and into the gneissoid granite. The essential minerals are feldspar, quartz, biotite, and muscovite, with more or less magnetite, pyrite, sphene, apatite, and zircon. The feldspar consists in part of orthoclase and in part of oligoclase. Portions of this granite approach alaskite in composition, the biotite and muscovite of the typical granite becoming subordinate, and the rock consisting mainly of quartz and feldspar. Very commonly also the granite becomes semipegmatitic and passes over into true pegmatite, which forms seams and blotches in the granite itself and intrudes the oldest gneissic rocks on a very large scale, being represented in them much more abundantly than is the granite. Much of the pegmatite passes into phases consisting only of quartz. On the whole the constituent minerals of the pegmatite are similar to those of the parent granite, but irregular and coarse crystallization is accompanied by irregular massing of the different constituents, one extreme of which is shown in the quartz veins. Other minerals are in places relatively more abundant in the pegmatite than in the granite. Magnetite and pyrite, for example, are in many places segregated into bunches of considerable size, both in the pegmatites and in the pegmatitic quartz veins.

Dikes of basic rock cut all the other rocks above mentioned. Mineralogically these basic rocks are identical, but texturally and to a certain extent structurally they are highly variable. The narrow dikes are distinctly porphyritic and fine grained, but the larger masses, though they may have a porphyritic contact phase, become relatively coarse grained away from the margin. The numerous fine-grained porphyritic dikes contain phenocrysts of feldspar, green hornblende, and biotite. Some also carry phenocrysts of quartz. Magnetite, pyrite, and apatite occur in crystals of smaller size. The feldspar has characteristically a zonal structure. In one specimen that was studied the inner portion of such a phenocryst consisted of labradorite-bytownite, another of labradorite-andesine. The smaller phenocrysts occurring in the rock were apparently all andesine and andesine-oligoclase. It is evident that the cores of the large zonal phenocrysts represent the first feldspar crystallized from the magma; this was more basic than the later-formed feldspar, which includes the smaller phenocrysts and the outer zone of the larger ones. The groundmass of these rocks is as a rule finely microgranular.

Larger masses of basic rock encountered in the tunnel have the same mineralogical composition as the basic porphyritic rocks, but a granular texture and irregular and variable massing of the different minerals. One specimen of such rock consists of about two-thirds green hornblende and brown biotite, most of the rest of the rock consisting of feldspar with some quartz. Magnetite was very abundant, with original pyrite. Another specimen from the tunnel is practically hornblendite, containing 80 to 90 per cent of green hornblende. Magnetite is very abundant in large grains with a little associated original pyrite. Feldspar and quartz are also present. This specimen was in contact with a small mass of pegmatitic quartz containing pyrite. This pegmatitic quartz is probably an integral part of the same rock mass, representing one extreme of the segregation (probably magmatic differentiation) of the diorite, as the hornblendite does the other extreme.

The general relations make it appear probable that all these dioritic rocks, whether fine grained and porphyritic, granitic, or pegmatitic, are phases of a single magma and a single period of intrusion.

Dikes of porphyry belonging to the types which are associated with the mineral veins of this district are also encountered in the tunnel. A decomposed dike near the breast is probably one of the group of bostonite dikes which occur in this region. The original phenocrysts consisted of feldspar and either pyroxene or hornblende in a feldspathic groundmass. Magnetite and apatite were plentiful. Another dike, the first encountered in the tunnel, is of granite porphyry containing abundant medium-sized phenocrysts of quartz, feldspar, and biotite.

Pyrite in the rocks.—The presence of original pyrite in the rocks traversed by the Empire tunnel is one of the most striking features in its geology. The older gneissic rocks, including the biotite gneiss and the gneissoid granite, contain very little pyrite and would not be worthy of particular mention on this score. The basic porphyries contain as a rule original pyrite, together with magnetite, and in some of them the amount of the former as well as of the latter becomes considerable. The porphyritic granite, however, contains pyrite in unusual abundance. This mineral can be detected in nearly every specimen of the granite, wherever collected.

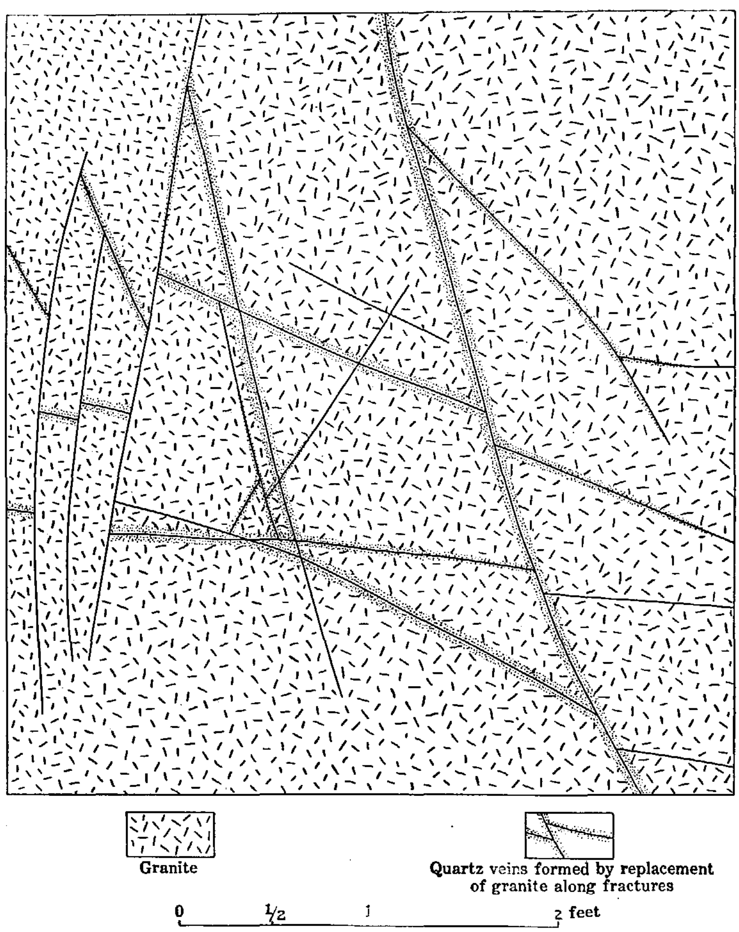


FIG. 145.—Sketch of portion of vertical wall of Empire tunnel, showing barren veins of replacement quartz which have formed along fractures belonging to an intricate system.

The abundance of the pyrite does not depend on the alteration of the rocks, for the mineral occurs in quite as large quantity in the fresh as in the altered rock. In the pegmatitic portions of the granite and in the pegmatite the pyrite is more abundant than in the ordinary granular-porphyritic phase, and has segregated into larger bunches. The pegmatite is therefore the chief pyritiferous rock encountered in the tunnel. In most places where pyrite occurs in fresh granite it follows tiny seams or gashes in the rock, indicating that its origin is subsequent to that of the other minerals. Very commonly, however, it occurs in such a way as to be positively a primary constituent, appearing as crystals in fresh feldspar, quartz, and biotite. In the pegmatites also it occurs as isolated particles and crystals in unbroken masses of quartz and feldspar. Magnetite and pyrite are in many places associated and contemporaneous, both in the granites and pegmatites; the two minerals are locally intergrown, and in the pegmatites each may occur in considerable lumps. The occurrence of large quantities of magnetite, much of it in considerable lumps, in pegmatite is characteristic of this whole region, but the Empire district shows more pegmatitic pyrite than is present elsewhere. Practically all of the pyrite in the granite and pegmatite here appears indigenous, and its occurrence in tiny seams and gashes is probably due largely to the fact that the pyrite was in great part a mineral of the pegmatitic period and was introduced along with the other pegmatitic minerals subsequent to the consolidation of the main rock mass. This pyrite not only crystallized, at many places in consolidated form, in the spaces occupied by the pegmatite, but permeated the already consolidated granite. A similar conclusion has already been reached in regard to the introduction of the magnetite in the magnetite-bearing pegmatites and pegmatitic quartz veins near Georgetown, and to a certain as yet undefined extent also in the previously consolidated granite. (See p. 182.) The original pyrite in the Empire granites, being more easily attacked by percolating waters than the magnetite, has migrated from its original position to a greater extent, so that it is now found coating fractures which are probably subsequent to all granitic consolidation, and also has been transferred into fracture zones which have formed the channels for circulating waters.

It was stated to the writer by an experienced mine foreman at Empire that free gold was occasionally found in the pegmatitic quartz.

NATURE OF VEINS.

A number of small lodes were cut in the tunnel. Most of them are pyritic, like the typical lodes of the Empire district, and contain only pyrite and chalcopyrite with a quartz gangue. Some, however, contrary to the general rule, contain argentiferous galena and blende. This difference is found in these veins at the surface as well as underground. The presence of these two chemically distinct types of veins in the same neighborhood makes the district a sort of link between the other mining districts in which only one or the other vein type occurs.

A specimen from a pyritiferous quartz vein encountered in the tunnel showed a deposit of ankerite in cracks and lining cavities, having formed later than the quartz and pyrite. Another specimen shows crystalline calcite with a similar relation.

Veinlets of pyritiferous quartz, although usually of no economic importance, are very abundant, especially in the granite. These granites and associated pegmatites show on fracture faces secondary pyrite, which thus has the aspect of having been derived from a solution and reprecipitation of that originally contained in the rock. What appears to be a further step in the segregation is the presence of small veinlets, which are locally abundant in the porphyritic granite and consist chiefly of jaspery gray quartz and pyrite (fig. 145). These have altered and bleached the granite along a narrow zone on either side of a central fracture. An interesting occurrence is shown in fig. 146. An original vein of pegmatitic quartz containing local feldspar and some pyrite crystals had been traversed by a slight fault. Along this fault fracture, which was marked by gouge as a result of the movement, had been deposited a very moderate amount of gray jaspery quartz with considerable pyrite. This phase contained relatively more pyrite than the original pegmatitic vein, especially below the junction of this vein. The derivation of the pyrite in the fault lode from that in the pegmatitic vein is strongly suggestive, and the location of the largest amount of pyrite in the former directly below its intersection with the latter indicates that the agency may have been descending water. On the whole, the inspection of many of these fracture zones in fresh granite that contain quartz and pyrite makes it appear very clear that the vein filling is derived from the adjacent

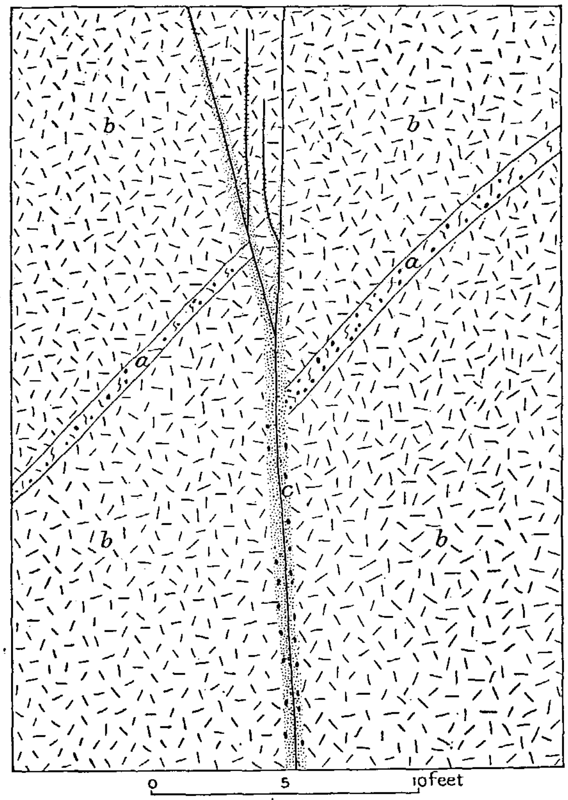


FIG. 146.—Sketch of portion of vertical wall of Empire tunnel, showing pyritiferous pegmatite vein (*a*), mainly quartz with some feldspar, faulted by later fracture, on both sides of which the silicification and replacement of the granite (*b*) has formed a vein of gray quartz (*c*). This later vein contains pyrite below the intersection with the pyritiferous pegmatite vein, but not above, showing that the later pyrite was probably derived from the older pyrite, and that the transferring agent has been descending water.

granite, which is altered for a short distance in their vicinity. This later-formed vein quartz is dense and grayish in color and is not to be confounded for a moment with the quartz of pegmatitic origin.

ALTERATION OF ROCKS.

The alteration of the rocks older than the diorites in this tunnel has not been investigated. The dioritic rocks as a rule are relatively fresh. Feldspars are typically largely or entirely clear, but a few are more or less altered. One zonal phenocryst which consisted inside of labradorite-bytownite and outside of labradorite-andesine had its core partly altered to sericite, while the outside was entirely clear. In other places feldspar has been altered to sericite and quartz. The hornblende is usually fresh, but some of it is more or less completely altered to chlorite, quartz, calcite, and epidote. In the neighborhood of fracture zones in the rock, both the feldspar and hornblende are altered and the biotite is bleached, with the separation of cloudy carbonates.

In the porphyritic granite the orthoclase is usually very clear, being only a little turbid from kaolinization, and the oligoclase is partly altered to sericite and calcite. The biotite is as a rule mainly fresh, but is in some places partly altered and bleached to a green color.

The bostonite dike described above is highly altered, as is usual with all rocks of this class. The abundant feldspar phenocrysts are altered to coarse sericite and calcite, and the feldspathic groundmass is also decomposed. A hand specimen of this rock shows deep purple fluorite associated with calcite, both being secondary. Phenocrysts of pyroxene and hornblende are also entirely altered.

A specimen of the granite porphyry, which is the first dike encountered in the tunnel, shows an altered groundmass consisting mainly of sericite. The feldspar is entirely altered to sericite and calcite, and the biotite is bleached, with the separation of carbonates.

HARRISON MINE.

LOCATION AND DEVELOPMENT.

The Harrison mine is located at an elevation of about 8,800 feet, on a southward-facing mountain slope about 1,700 feet N. 87° E. of the central portion of the town of Empire. The main tunnel, which is 400 feet or so in length, follows a vein that strikes in general N. 10° E. and dips 70° E.

RELATION OF DIFFERENT VEINS.

This north-south vein consists of a clay and crushed-rock lead from 4 to 10 inches in width, which is replaced along certain parts by dark jasper-like quartz heavily impregnated with pyrite. About 200 feet from the mouth of the tunnel is a vein trending N. 52° E. which crosses the north-south tunnel lead, though little if any displacement has occurred at the crossing, where both leads consist of quartz, crushed gneiss, and pyrite. The N. 52° E. vein, which breaks up in micaceous gneiss at the east breast of the 125-foot drift, carries specks of sphalerite mixed with the pyrite and quartz, but these occur only near places where stronger seams of sphalerite ore join the vein from the west.

The pyrite-bearing tunnel vein at distances of 250 and 335 feet from the mouth of the tunnel also intersects and faults two approximately east-west veins which carry sphalerite ore. The first of these sphalerite veins, which strikes S. 80° W. and dips 73° N., is faulted about 10 inches, the east portion of the vein being offset to the south. The vein at 335 feet from the mouth of the tunnel is relatively stronger, and consists of 3 to 8 inches of sphalerite, quartz, and pyrite, separated from the granite walls by only a thin selvage of gouge. This vein, where crossed by the north-south pyrite and quartz vein, is faulted for a distance of about 3 feet (see fig. 147); the east portion of the vein, which has a trend of N. 65° E., is offset to the south of the west portion, which trends N. 58° E. The dip of the eastern portion of the faulted vein, which is about 67° N., is somewhat flatter than that of the western portion. Between the faulted ends of the sphalerite-bearing vein on the west side of the pyrite and quartz vein is a small area of crushed rock inclosing angular fragments of granite and of sphalerite, pyrite, and quartz ore, the latter probably representing the drag from the east-west vein along the line of the displacement.

The east-west vein in places carries black zinc blende next to the two quartz layers which coat the granite walls, a mixture of quartz and pyrite occupying the center of the vein. In other places along the same vein pyrite streaks occur along the two walls, the center of the vein containing a breccia made up of angular fragments of sphalerite ore in a cementing matrix of pyrite and quartz. These occurrences would indicate that sphalerite ore had at one time filled a fracture which was later reopened, the new fracture being subsequently filled by pyrite and quartz.

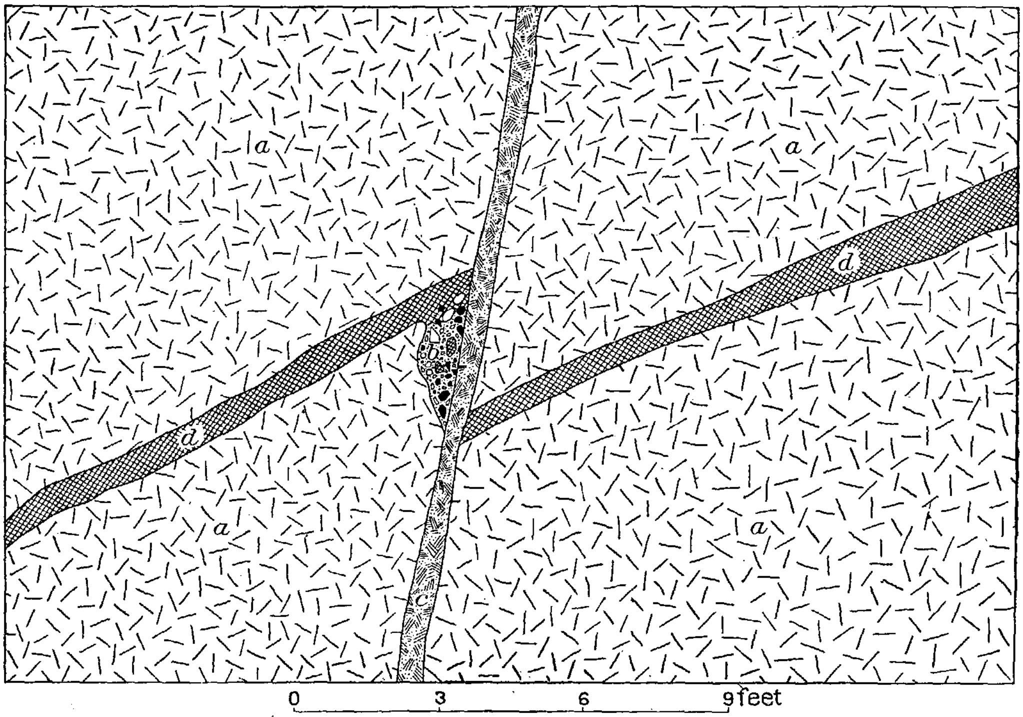


FIG. 147.—Horizontal plan of portion of Harrison tunnel, showing faulting of earlier sphalerite-bearing vein (Harrison lode) by later pyrite-bearing vein: *a*, Granite; *b*, breccia of sphalerite ore and crushed rock, representing drag along fault line; *c*, pyrite vein; *d*, sphalerite vein.

Midway between the two east-west sphalerite veins the north-south vein of pyrite and quartz which faults them is itself faulted by a vertical and apparently barren clay lead which runs N. 84° E. and offsets the south portion of the pyrite vein 3½ to 4 feet to the east of the north portion.

HISTORY OF VEIN FORMATION.

From these different veins and their relations to one another the following outline of the geologic history has been worked out: (1) Fracturing of the granite and gneiss country rock by a series of approximately east-west fissures; (2) filling of east-west fissures by black sphalerite ore containing some contemporaneous pyrite and rarely specks of galena; (3) reopening of fissures and brecciation of sphalerite ore; (4) filling of new fractures by quartz and pyrite; (5) formation of north-south fractures which fault the earlier east-west sphalerite-bearing veins; (6) filling of north-south veins by pyrite and quartz; (7) formation of a new set of east-west fractures, at present probably unmineralized, which fault the north-south pyrite and quartz veins.

UPPER HARRISON TUNNEL.

About 200 feet up the mountain slope to the north from the tunnel just described is a second tunnel 100 feet in length which connects with a 190-foot drift on a vein that strikes N. 60° E. and dips 70° to 75° NW. This vein is approximately parallel to and may possibly be a part of the east-west vein described as occurring 335 feet from the mouth of the lower tunnel. The vein in the upper tunnel is sphalerite bearing to a slight degree but consists mainly of a strong crushed-granite, quartz, and pyrite lead 1 to 2 feet wide. The sphalerite where present occurs as small discontinuous streaks. This east-west vein is also faulted by a N. 10° E. quartz- and pyrite-bearing vein, very similar in attitude and structure to the lower tunnel lead.

FEATURES OF THE ORES.

The ores from the east-west veins of both tunnels are remarkable for the scarcity of the galena associated with the black sphalerite. A little pyrite is found associated with the sphalerite in both places, but in the ores from the upper tunnel the pyrite seems to be much more cupriferous. The ores from the east-west vein on the upper tunnel level also show angular fragments of sphalerite ore with specks of cupriferous pyrite embedded in the matrix of later pyrite and gray quartz.

HECLA TUNNEL.

The Hecla tunnel is located about 1,700 feet due east of the central portion of the town of Empire. The workings are entirely in a mixture of hard micaceous gneiss, pegmatite, and granite. The crosscut tunnel (fig. 148) is more than 400 feet in length. At a distance of about 225 feet from its mouth it intersects a pyrite and quartz vein striking N. 77° E. On this vein there is a drift stope 100 feet long. The east end of this drift is joined by a north-south drift about 250 feet long, which follows for most of its length a small clay and pyrite lead dipping 50° to 70° E.

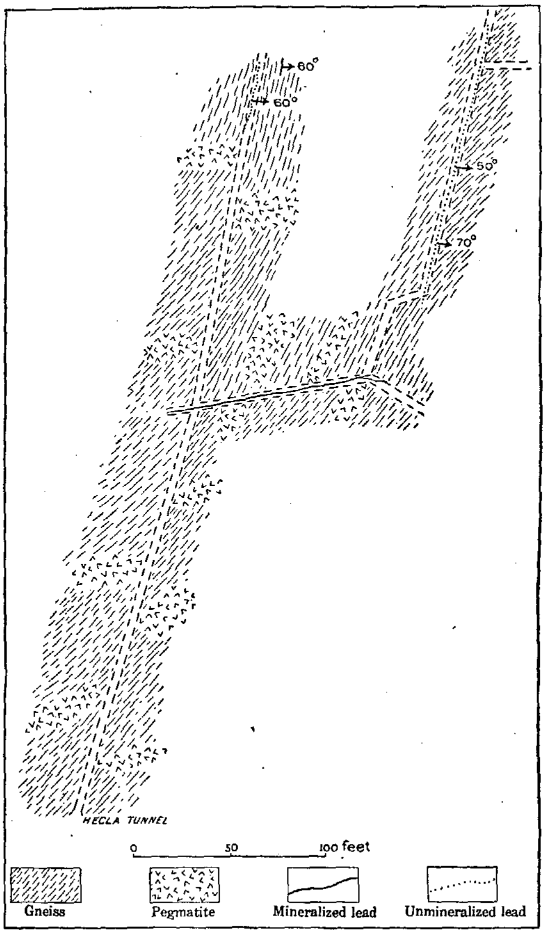


FIG. 148.—Geological plan of Hecla tunnel.

This mine has not been worked for a good many years. In view of the small amount of material taken from the drift stope above mentioned, it has probably not yielded much ore.

MINT AND CASHIER MINES.

LOCATION AND DEVELOPMENT.

The Mint mine is located at an elevation of about 8,650 feet just east of the town of Empire. The mouth of the Cashier tunnel is situated about 50 feet farther east. The development on the veins in the Mint mine consists of about 500 feet of tunneling and of a drift on a level 150 feet below the tunnel level, connected with a crosscut from the Cashier workings that starts at a point 160 feet in from the Cashier shaft. Besides raises and stopes, there are also two shafts sunk from the Mint tunnel level to depths of 80 and 50 feet at points distant about 50 and 250 feet, respectively, from the mouth. The Cashier mine consists of a tunnel level with drifts aggregating 450 feet and a shaft from which several drifts run. However, all the workings of both the Mint and Cashier mines below the tunnel levels are at present filled with water.

NATURE OF WALL ROCKS.

The wall rocks consist entirely of granite, cut in places by seams of pegmatite and of what appears to be white pegmatitic quartz, which contain small inclusions of probably original pyrite. Near the northeast breast of the tunnel some of these pegmatite dikes run parallel to and are closely associated with the vein. The granite forming the walls is here and there highly altered.

NATURE OF VEINS.

The two mines have developed a series of branching veins which diverge going to the northeast. The general trend of the vein followed by the Mint tunnel is N. 20° E.; the Cashier vein runs N. 50° E. for most of the way, but as it nears the Mint vein it turns slightly and runs somewhat parallel to that vein, although it probably joins it a little farther to the south.

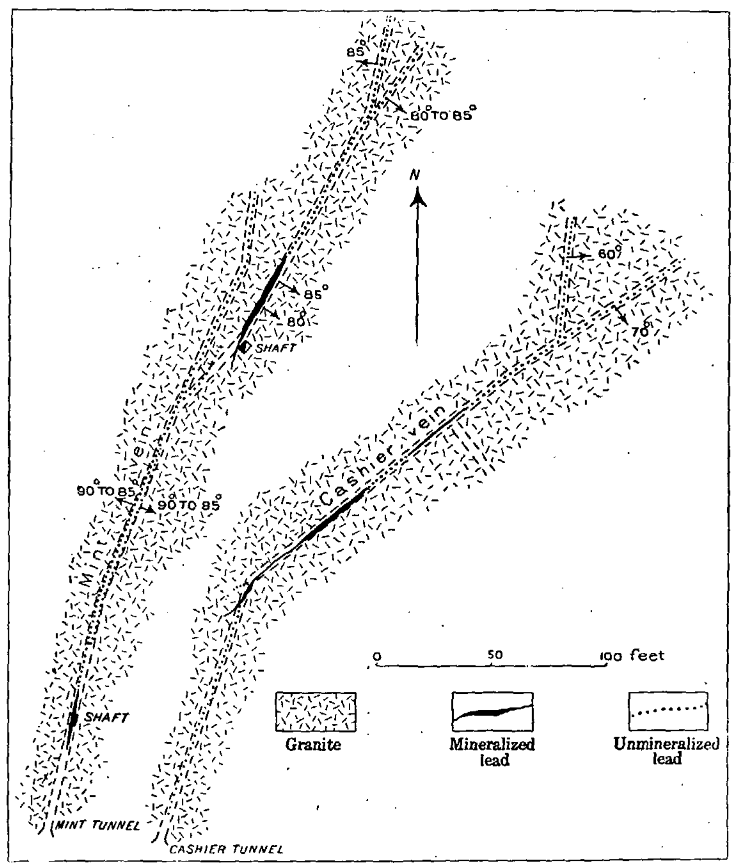


FIG. 149.—Geological plans of Mint and Cashier tunnels.

The Mint tunnel (fig. 149) for 150 feet follows a slightly mineralized crushed-granite vein, which consists either of a single lead several inches wide or of foot- and hanging-wall leads that loop apart several feet and inclose horses of granite. At 150 feet from the mouth a split in the vein takes place, the west branch consisting of a vertical lead 6 inches to 1 foot wide composed of dark-gray quartz and crushed granite impregnated with pyrite, and the east branch forming a small lead which connects the tunnel lead just mentioned with a somewhat parallel and overlapping vein trending N. 32° E. and dipping 80° to 85° SE. This vein, near the point where it was first encountered, contained considerable ore for a distance of more than 50 feet. It was stoped for a height of 30 feet or more above the tunnel level and was worked out below the tunnel to either side of the 50-foot shaft sunk at this place.

The tunnel of the Cashier mine (fig. 149) follows a faint quartz lead for about 100 feet from the mouth to the point where it encounters the main vein, which strikes N. 50° E., dips 70° SE., and is composed of clay or of clay and crushed granite that in places gives way to quartz and pyrite. Just northeast of the point where the main vein was first encountered by the tunnel there is a small stope worked up nearly to the surface, and about 50 feet farther northeast is another small stope. Both the Mint and the Cashier veins break up toward the northeast end of the tunnel levels into several smaller veins. The lower workings are filled with water.

COMPOSITION OF VEINS.

All of the vein material observed in the two tunnels consisted of pyrite and chalcopyrite associated with quartz, and, according to Mr. Swanson, one of the owners of the mines, all the ore obtained along the Cashier vein, both on the tunnel level and on the workings reached by the shaft, consisted of a mixture of these same minerals, which carried values as high as 3½ to 6 ounces in gold to the ton. On the Mint vein, according to the same authority, the noticeable feature was the change in character of the ore with depth. Near the surface and for some distance below the tunnel level the ores consisted of cupriferous pyrite or of a mixture of pyrite and chalcopyrite, carrying from 3½ to 4½ ounces in gold and 14 to 18 ounces in silver to the ton. However, in the bottom of the 50-foot shaft, located 225 feet from the mouth of the tunnel, and also on the drift on the Mint vein connecting with the Cashier shaft, about 150 feet below the tunnel level, the ore consisted of a mixture of galena, chalcopyrite, pyrite, and a little zinc blende, which carried about 2½ ounces in gold and 23 ounces in silver to the ton.

EMPIRE CITY-GOLD BUG GROUP.

LOCATION AND DEVELOPMENT.

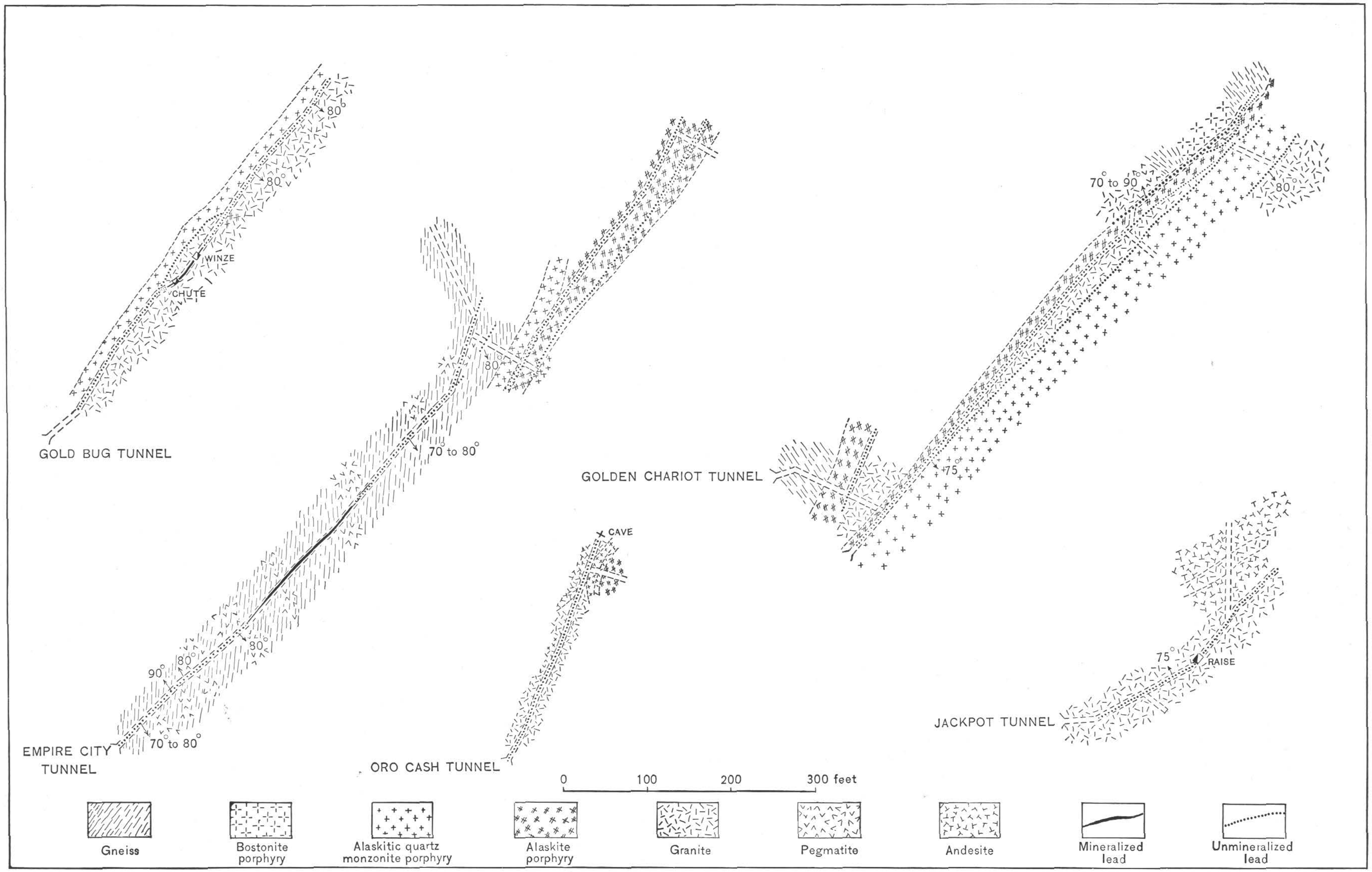
The Empire City-Gold Bug group of mines (see Pl. LXXIX, *B*) is situated in the small gulch which starts near the northern edge of the town of Empire and extends about N. 35° E. for a little more than half a mile up the steep mountain slope. The group consists of the veins developed in the Empire City, Golden Chariot, Jackpot, Oro Cash, and Gold Bug mines. Belonging to it is a whole series of veins running more or less parallel to and at or near the contacts of a series of porphyry dikes, which in general trend northeastward.

NATURE OF WALL ROCKS.

The country rock forming the walls of the veins consists of granite, biotite gneiss, and pegmatite. This series of rocks is intersected by a number of porphyry dikes, which vary widely from one another in composition. The dikes fall into four different classes, which include the following porphyries: Alaskite, bostonite, alaskitic quartz monzonite, and andesite. In the Empire City tunnel, which is located just east of the road at the north end of the town of Empire, is an alaskite porphyry dike, occurring between two dikes of alaskitic quartz monzonite. The alaskite dike in going northeastward splits up into as many as three branch dikes, separated from one another by about 5 feet of black crushed biotite gneiss. In the Golden Chariot mine, which is about 1,500 feet N. 32° E. of the Empire City tunnel and 485 feet higher in elevation, there are two alaskite dikes which diverge going northward and one alaskitic quartz monzonite dike which runs along the southeast side of the eastern alaskite dike. (See Pl. LXXXII.) On the northwest wall, near the breast of the Golden Chariot tunnel, was found a small patch of bostonite porphyry, separated from the northeast alaskite porphyry dike by a slightly mineralized vein. In the Gold Bug mine, still farther northeast, at an elevation of 9,500 feet, is an alaskitic quartz monzonite dike which runs the whole length of the northwest wall of the vein. A small isolated patch of alaskite porphyry was also noticed on the southeast wall of the same mine. In the Jackpot mine, several hundred feet south of the Gold Bug, are two dikes 30 and 45 feet wide, of dark-colored andesite porphyry. Near the breast of the Oro Cash tunnel, which is about 400 feet east of the Gold Bug, are found three different kinds of porphyry. A dark-colored rock, probably andesite, forms the northwest wall of the vein near the breast of the drift, and a 20-foot dike of alaskite porphyry occurs near the breast of the crosscut running southeastward from the end of the main tunnel. Between these two dikes, and separated from them by several feet of crushed granite and micaceous gneiss, is a 12-foot dike of granitic appearing alaskitic quartz monzonite porphyry.

NATURE OF VEINS.

Veins in Empire City mine.—In the Empire City mine the main tunnel follows what is termed the Empire City vein for over 650 feet. A crosscut drift, about 60 feet in length, connects with a second somewhat parallel vein, which is drifted on for about 350 feet farther to



GEOLOGICAL PLANS OF TUNNELS OF EMPIRE CITY, GOLDEN CHARIOT, JACKPOT, GOLD BUG, AND ORO CASH MINES.

the northeast. The Empire City vein itself consists of a clay and crushed-gneiss lead, in many places containing considerable quartz, which gives way, locally, to the pyrite, chalcopyrite, and quartz ore. The strike of the vein is about N. 43° E. and the dip ranges from 70° or 80° NW. to 80° SE. For the entire length of the drift the walls of the vein consist of soft biotite gneiss containing numerous patches of pegamite. Toward the northeast end, however, the vein splits into two branches that enter soft biotite gneiss, the schistosity of which strikes a little east of north. The somewhat parallel vein, about 60 feet southeast of the Empire City vein, has a strike of N. 36° E., and consists of 1 to 1½ feet of crushed pegmatite, gneiss, and quartz which in places changes to small streaks of pyrite and quartz. This crushed-gneiss and clay lead runs for its whole length between two bodies of porphyry, but is at many places separated from the northwest porphyry mass by about 1½ feet of a soft friction breccia, which is gray in color and has a few white specks resembling altered feldspar crystals. In the northeast end of the mine workings this vein separates two tongues of the alaskite porphyry, the one on the southeast being about 22 feet in width and the one on the northwest only about 4 to 6 feet. Where first encountered in the crosscut from the Empire City vein two somewhat similar alaskite porphyry dikes form its walls, but on the northwest of the 6-foot porphyry dike forming the northwest wall is a 15-foot dike of alaskitic quartz monzonite which, according to Mr. W. P. Clough, one of the owners of the mine, swerves to the northeast and cuts through the 4- to 6-foot porphyry dike, and then, without entering the alaskite porphyry body forming the southeast wall of the vein, turns northward again and disappears from the workings. However, this alaskitic quartz monzonite dike is probably encountered again in the Golden Chariot mine, farther up the hill.

What could possibly be termed a vein was also found between the southeast dikes of alaskite porphyry near the breast of the mine workings. This vein consisted of 5 feet of crushed micaceous gneiss and clay containing stringers of quartz, chalcopyrite, and pyrite, which were reported to carry about $8 in values. Near the southwest breast of the crosscut connecting the two main veins there was also a small unmineralized lead of white clay, which had alaskite porphyry for both of its walls near the back of the drift, while near the bottom of the drift the southeast wall was alaskitic monzonite and the northwest wall the 15-foot alaskite porphyry dike which forms the southeast wall of the main southeast vein.

Veins in Golden Chariot mine.—In the Golden Chariot mine the main tunnel for 150 feet follows a white unmineralized clay lead only one-half to 1 inch wide, which dips 75° SW. and separates a 4-foot dike of alaskite porphyry on the northwest from a 50-foot dike of alaskitic quartz monzonite on the southeast. Where the two dikes separate and loop about a lens or horse of granite several hundred feet long and 25 feet wide in the widest part, the tunnel follows a faint lead along the southeast side of the alaskite porphyry dike to a point a little more than 500 feet from the mouth, where it crosses to the northwest side of the dike and continues to the breast of the tunnel, 200 feet distant, along a clay, quartz, and crushed-rock lead 1 to 3 feet wide which in places carries pyrite and chalcopyrite.

The strike of this vein, which ranges in dip from vertical to 75° NW., is N. 50° E. In the breast of the main tunnel both walls of the vein are gneiss, but a short distance southwest of the breast the northwest or hanging wall of the vein is a dense fine-grained porphyry, which on microscopic examination proves to be bostonite. The southeast wall at the same point is pegmatite for a portion of the way and alaskite porphyry for the rest. In a crosscut spur to the southeast near the breast this alaskite porphyry dike is 11 feet wide and is separated from the 50-foot dike of alaskitic quartz monzonite to the southeast by an 8- to 10-inch clay and crushed-rock lead which in places carries pyritized quartz. Along the southeast side of the 50-foot dike and between it and granite is a clay and crushed-gneiss contact lead 8 inches to 2 feet in width, which strikes N. 35° E. and dips 80° SE. About midway of the crosscut tunnel, whose mouth is about 125 feet N. 40° W. of the mouth of the main tunnel and which runs southeastward to meet the latter at a point about 75 feet in, is a second alaskite porphyry dike, approximately 30 feet wide, that trends N. 20° E. This porphyry body, which is badly altered and heavily stained with iron and manganese oxides near the margins, is separated by a soft unmineralized gouge lead from the granite on the southeast side, whereas on the northwest side the contact with the micaceous gneiss is rather tight.

Vein in Gold Bug mine.—In the Gold Bug mine, located 700 or 800 feet N. 55° E. of the Golden Chariot mine, the vein, which is followed by a tunnel about 550 feet in length, strikes N. 40° E. and dips 8° SW. For this whole distance the southeast or hanging wall of the vein, aside from a small patch of alaskite porphyry about 350 feet from the mouth, is granite containing a small amount of pegmatite. The foot wall of the vein is usually alaskitic quartz monzonite porphyry, which is probably the continuation of the dike in the Golden Chariot mine. However, about 225 feet from the mouth of the tunnel there is a split in the vein, and though a small clay selvage streak continues along the contact with the porphyry, which here swerves slightly to the northwest, the main vein turns slightly eastward and loops around a horse of granite about 125 feet in length before again continuing along the porphyry contact farther to the northeast.

Vein in Jackpot mine.—The vein in the Jackpot mine, situated several hundred feet S. 25° W. of the Gold Bug, is in granite for the whole length of the tunnel, which is more than 300 feet. A crosscut drift to the north, however, about 75 feet from the breast of the tunnel, intersects two dark-colored andesite porphyry dikes 20 and 35 feet in width. The vein in the Jackpot mine in places consists of a broad, soft lode impregnated with pyrite; elsewhere it is made up of hard quartz and cupriferous pyrite stringers intersecting granite.

Vein in Oro Cash mine.—The Oro Cash mine, located on the road about 400 feet west of the Gold Bug mine, is developed by a tunnel on a vein which runs N. 22° E. for about 300 feet to a point where the drift was caved shut. For most of this distance the walls of the vein consist of gray granite, but porphyry is probably but a few feet distant from the vein on both sides, as near the breast of the tunnel three dikes of different kinds of porphyry were encountered. At this point dark andesite porphyry formed the northwest wall of the main vein, and a gray speckled porphyry, probably alaskitic quartz monzonite, formed the southeast wall. This dike, which is about 12 feet in width, was separated from a 20-foot alaskite dike farther to the southeast by about 7 feet of granite and micaceous gneiss. Although some pyrite and quartz occurred along a clay and crushed-rock vein, but little signs of ore were noticed along the vein up to the point where the cave in the drift occurred.

NATURE OF ORE.

In the Empire City mine the ore occurring along the Empire City vein consisted of quartz and copper-bearing pyrite, with possibly some chalcopyrite. According to Mr. Clough, this ore in spots ran as high as 8 ounces in gold. Although considerable stoping has been done along this vein, however, the mineralized streaks have been so narrow and the quantity of ore so small in comparison with the amount of work necessary for mining it that the mine has not been highly productive. The middle tongue of white alaskite porphyry near the breast of the Empire City workings, which is highly altered and impregnated with some pyrite, is said to have given assays running as high as 8 ounces in silver and $3 or $4 in gold. None of this porphyry, however, has yet been shipped as ore. In the breast of the drift running northwestward from the end of the tunnel on the Empire City vein is a seam of pyrite ore 1 to 1½ inches wide, which is said to have assayed 18 ounces in silver to the ton, an extraordinarily large amount of silver for straight pyrite ore. Several of the minor leads associated with the porphyry dikes in the Empire City tunnel also showed some values in gold and silver, but these were not of sufficient richness or size to warrant the mining of the material as ore.

In the Golden Chariot mine the only vein that showed evidence of much mineralization was the one along the inner 175 feet of the main tunnel, on the northwest side of the southeast alaskite dike. No stoping had been done on this level, however, and therefore there was little if any production.

The Gold Bug vein shows evidences of mineralization for much of its length. This mineralization consists of solid pyrite and quartz streaks a few inches in width, or of small stringers of pyrite forming a network several feet wide in granite. Stoping, however, has been confined to two places, about 50 feet in length, at distances of 100 and 275 feet from the mouth of the tunnel. The stope at 275 feet, which was much the larger one, was entirely in granite on the southeast branch of the vein, where the vein splits and loops about a horse of granite about 125 feet in length.

The vein in the workings of the Jackpot mine shows considerable pyrite ore for its whole length. Much of this pyrite, however, carries but little copper and is probably of rather low grade, for aside from some drift stoping little effort has been made to mine the ore.

SILVER MOUNTAIN ORE ZONE.

NATURE OF ORE ZONE.

Some of the principal mines in the Empire district occur in the zone of crushing and decomposition which has a general northeast strike. The zone has been traced along the strike, as shown on the accompanying sketch (Pl. LXXXIII, *A*), for about 3,500 feet, and is several hundred feet wide. Within this zone the rock is in a general fractured and altered condition, but the fracturing and alteration are by no means regular, being more intense along certain zones. The principal zones of maximum alteration and mineralization have a northeast strike parallel with the general trend of the main zone of crushing, but there are many other slips and fractures intricately branching and crossing one another. In many places one slip passes into another in zigzag fashion.

CHARACTER OF LODES WITHIN THE ORE ZONE.

The minor ore zone that is known as the Silver Mountain lode in the Silver Mountain mine has a northeast trend and is a thoroughly crushed and altered zone in gneiss. It is in places 60 or 70 feet wide and is exposed both at the surface and in the Aorta tunnel, which is the lowest level of the mines. The line drawn on the plan (Pl. LXXXIII, *A*) to represent the Silver Mountain lode delineates the course of a small gouge slip, which is the most persistent feature of this crushed zone, for the altered rock adjoining it is without definite walls and is irregular in its outline. At the surface this soft and decomposed rock is iron stained, but in the lower levels the origin of this stain is seen in the pyrite which is everywhere disseminated in it. On the first level of the Silver Mountain mine this lode shows 30 feet of irregularly decomposed and mineralized porphyritic granite with bunches of pay ore scattered throughout.

The Silver Mountain lode is typical of the other lodes within this general crushed zone. All have formed along slips or zones of especially intense crushing within the disturbed belt and are bordered on each side by highly altered and mineralized rock. As a rule some of the best ore occurs along the main slips or narrow fracture zones, so that relatively definite veins exist; but the wall material is also in many places sufficiently mineralized to become an ore, and the resulting stopes are of very irregular form and extent. Here and there good walls are present along the veins, there being in some places a single wall, in others two, and in still others three or more. At many points there are none, and some of the largest and richest ore bodies consist only of an irregular impregnation of the country rock by sulphides on either side of a central small crack.

As compared with most of the other veins in this region, these separate lodes are weak and unreliable. Since the definite slips or narrow fracture zones may run out into broad zones of decomposition, and since other irregularities, such as the diverging of the two walls of a lode, the branching, and the intricate crossing of one mineralized seam by another, are constantly encountered, the lodes are in general not easy to follow for any long distance, and baffling complications may be met at any point.

PROCESS OF MINERALIZATION.

The mineralization which has resulted from waters circulating through the crushed zone, especially along the main slips and narrow fracture zone which form the present lodes, has been accomplished chiefly by the filling of microscopic spaces in the altered and shrunken rock (the process of impregnation), with undoubtedly some replacement. There is no evidence anywhere of fissure filling.

POSTMINERAL MOVEMENTS.

The movements along this general zone of crushing and fracturing are not all of ancient date. Zones of crushed and broken rock constituting masses of uncemented rubble are not infrequently encountered underground, even at depths of several hundred feet from the surface. For example, in the Aorta tunnel, about 700 feet in and 200 feet below the surface, a belt of quartz diorite has been thus broken into fragments by comparatively recent movements, as there is no indication of any cementation, such as would have set in had the date of the crushing been even moderately remote.

On the third level of the Silver Mountain mine also, in the northeast workings, the rocks have been scattered so as to form a loose, unconsolidated breccia. This is about 270 feet from the surface. The same breccia, apparently representing a relatively recent zone of crushing transverse to the main northeast trend of the veins at this point, is encountered also on the fifth level, 100 feet below. Near this breccia on the fifth level the Silver Mountain vein is displaced by an open fault fissure 18 inches to the southeast on the northeast side.

Such postmineral transverse faults have been observed elsewhere; for example, in the B. B. tunnel the Lafayette vein is faulted at one point by a movement involving a horizontal offset of about 3 feet.

It is probable that other postmineral faults have a larger displacement, for in several places the mineralized vein slip was followed up to a poorly mineralized or barren transverse slip, which terminated the ore.

ORIGIN AND DEVELOPMENT OF ORE ZONE.

This broad general zone of crushing movement and faulting probably originated as early as the period of porphyry intrusion. This is indicated by the porphyry dike which is shown on the plan (Pl. LXXXIII, *A*) as having been encountered within this zone at several points, and is approximately parallel to its main trend, as if at the time of the intrusion the zone had already offered an inviting zone of weakness. This dike is shown in the B. B. tunnel, and what is probably the same dike, having a similar composition, thickness, and attitude, is found at several points in the workings of the Gold Dirt mine.

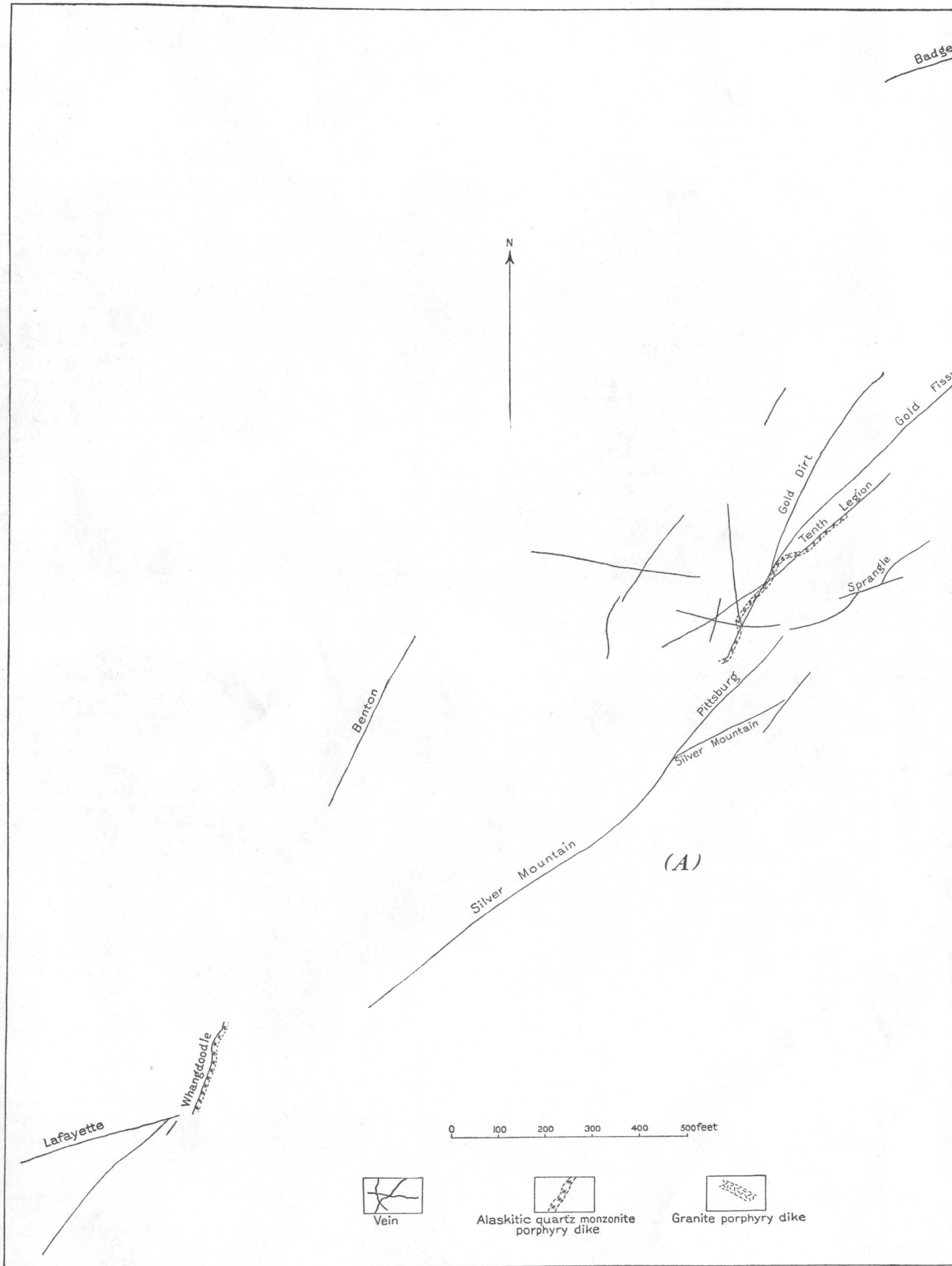
Movement took place along the zone subsequent to the intrusion of the dike, for on the different levels of the Gold Dirt mine where this porphyry is encountered it is found only in fragments of small extent which are separated from one another. These fragments have evidently been torn apart by strike faulting complicated with oblique movement.

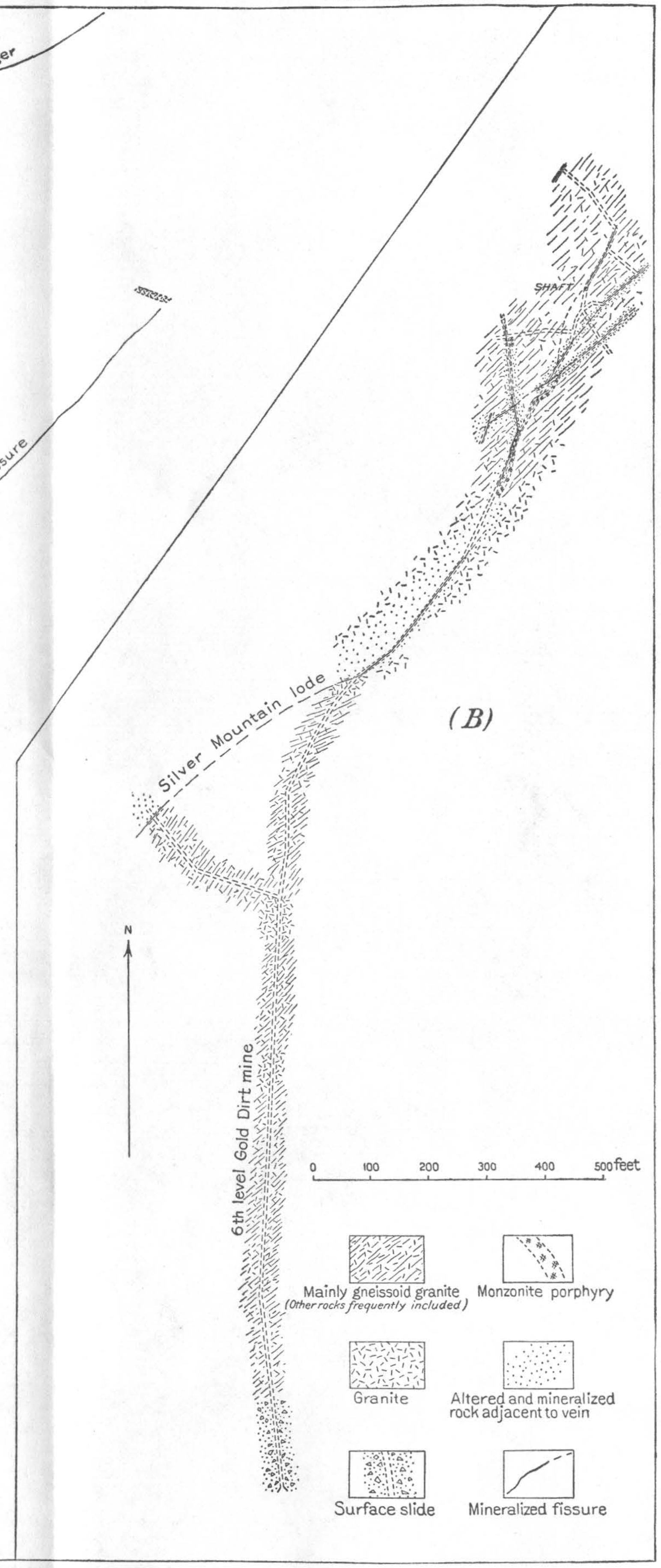
The principal mineralization was subsequent to the faulting disturbance of the dike, and occurred principally along the same fault planes, where, as above stated, there is evidence of a not inconsiderable amount of faulting subsequent to the main mineralization. Other than this, however, there is no evidence fixing definitely the period of mineralization, and the complicated crossing of the mineralized and unmineralized slips suggests that different sets of fractures, which were subsequently mineralized, were formed at distinct periods.

PRINCIPAL VEINS WITHIN THE ORE ZONE.

Though some of the mineralized slips or veins within the ore zone can not be followed for any considerable distance, as at many places they branch and zigzag and pass from veins to unmineralized and splintering slips, there are others which are so strong and persistent as to be reliable for long distances, and some of these have been traced for hundreds of feet.

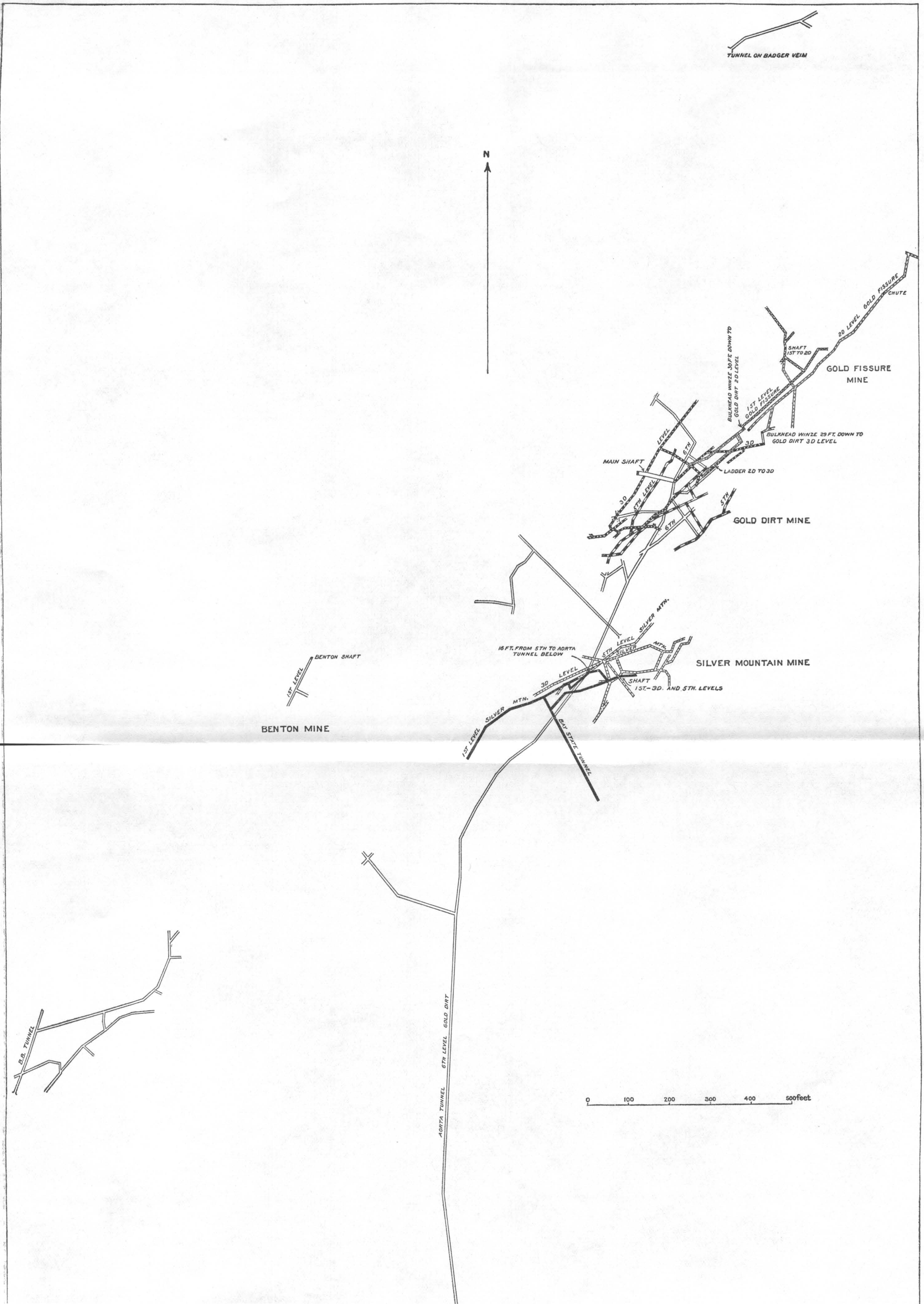
The chief veins have a northeast direction and are represented principally by the Silver Mountain lode and the Gold Fissure lode. From these veins branch out others which are also more or less persistent. Of these branches the principal ones are perhaps the Gold Dirt and the Tenth Legion veins, both of which have been followed from the surface down to the Aorta tunnel level and probably extend downward considerably farther, although they are locally confused and complicated by intersecting slips. In the Silver Mountain mine there is a branching of the main lode opening out to the northeast. The direct extension of the main lode to the northeast has been locally called the Pittsburg vein, and the southwestern branch retains the

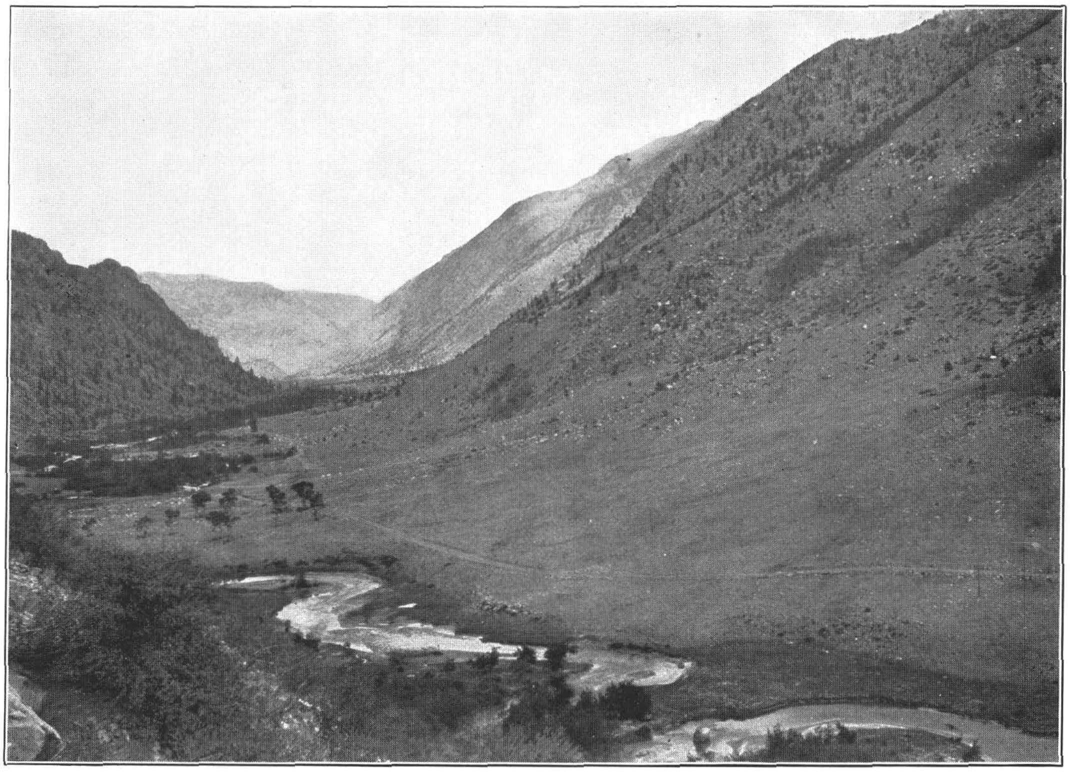




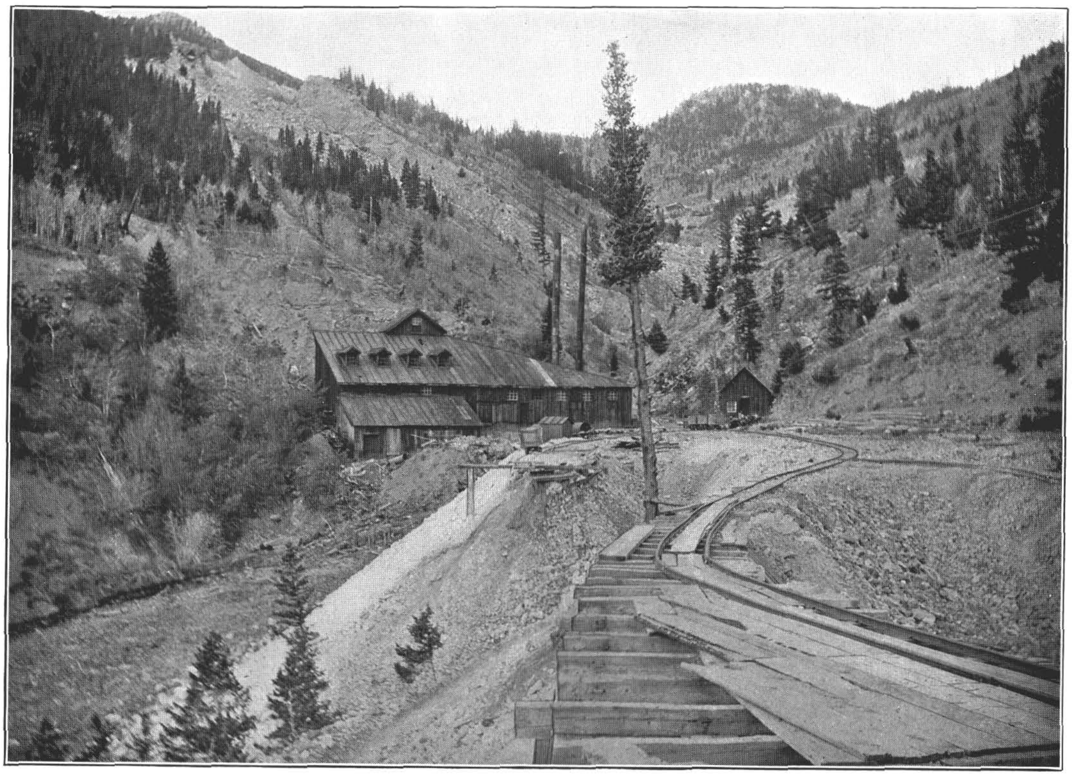
HORIZONTAL PLAN SHOWING RELATIONS OF DEVELOPED VEINS IN THE SILVER MOUNTAIN ORE ZONE.

B. GEOLOGICAL PLAN OF AORTA TUNNEL.


TUNNEL ON BADGER VEIN
N
2D LEVEL GOLD FISSURE
CHUTE
SHAFT 1ST TO 2D
BULKHEAD WINZE 30 FT. DOWN TO GOLD DIRT 2D LEVEL
1ST LEVEL GOLD FISSURE
GOLD FISSURE MINE
BULKHEAD WINZE 29 FT. DOWN TO GOLD DIRT 3D LEVEL
3D
LEVEL
6TH
MAIN SHAFT
LADDER 2D TO 3D
3D
5TH LEVEL
6TH
5TH
GOLD DIRT MINE
SILVER MTN.
5TH LEVEL
SILVER MTN.
16 FT. FROM 5TH TO AORTA TUNNEL BELOW
SILVER MOUNTAIN MINE
BENTON SHAFT
1ST LEVEL
3D LEVEL
SHAFT 1ST.-3D. AND 5TH. LEVELS
1ST LEVEL SILVER MTN.
BAY STATE TUNNEL
BENTON MINE
B.S. TUNNEL
AORTA TUNNEL 6TH LEVEL GOLD DIRT
0 100 200 300 400 500 feet



A. VALLEY OF CLEAR CREEK FROM EMPIRE PASS ROAD.
Showing meandering of stream.



B. AORTA TUNNEL, EMPIRE, AND SURFACE WORKINGS ON SILVER MOUNTAIN AND BENTON LODES.

name Silver Mountain. The northeastern branch is persistent from the surface down to the lowest (Aorta) tunnel level; the other branch, which is strong on the first level, is very weak on the third and not recognizable on the fifth.

The accompanying plans (Pl. LXXXIII) show only the veins which have been noted in the writers' study of the mine workings, with a little conservative projection in some places. They undoubtedly do not represent all the veins or principal mineralized slips within the ore zones, a full list of which would be much larger. Moreover, some of the veins which are shown may unite and be practically the same lode; for example, the Silver Mountain and the Lafayette veins are in line, and also the Whangdoodle and the Benton. In general, however, in this district the veins are so irregular that it is unsafe to correlate them across any considerable intervening space.

MINE WORKINGS.

The principal mine workings in this zone are those of the Gold Dirt, Gold Fissure, and Silver Mountain mines, which are close to one another. (See Pl. LXXXIV.) These were all originally worked by shallow tunnels and shafts, from which deeper levels were run. Later the Aorta crosscut tunnel was run in from the gulch to the south of the mines to tap the veins at a lower level. The Aorta tunnel level (Pls. LXXXIII, *B;* LXXXV, *B*) passes under the Silver Mountain and Gold Dirt mines and forms the sixth level of the latter. Along the zone southwest of the mines, mentioned above, is the Bay State tunnel, which starts in on nearly the same level as the Aorta and opens up some of the veins of the zone. Northwest of this tunnel and southwest of the other mines mentioned is the Benton shaft, from which a number of different levels have been run. Several hundred feet north of the Gold Fissure shaft there is a tunnel on the Badger lode.

COMPOSITION OF VEINS.

The metallic minerals consist chiefly of pyrite and chalcopyrite with a gangue of quartz. Galena and blende were not observed in these mines. Subsequent black sulphides of copper, which have formed along fractures in the chalcopyrite, occur in the upper workings, especially in the Gold Fissure mine. Native copper in small amounts is reported in different places, especially in the upper portions of the veins. A small quantity of native bismuth is reported as having occurred on the third level of the Gold Fissure mine. (See Pl. LXXXVI.) In the Silver Mountain mine along a barren slip tabular crystals of barite were found. A specimen of the ore from a vein in the Aorta tunnel level of the Gold Dirt mine examined microscopically was found to consist of abundant pyrite, finely crystalline quartz, disseminated brown crystals of siderite, and some fine sericitic material.

The valuable materials in this ore are chiefly gold and secondarily copper. Silver is present in small quantity. The gold is apparently confined mainly to the chalcopyrite; the pyrite is usually of low grade or barren, although exceptionally it may contain enough gold to be a profitable ore. Up to the present time the ore has been treated by hand sorting, to separate the chalcopyrite as well as possible from the pyrite, and the material which is of sufficiently high grade is smelted. The ore that has a value of less than $10 is characterized as "mill dirt," and no satisfactory process for treating it has yet been found. Mechanical concentration has failed to separate the chalcopyrite from the pyrite, and on account of the presence of so much copper the ore is not well adapted for cyaniding even after roasting. According to Mr. F. A. Maxwell, of Georgetown, the sulphides yield on assay only about 80 per cent of the values indicated by assay of the whole ore; the rest must occur as free gold, for this can be obtained by panning the ore.

The highest grade ore which has been extracted contained several ounces of gold to the ton. One carload of ore from the Sprangle vein on the fifth level of the Gold Dirt is reported to have averaged several ounces to the ton. This was the richest ore in the mine. Picked smelting ore from the third level of the same mine is reported as containing 3 ounces. On the Tenth Legion vein some ore rich in copper was encountered. This ore carried as high as 12½ per cent of copper, with 7 ounces of gold and 20 ounces of silver to the ton. These values apparently represent exceptional spots, for 2 feet of high-grade ore from the same vein on the 125-foot level is reported as having yielded from $45 to $50 per ton in gold. There are, however, apparently large masses of low-grade ores.

LOCATION OF ORES.

In this zone the ore bodies seem to have no relation to the junction of slips or leads, thus forming an exception to the general rule for this region. It is quite likely that this fact is due to the successive development of the intersecting fractures, which obscured the original junctions, if there were any, and created a number of junctions subsequent to the earlier stages of mineralization.

NATURE OF WALL ROCKS.

The oldest rock within this ore zone is a dark, usually biotitic gneiss, which is also the oldest formation known in this whole region—the Idaho Springs formation described by Mr. Ball. A large amount of gneissoid granite was encountered in the underground workings, especially in the Aorta tunnel. This rock is cut by the other igneous rocks described below.

Dark-colored dioritic rocks occur at numerous places underground in dikes and larger intrusive masses. These rocks are similar to those in the Empire tunnel already described. They range in texture from relatively fine grained porphyries to coarse porphyritic granular rocks and to both fine and coarse nonporphyritic granular rocks. The mineral composition, however, is similar throughout, although the relative proportions differ somewhat, especially in the granular parts, where there has evidently been some segregation and differentiation, further indicated by pegmatitic streaks and bands of fine siliceous aplitic rock, apparently contemporaneous in origin with the inclosing diorite. The principal minerals are feldspar, hornblende, and biotite. Quartz is usually present in varying quantity. As accessory minerals occur sphene, zircon, magnetite, pyrite, and apatite. The feldspar is mainly andesine-oligoclase and andesine. In the porphyritic rocks some of the phenocrysts, which in the coarse-grained phases are an inch or more in length, show a zonal structure. The core of one of these crystals was determined to be labradorite and the outside layer andesine. Small fragments of augite were noted in one or two places.

The porphyry dike that follows the Whangdoodle vein in the B. B. tunnel and the Tenth Legion vein in the Aorta tunnel and the upper levels of the Gold Dirt mine is for the most part entirely altered. The original phenocrysts appear to have consisted chiefly of feldspar and biotite; apatite and magnetite still remain unaltered. The rock appears to belong to the class of alaskitic quartz monzonite porphyries, as determined by Mr. Ball.

The porphyry dike encountered in the extreme end of the Gold Fissure workings belongs to the class of granite porphyries.

ALTERATION OF WALL ROCKS.

The granitic gneiss, which when fresh has the composition of an alkaline or alaskitic granite, is as a rule entirely decomposed within the ore zone, and is changed to secondary quartz and sericite, the original quartz and zircon of the rock remaining unattacked. A specimen of this gneiss from the Aorta tunnel appeared at first sight to be altered to quartz and sericite, but an investigation of the latter mineral showed it to be a pale-brown pleochroic mica of sericitic habit. Pyrite is always abundant in these altered rocks. A specimen of the gneissoid granite from the dump of the Aorta tunnel contains a small seam of brilliant specular iron, apparently secondary in origin.

The porphyry dike encountered along the Tenth Legion vein is probably identical with that encountered along the Whangdoodle vein, and both are everywhere highly altered. The feldspar is characteristically changed to clear, translucent kaolin. The biotite is bleached and is filled with reddish cloudy carbonates, chiefly siderite. Apatite and probably magnetite remain unaltered. The groundmass is usually altered to quartz with some siderite. Specimens of the dike from the B. B. tunnel show a slightly different and rather more intense alteration than those from the Tenth Legion vein, above referred to. They are entirely altered to quartz, sericite, and siderite, the original structure as well as the composition of the porphyry being completely obscured.

A specimen of the porphyritic granite taken from the north breast of the Sprangle vein on the fifth level of the Gold Dirt mine shows some of its feldspars entirely altered to sericite, while some show no alteration except that they are slightly turbid as if from kaolinization. There is considerable crystalline pyrite, associated with a fine crystalline aggregate of brownish siderite, the iron minerals being probably derived from the alteration of original biotite. The original quartz and zircon of the granite remain in the unaltered mass. The rock also contains microscopic veinlets, the borders of which, representing the first deposition in the tiny fissure, are of fine crystalline quartz, while the interiors are filled with clear, translucent kaolin.

The quartz diorites examined from this zone underground are as a rule relatively fresh; some of the feldspars are altered more or less to sericite or to kaolin. The hornblende is in places slightly altered to epidote. A specimen of the diorite from the crushed zone which has been described as appearing along the Aorta tunnel about 700 feet from the mouth is, however, unusually altered, the feldspars being partly clouded by alteration products which appear to be mainly kaolin with some sericite. The hornblende also in this rock is entirely decomposed. The unusual alteration in this specimen is evidently due to ordinary waters circulating through the breccia zone.

RELATION OF ORES TO DEPTH.

No accurate data as to the relation of the strength of the veins to depth from the surface were obtained. The general impression received, however, was that the several lodes were decidedly stronger in the upper portions of the mines than, for example, in the Aorta tunnel level. On this level the different lodes, which in the overlying workings were represented by numerous definite and stronger deposits of quartz and sulphides, are characteristically only mere slips in the zones of altered and pyritized rock, and many of them are marked by very little or no especial mineralization. On the upper levels of the mines the veins are stoped at many places for a width of several feet and may be relatively regular. It also seems probable that the proportion of chalcopyrite to pyrite is much larger on the upper than on the lower levels and that the Aorta tunnel level is mostly below the rich chalcopyrite zone. The superficial portion of the ores, extending from the surface down to a depth of 40 feet or more, is entirely oxidized, and the gold below, associated with and mostly contained in sulphides, is in a free state.

The discovery of gold in this oxidized and decomposed superficial rock was the cause of the first mining activity in the Empire in 1862 and 1863. The softened material was washed into sluices and treated in the same way as placer gravels, yielding a good profit. Water was brought in a ditch from Mill Creek, 3½ miles distant, and most of the surface material was sluiced off. The diggings were scenes of great excitement for three or four years.[a] Later, when the surface material had been mostly removed, sulphides were encountered in depth, and as these ores were not amenable to the same simple treatment the mining industry suddenly languished.

The writers were informed by the miners at Empire that the oxidized and decomposed surface ores were much poorer than the sulphides below, and this information is published in an earlier report.[b] Further information renders it doubtful whether this is strictly true when applied to the material which has been removed, although it may be true with reference to the poorer portions that have not been washed away. These residual portions are said to contain from $2.50 to $7 in gold to the ton. It is stated by earlier writers, however, that the material sluiced away and passed through a stamp mill yielded $70 to $85 per ton. The surface of the Tenth Legion lode is said to have yielded, locally at least, $35 per ton.[c] According to this, it seems probable that the surface material was as high in gold or higher than the sulphide material below.

[a] Fossett, Frank, Colorado, 1883, p. 5. [b] Bull. U. S. Geol. Survey No. 260, 1905, p. 120. [c] Hollister, Mines of Colorado, 1867, p. 245.

Not only do the sulphides immediately beneath the oxidized zone contain a large amount of chalcopyrite, but along the fractures in this ore black sulphides of copper[a] have formed which are undoubtedly of secondary origin. In the Gold Fissure mine the best ore was of this character, and extended from 25 to 150 feet beneath the surface. Much of this ore was of high grade, some of it assaying 10 ounces of gold to the ton.

The actual difference of elevation between the surface at the outcrop of the Gold Fissure vein and the Aorta tunnel level, where the quantity of chalcopyrite seems very much less, is about 500 feet. This recalls the Centennial vein, where similar gold ores whose values are associated closely with chalcopyrite and black or gray copper sulphides (tetrahedrite, in part at least) give way to lean ores at about 550 feet below the surface. In the Centennial mine and perhaps also in the Empire mines the effect of descending surface waters is suggested. In veins carrying considerable copper the amount of rearrangement produced by a given quantity of descending surface waters within a given period is usually much greater than in veins of different composition, on account of the easy solubility of copper.

PRESENT WORK OF SURFACE WATERS.

The water in the mine is very acid, evidently as a result of the superficial oxidation of sulphides. It also contains copper. Iron rails in the mine are rapidly eaten up and in places shells of copper are deposited on them. Deposits of amorphous copper minerals, probably both carbonate and sulphate, were noted at several places as having formed since the opening of drifts. Fine greenish stalactites were taken from the roof of the Bay State tunnel on the first level of the Silver Mountain mine. These were examined by E. C. Sullivan and determined to be hydrous ferrous sulphate of iron containing a trace of calcium, a little magnesium, and a faint trace of copper. The underground waters which circulate along the zone of brecciated diorite described above as occurring in the Aorta tunnel about 700 feet from the mouth deposit considerable iron oxide (limonite). Pools of water standing in the bottom of the drift at this point have a film of blood-red iron oxide on top.

CONQUEROR MINE.

LOCATION AND DEVELOPMENT.

The Conqueror mine is located on the west side of North Empire Creek, 1.7 miles due north of the town of Empire. On the tunnel level the development consists of a crosscut tunnel about 1,100 feet in length and 2,000 feet or more of drifting. A shaft also extends up and down from the tunnel level on the Conqueror vein, but the extent of the workings connecting with the shaft was not learned.

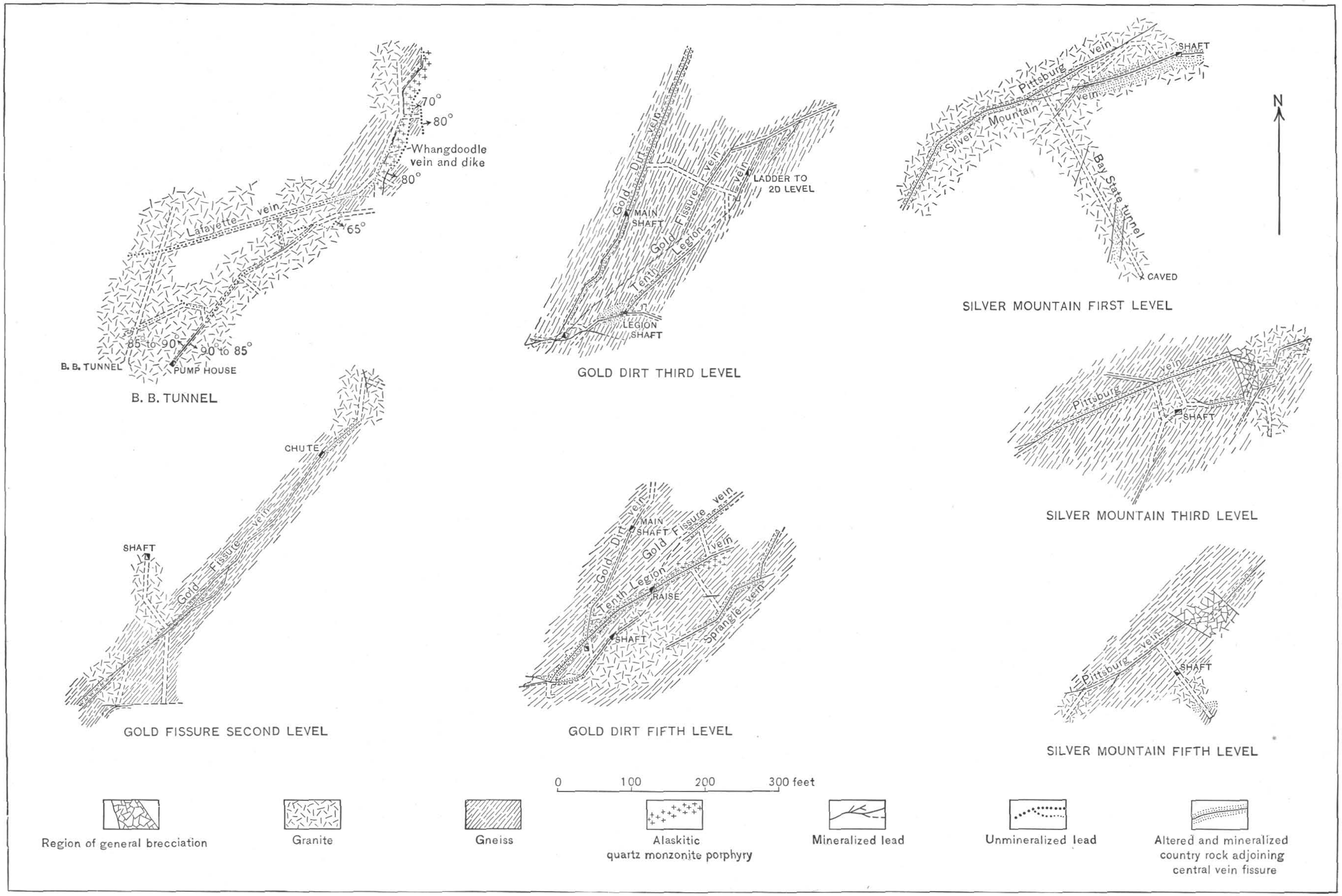
NATURE OF WALL ROCKS.

The wall rocks throughout the mine consist almost entirely of biotite granite of the Silver Plume variety, but a few small patches of black gneiss and a little pegmatite were also noted, and at two points along the northeast workings on the Conqueror vein portions of a fine-grained alaskitic quartz monzonite porphyry dike 3½ feet wide appeared as the northwest wall of the vein and ran parallel to the vein for a short distance. A mass of dark-colored, highly silicified, and badly altered porphyry about 40 feet in width was cut by the tunnel about 50 feet south of the Conqueror vein. (See Pl. LXXXVII.) This porphyry was so intensely altered that its variety was indeterminable. On the surface an outcrop of bostonite porphyry was observed just west of the boiler house. The groundmass of this rock was very fine grained and contained only a very few minute phenocrysts embedded in it. Under the microscope this groundmass showed the trachytic structure formed by intergrown lath-shaped feldspar crystals.

NATURE OF VEINS.

The main vein developed in this mine is the Conqueror vein, which was encountered in the tunnel at a point between 1,000 and 1,050 feet from the mouth. The general strike of the

[a] A specimen taken proved to be too thin a crust for chemical determination, but is probably chalcocite.



GEOLOGICAL PLANS OF SEPARATE LEVELS, SILVER MOUNTAIN ORE ZONE.

Conqueror vein is about N. 70° E., and its average dip is 75° NW. The vein is a strong one, and consists of a zone of clay and crushed wall rock several feet in width, which represents a line of faulting or movement, as indicated by slickensided surfaces darkened by pulverized pyrite and showing movement striæ dipping 45° NE.

The Conqueror shaft, located about 80 feet northwest of the tunnel, is at a point where the Conqueror vein splits going northeast and loops about a horse of granite 100 feet or more in length. The point where these branches come together again is not shown in the present workings, but the continuation of the vein as exposed about 100 feet farther northeast, in a drift connecting with what is called the drift on the "Patsy," consists of a single lead, showing that the union has probably taken place. To the west of the shaft the vein has been opened for 600 feet or more. In the drift on the Conqueror vein in the northeast part of the mine the vein consists of 2 feet of clay or gougelike triturated material, resting to the southeast upon an altered granite foot wall highly impregnated with pyrite, and to the northwest of the clay streak is a belt of soft altered granite and gneiss permeated with pyrite. In spots this hanging-wall belt gave good values and was being stoped at the time the mine was visited.

Most of the stoping on the Conqueror vein, however, has been in the immediate vicinity of and to the west of the shaft. Although the two branches of the vein to the east of the shaft yielded some ore, the highest grade and largest body of ore was obtained near the shaft, where the two branches come together. At this point the ore was stoped for a height of 125 feet above the level, and for a width of 5 feet is said to have averaged between 3 and 4 ounces in gold to the ton. The stope continued for a distance of nearly 250 feet southwest of the shaft, but to the west the ore streak was neither so wide nor so rich as near the shaft. Some ore was also found along the vein for 300 or 400 feet to the southwest of the large stope, and a little drift stoping was done at various points along this stretch, although little pay ore was obtained. The best ore procured, which carried about 5 ounces in gold to the ton, came from the tunnel level near the shaft; the ore both above and below this level decreased in value.

Near the breast of the northeast workings of the mine the Conqueror vein intersects and faults, by a distance of about 3 feet, a vein termed the Patsy vein. The Patsy vein, which has a general N. 23° E. trend and a dip of about 80° SE., consists of a fairly strong crushed jaspery quartz and gouge lead, which was drifted on for a distance of more than 300 feet southwest of the Conqueror vein, to a point where it either terminates or changes rather abruptly to a series of faint leads in friable granite. It is very possible that the Patsy vein is cut off on the southwest by a cross lead somewhat parallel to the Conqueror vein. Although showing some pyrite in places, the Patsy vein usually carries little mineral of value and has produced only a small quantity of ore, if any.

About 250 feet S. 33° W. of the point where the Patsy vein was intersected by the tunnel, another vein, termed the General Harrison vein,[a] was intersected by a drift that followed the Patsy vein for about 50 feet and then continued to the southwest as a crosscut drift in friable granite. The General Harrison vein, which is considered to be the same vein as the one developed in the Rosecrans mine, is a soft lode from 3 to 7 feet wide, consisting of quartz, pyrite, and soft kaolinized and otherwise altered granite, containing disseminated pyrite. Some stoping has been done on this portion of the vein, which has yielded some ore. Although the General Harrison is a much broader and softer vein than the Patsy and differs from the latter somewhat in structure, it possibly represents a continuation of the Patsy vein, which has been faulted some distance to the southeast.

About 70 feet southeast of and parallel to the General Harrison vein is another vein called the Rosecrans, which is thought to be a continuation of the vein of that name developed in the Rosecrans mine. Where encountered this vein, which was trending N. 32° E., showed nearly 4 feet of quartz and altered granite impregnated with pyrite, much of which was in well-formed cubical crystals. Practically no development work had been done on this vein, which at this point probably carried very low values.

[a] This is to be distinguished from the Harrison vein in the Harrison tunnel (pp. 390-391.).

Still another vein is found in the mine. It is located about 60 feet northwest of the Conqueror vein, near the shaft, and has been drifted on for about 100 feet. The vein, which strikes S. 63° W. and is generally vertical or dips slightly to the northwest, is a slight lead of quartz and pyrite 1 to 3 inches wide, which has yielded no ore.

NATURE OF ORE.

The ore from the different veins encountered in the workings of the Conqueror mine consists in the main of pyrite and quartz from the main lead, or of a pyrite ore formed by the impregnation and partial or entire replacement of the wall rocks on the two sides of the main fracture.

The pyrite is slightly cupriferous, and in places along the Conqueror vein carries as much as 5 ounces in gold to the ton and a small amount of silver. In the northeast drift on the Conqueror vein patches of ore gave assays of 3 ounces in gold and 3 or 4 ounces in silver to the ton, but in general the ore throughout the mine averaged much lower in value. The exact production of the mine could not be ascertained, but is known to have been considerable, practically all having been from the Conqueror vein itself.

FAULTING.

The only faulting recognizable in the mine is that which resulted in the dislocation of portions of the Patsy vein. As already stated, the Conqueror vein cuts through the Patsy vein and causes a displacement of the south portion of that vein 3 feet to the northeast of the north portion. Near the fault the Conqueror vein dips 72° NW. and the Patsy dips 8° E.

About 100 feet farther south the Patsy vein is again faulted by a vein running approximately parallel to the Conqueror vein. Here also the south portion of the Patsy vein is offset about 3 feet to the east of the north portion. This cross vein, which dips about 75° SE., consists of a narrow clay and crushed-rock lead, apparently mineralized but slightly, if at all. It is possible that where the Patsy vein appears to end abruptly at the southwest end it is cut off by a cross lead, by a displacement similar to that of the faults which intersect it in the other two places. A small east-west pyrite and quartz lead observed 40 or 50 feet southeast of the Patsy vein in the tunnel may be the lead which is responsible for the faulting. The General Harrison vein, developed farther to the southwest, has a strike like that of the Patsy, and if projected to the northeast would run only a short distance southeast of it. As the General Harrison vein is not recognized in the tunnel, which it should cross if its course is undisturbed, it is very likely that it represents the south portion of the Patsy vein, which has been offset to the southeast by a displacement similar to that of the faulting which has affected it in the other two places.

ROSECRANS MINE.

LOCATION AND DEVELOPMENT.

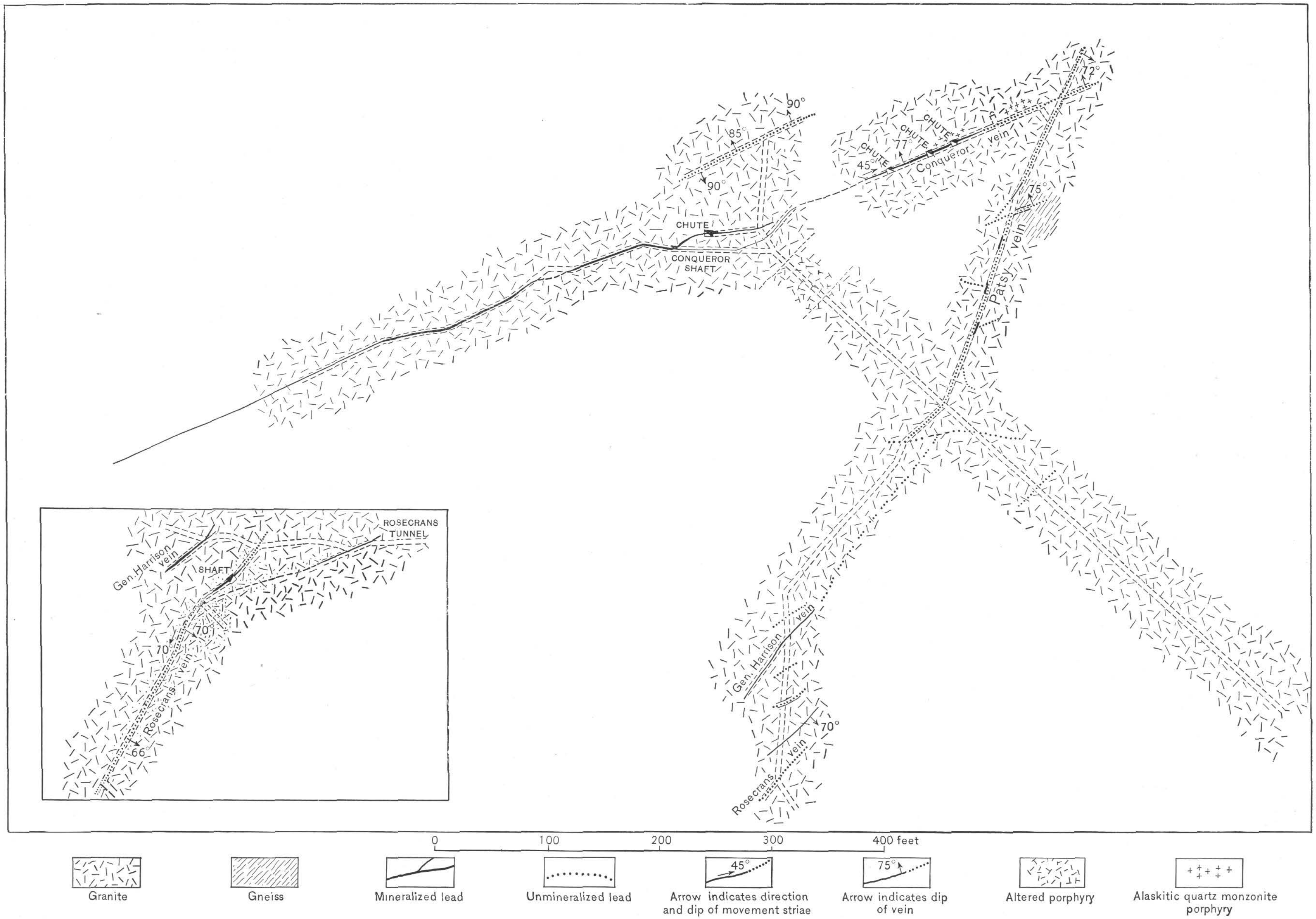
The Rosecrans tunnel mouth is located on the west side of North Empire Gulch, 500 or 600 feet due west of the Conqueror mine. The development consists of a tunnel level with about 600 feet of drifting and a shaft extending for a short distance below the tunnel level and connecting it with the surface.

NATURE OF WALL ROCKS.

The workings are all in granite, which is in general highly altered. The friable altered granite is as a rule highly impregnated with pyrite for a distance of several feet on either side of the main leads, or has small pyrite stringers scattered all through it.

DESCRIPTION OF VEINS.

The Rosecrans vein, which was encountered about 150 feet west of the mouth of the tunnel, dips 65° to 70° SE. and trends S. 45° W. for 100 feet and then bends to S. 30° W., continuing in the latter direction to the breast of the drift, about 200 feet distant. That the vein represents a prominent line of faulting or movement is shown by the smooth wall along the southwest 200



GEOLOGICAL PLANS OF TUNNELS IN CONQUEROR AND ROSECRANS MINES, EMPIRE.

feet of the vein. Movement striæ dipping 70° SW. were observed on this smooth wall, which probably represents the southeast or hanging-wall lead of the vein, which possibly occurs slightly northwest of the present drift. Along the northeast 100 feet of the drift the Rosecrans vein, which consists mainly of clay and quartz, is rather heavily mineralized in places and has been worked upon nearly to the surface along the line of the shaft. The granite south and southeast of the shaft is altered to a white gougelike mass and heavily impregnated with pyrite for a distance of 30 feet or more from the main lead. According to lessees at work near this point, assays made from material taken from a groove 10 feet in length along the wall of a crosscut spur in this impregnated granite gave an average value of $4.50 per ton for the whole mass.

A plausible reason for the large amount of mineralization in this place is that the branch mineralized lead which was encountered about 50 feet from the mouth of the tunnel and drifted on to the S. 68° W. probably joins the Rosecrans vein at this point.

Another vein, termed the General Harrison vein, which runs S. 50° W., approximately parallel to the Rosecrans vein, is located about 40 feet west of the latter vein where cut by the tunnel. The General Harrison vein consists of a 5-foot belt of altered granite and pyrite in equal proportions, the mass being cut by local streaks of solid pyrite up to 1 foot in width. This vein was opened only for a length of about 50 feet, but at the time of visit a small amount of stoping was being done on it.

Both the General Harrison and Rosecrans veins are supposed to have been encountered at a lower depth in the workings of the Conqueror mine.

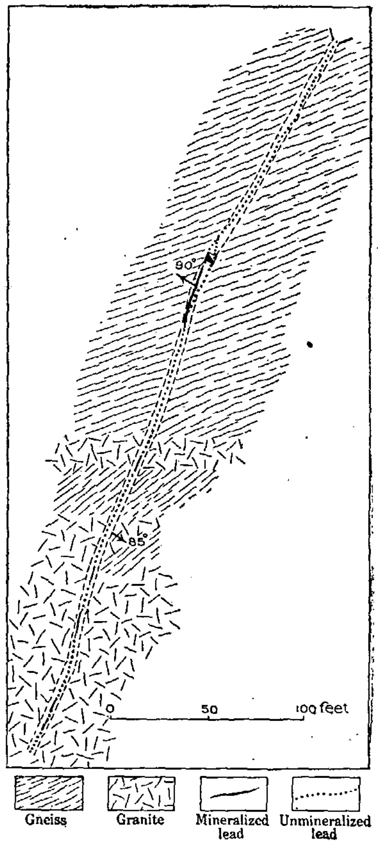


FIG. 150.—Geological plan of Union tunnel.

CHARACTER OF ORES.

The ores from this mine are chiefly low-grade gold ores consisting of pyrite associated with considerable quartz or silicified and altered granite. The pyrite as a rule is not highly cupriferous, but locally contains some copper, as is shown by the fact that the ores obtained from the present workings, which are comparatively near the surface, are here and there associated with a dull-black sooty mineral of secondary origin which W. T. Schaller, of the Geological Survey, found to contain both copper and sulphur and considered to be chalcocite. Near the shaft on the Rosecrans vein some porous or spongy quartz ore which on panning showed a little free gold was also obtained.

UNION TUNNEL.

The Union tunnel is located in North Empire Gulch, between 200 and 300 feet S. 57° W. of the mouth of the tunnel of the Conqueror mine. The tunnel (fig. 150), which follows the vein for 400 feet in a S. 25° W. direction, at about 125 feet from its mouth intersects a shaft which extends to the surface, a distance of about 86 feet, and has been sunk about 20 feet below the tunnel level.

The wall rocks in the northern part of the drift consist chiefly of gneiss, patches of which are so altered and silicified that they form a fine-grained mass resembling porphyry. Near the south end of the tunnel the wall rocks are chiefly granite, with some gneiss.

The vein is an irregular or wavy fault plane trending S. 25° W. and either vertical or dipping slightly to the southeast. In places the single vein splits and loops about horses of rock. In the main the vein consists of a gouge lead 4 inches to $1\frac{1}{4}$ feet wide, one-fourth inch to 4 inches of which is in many places heavily specked with pyrite. The vein in general contains but little pay ore, although some values were obtained near the shaft, where the vein loops about a horse of rock. Here the ore was a pyrite ore slightly stained by blue copper carbonate and containing some sooty black sulphides, probably chalcocite for the most part, in small vugs in the porous quartz. Some well-formed crystals of barite were found in vugs in the quartz gangue of the ore.

CROWN PRINCE-ATLANTIC GROUP.

GENERAL DESCRIPTION.

The Crown Prince-Atlantic group of veins includes the veins developed in the Crown Prince, Comet Extension, Atlantic, and Cleopatra mines. The first three of these mines, although separated by considerable unexplored ground, are probably either located on the same strong vein or belong to a set of nearly parallel veins a short distance apart which occupy the same fault zone. On the surface this fault zone runs N. 40° E. from the point where it crosses Lion Creek, at an elevation of about 9,700 feet, to a point some distance northeast of the Atlantic mine, which is located on the crest of the same mountain spur at an elevation of 10,280 feet. The Cleopatra mine is located on a vein which evidently is a branch of the main Crown Prince-Atlantic vein series. The veins vary considerably in width and structure throughout the different mines, owing mainly to the nature of the country rock. The mines will be described separately.

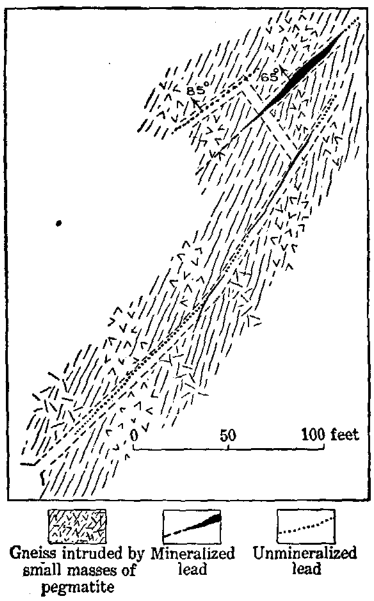


FIG. 151.—Geological plan of upper Crown Prince tunnel.

CROWN PRINCE MINE.

The workings of the Crown Prince mine consist of three tunnels running into the hillside and following the vein to the north-northeast. The lower two of these tunnels were caved shut at the time of visit, no work having been done on the mine for a year.

The upper tunnel, which is located a little over 7,000 feet N. 15° W. of the central portion of the town of Empire, follows in a N. 45° E. direction along a branch quartz and pyrite lead 6 inches to 1½ feet wide for about 125 feet, to a point where it joins the main vein, along which it runs in a N. 32° E. direction for 125 feet more (fig. 151). The main vein consists of a zone of gray jaspery quartz and highly silicified crushed country rock from 3 to 8 feet wide, which is in many places highly impregnated with pyrite for the whole width and contains numerous angular embedded fragments of pyrite. This massive pyrite and quartz ore, which contains a few small specks of crushed galena, evidently is of too low grade to warrant extraction, for no stoping has been done on the main vein on this level. Near the breast of the upper tunnel a crosscut to the northwest cuts two veins at distances of 30 and 45 feet from the main vein; both of these veins are evidently branches of the main vein, and if followed would be found to unite with it farther to the northeast, for they have strikes of N. 50° E. and N. 55° E. and dips of 65° and 85° NW., respectively. Both of these branch veins show some quartz and pyrite associated with a clay lead, and the branch nearer the main vein has been stoped up to a height of 30 feet, although the vein weakens in fractured gneiss and pegmatite.

All the upper tunnel workings on the Crown Prince are in granitic gneiss, with patches of granite and pegmatite scattered throughout. In places some of the granitic gneiss is so fine grained and so highly silicified that it resembles porphyry.

COMET EXTENSION MINE.

The Comet Extension mine, which is located a little more than 500 feet northeast of the upper tunnel on the Crown Prince, is developed by a single tunnel about 400 feet in length which follows the vein all the way (fig. 152). The wall rock consists entirely of granite.

The general strike of this vein underground is about N. 34° E. and the dip 65° SE. For the first 100 feet the tunnel follows a small quartz and crushed-granite lead which beyond this stretch splits into two forks, each of which is mineralized beyond the junction. These two branches, after looping about a horse of fractured granite, approach each other again and form the foot- and hanging-wall leads of the vein, which for the rest of the 250 feet to the breast consists of two streaks of solid low-grade pyrite ore 1 inch to 1 foot wide along each of the walls. These ore streaks are separated by 5 to 8 feet of fractured and silicified granite, with irregular stringers of pyrite up to several inches in thickness running throughout. Moreover, in some places the granite is highly impregnated, and in others it is partly or completely replaced by pyrite. The ore consists of pyrite containing only a small percentage of copper and quartz. Considerable stoping has been done along the vein, northeast of the point where it splits.

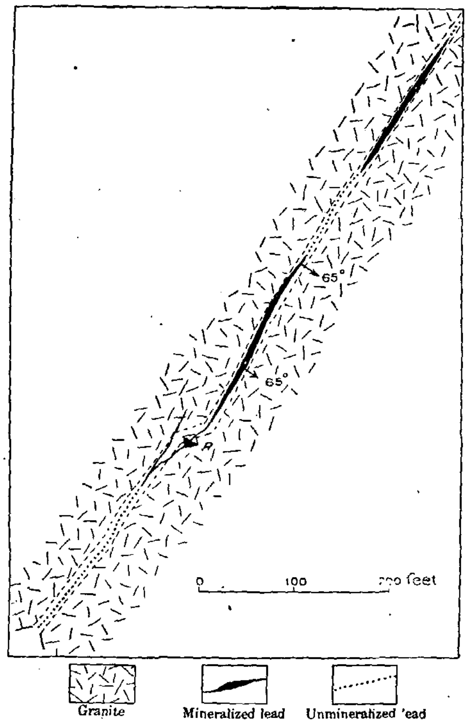


FIG. 152.—Geological plan of Comet Extension tunnel.

ATLANTIC MINE.

The Atlantic mine is located at an elevation of 10,280 feet, on the crest of a ridge 1½ miles N. 6° W. of the central part of the town of Empire. The mine is developed by a shaft several hundred feet deep and a considerable number of drifts, but at the time of visit it had long been idle and the workings were inaccessible owing to water, which partly filled even the first level connecting with the shaft. Granite is the prevailing country rock in the immediate vicinity. The general strike of the vein on this first level is N. 38° E., and the shaft and vein dip about 80° to 85° SE. The vein at this point consisted of 5 to 7 feet of gouge and decomposed friable and crushed granite impregnated with pyrite, some of which is copper bearing.

Specimens obtained from the dump showed the vein filling to consist of a mixture of angular fragments of pyrite and finely crushed granite, cemented by quartz and crystalline pyrite, showing two periods of ore formation or a movement midway in the process of mineralization. The chief values in the ore of this vein were in gold, with less copper. Considerable stoping has been done in this mine.

CLEOPATRA MINE.

The vein in the Cleopatra mine is developed by two tunnels, the lower one of which is a little more than 250 feet and the upper one about 400 feet in length (fig. 153). The upper tunnel is located at the end of the same branch road as the Comet Extension, but between 300 and 400 feet farther northwest, at a distance of about 1½ miles N. 12° W. of Empire.

Aside from a crosscut about 100 feet in length through soft biotite gneiss near the mouth, the lower tunnel is entirely in granite. The vein in the lower tunnel consists of a series of imbricating or overlapping fractures connected by transverse veinlets, and is composed of small quartz and pyrite stringers in friable biotite granite. On the upper level, however, the vein is stronger, more highly mineralized, and more regular in trend, the strike being about N. 35° E. and the dip from 60° to 70° NW. In contrast to the soft, friable granite of the lower level, the granite walls on the upper level are comparatively hard. The vein on the upper level consists as a rule of a fractured zone in granite with stringers of pyrite and chalcopyrite ore cementing the granite fragments. Vugs lined with drusy quartz and pyrite are common. The pyrite in places is very light colored and shows little evidence of copper, but elsewhere the copper content is much larger and the pyrite becomes coated with a bluish-black film of copper sulphide, or with a brightly colored iridescent film. Considerable stoping has been done along the vein on the upper level, but the yield so far has not been very large.

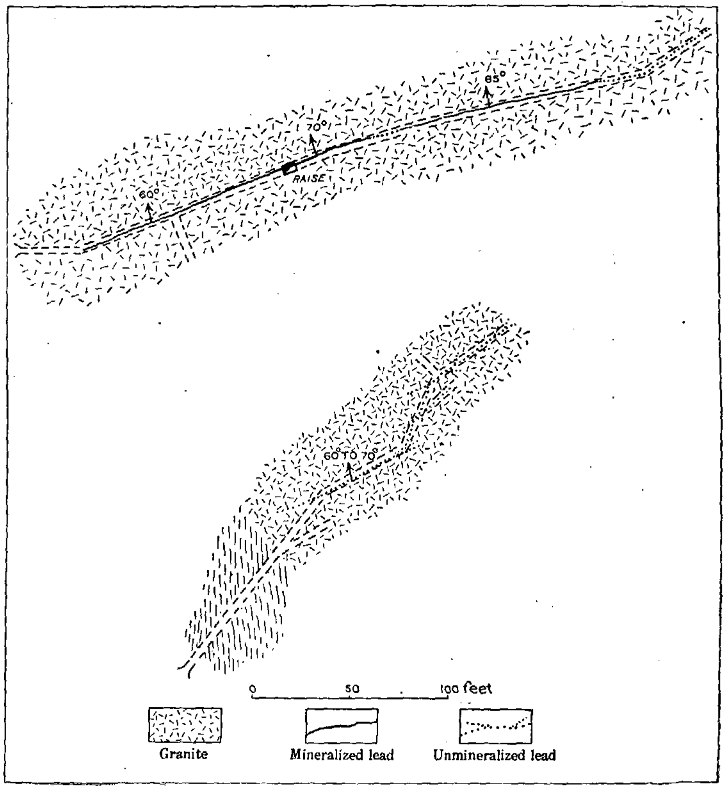


FIG. 153.—Geological plans of upper and lower Cleopatra tunnels.

MINES OF LINCOLN MOUNTAIN WITHIN THE AREA SHOWN ON THE EMPIRE MAP.[a]

HEADLIGHT MINE.

The Headlight or Mickmac mine, which is located on the Swanson lode about 3,600 feet south-southwest from the central portion of the town of Empire, is developed by a shaft 215 feet deep, from which short drifts are run on three levels, and also by a tunnel 125 feet in length which connects with a drift 150 feet in length on the Swanson lode on the first level (fig. 154). The latter drift connects with the shaft about 75 feet below its collar. The largest drift in the mine starts from the shaft at a point 60 feet below the tunnel level and runs for 260 feet to the south. The drifts on the mine aggregate about 700 feet in length.

The wall rocks immediately in contact with the vein consist of biotite granite, but some granitic gneiss was encountered in the crosscut tunnel.

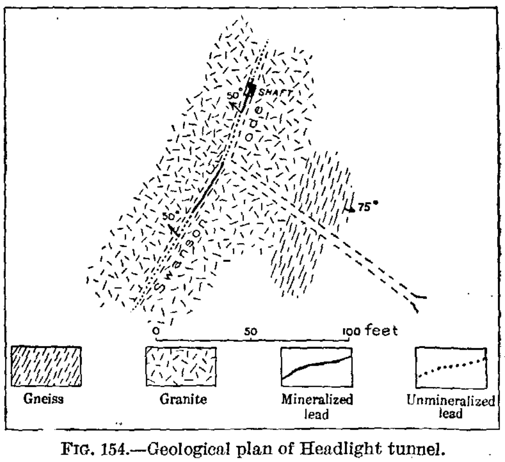


FIG. 154.—Geological plan of Headlight tunnel.

The vein, which has a dip of 50° NW., strikes N. 25° E. and consists in some places of a mere fracture or a series of small quartz stringers in fractured granite, while in others it is a pyrite-specked quartz lead from 1 to 8 inches wide. This quartz was "frozen" to the walls and graded directly into silicified granite, and this in turn into comparatively fresh granite. Most of the ore taken out came from between the first or tunnel level and the surface, where several small pockets of very rich ore were stoped out. The best ore was a chalcopyrite or cupriferous pyrite and quartz ore, carrying, it is stated, from 3 to 15 ounces of gold per ton. Some milky quartz ore, containing only a few specks of mineral, was also said to carry several ounces of gold to the ton.

[a] For descriptions of the mines of Lincoln Mountain within the area of the Georgetown quadrangle, see pp. 309-311.

The Halifax or Anderson lode, which lies a short distance northwest of the Headlight mine, on the surface shows a silicified streak with a few specks of galena and pyrite scattered throughout. The Halifax is said to have a porphyry dike running along its east side.

HIDDEN TREASURE MINE.

The lower level of the Hidden Treasure mine is located at an elevation of 9,000 feet about 1⅓ miles S. 75° W. of Empire, on the north slope of Lincoln Mountain, just beyond the north boundary of the Georgetown quadrangle. The mine is developed by two tunnels, but the upper one, which is about 700 feet above the lower one just mentioned, has been caved shut for some years, though formerly it produced considerable ore of an exceptionally rich nature. It is claimed that this mine produced the largest and finest specimens of native gold obtained in the district. This free gold consisted both of leaf gold and of small irregular masses resembling nuggets.

On the dump of the upper tunnel were found some chunks of massive cupriferous pyrite ore, some of which contained angular fragments of granite, quartz, and granitic gneiss entirely surrounded by the pyrite, although a thin layer or film of quartz usually intervened. One of these specimens showed crustification, for small specks of galena and sphalerite were asso-

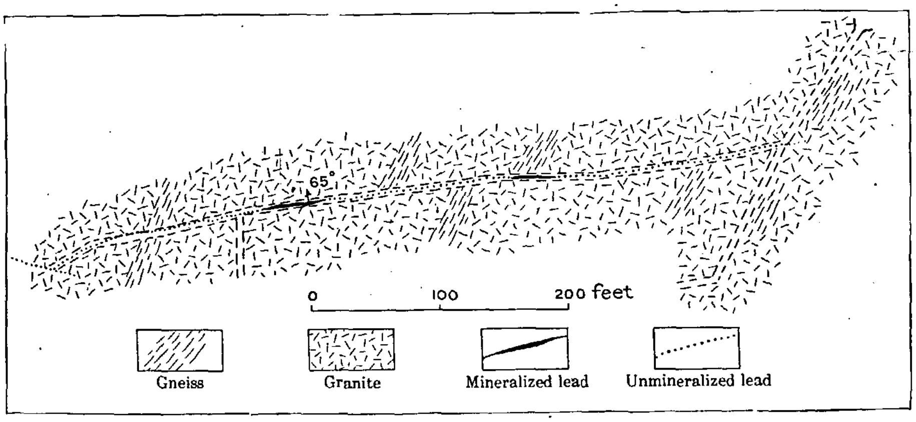


FIG. 155.—Geological plan of lower Hidden Treasure tunnel.

ciated with the narrow quartz layer between the massive pyrite ore and the included fragment, thus indicating that the galena and sphalerite had been deposited at an earlier stage in the period of ore deposition.

The lower tunnel (fig. 155), which was run to cut the same vein that produced the rich ore on the level above, extends for about 225 feet S. 32° W. to the breast, where a clay lead striking S. 78° W. was encountered. At 100 feet from the mouth of the tunnel a strong clay and crushed-rock lead slightly mineralized in places was also encountered and drifted on about 600 feet to the S. 82° W., to a point where it joined a clay lead striking N. 75° W. All the drifts of the lower tunnel were in granite and granitic gneiss.

ALLEN MINE.

General description.—The Allen mine, which is located between the Virginia City and Hidden Treasure mines on the north slope of Lincoln Mountain, at an elevation of about 10,000 feet, is about 9,000 feet south-southwest from the town of Empire. The workings consist of a crosscut tunnel 130 feet in length which runs S. 20° W. and connects with a drift about 200 feet long to the southwest on the lode.

The workings are all in gray granite. This rock is slightly fractured and mineralized for some distance from the vein, at least on the foot-wall side, as is shown by the walls of the crosscut tunnel, where small irregular stringers of pyrite run through the granite mass in lines somewhat parallel to the main vein. The vein represents a strong fault line trending S. 48° W. and dipping 50° SE.

Structure of vein.—This vein, although it is mineralized to only a slight extent, has an interesting structure. Next to the foot wall, which consists of gray granite, is present in places a thin seam of sphalerite and galena only three-eighths to 1 inch in thickness, separated from a somewhat similar but discontinuous seam of sphalerite and galena farther southeast and within the vein by 3 inches to 1 foot of pyrite-bearing gray jasper-like quartz, which locally changes to massive pyrite. Next to the southeast sphalerite-galena streak, or separated from it by a non-mineralized zone of crushed and friable granite 1 to 2 feet wide, is a belt of soft friction conglomerate 4 inches to 1 foot in width having a stiff, putty-like blue-clay or pulverized-rock matrix in which are embedded rounded and subangular pebbles of granite and quartz as well as of quartz and ore. The ore consists of cupriferous pyrite and massive galena and sphalerite. This friction-conglomerate belt is for the most part immediately in contact with the gray granite of the hanging wall.

Evidences of two periods of mineralization.—The fact that the sphalerite-galena streaks near the two walls are separated by a central seam of pyrite-bearing quartz suggests the possibility that there were at least two periods of mineralization and that the zinc-lead ore represents an earlier deposit filling a vein that was reopened by a fissure in which pyritiferous quartz was subsequently deposited.

The finding of rounded pebbles of both galena-sphalerite and pyrite ores in the soft friction conglomerate would indicate that this belt of soft crushed rock was the result of movements of a still later date than that at which the pyrite ores were deposited. Specimens of massive pyrite ore on the dump showed vuglike openings lined by a layer of marcasite one-eighth inch thick.

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